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Myron Hohol[1], Pavlo Dynka[2], Dmytro Sydorak[1], Marko Hohol[3]

EFFICIENCY OF RATIONAL COMBINED STEEL TRUSSES

[1] Department of Building Production, Lviv Polytechnic National University
[2] Department of Management and Marketing, Ukrainian National Forestry University
[3] Department of Highways and Bridges, Lviv Polytechnic National University
dmytro.p.sydorak@lpnu.ua

In this article, a comparative assessment of the technical and economic efficiency of rational combined steel trusses with typical trusses according to DSTU is considered. New rational constructive combined forms of covering systems (roof trusses) have been developed for spans of 18, 24 and 30 m, with less material consumption and labor intensity compared to existing analogues. It is shown that the mass of such rational combined steel trusses with a span of 18 m is less than a typical one by 13 % to 16.5 % depending on the value of load, for a combined truss with a span of 24 m the mass is less by 20.5 % to 25 %, and for a 30 m – from 12.5 % to 17 %. The results of the evaluation of the technical and economic efficiency are presented. The main criterion for the economic efficiency of constructions is general costs. A comparison of the technical and economic efficiency proves that our proposed option provides a significant saving of material and labor resources. Widespread implementation can provide a significant economic effect, which is important in the conditions of post-war reconstruction of Ukraine.

Key words: steel combined trusses; rational design; mass; metal consumption and labor intensity of production; criterion of economic efficiency; technical and economic efficiency.

Introduction

Steel trusses are widely used in industrial and civil buildings. Both the architectural appearance of the building and its cost depend on their constructive decision, since the trusses make up approximately 30-40 % of the total cost of the building during construction (Pichugin et al., 2014). The steel systems used as building structures are extremely diverse and widely used. These are statically determined and indeterminate trusses, as well as combined roof trusses. The use of such structures opens up wide opportunities for the creation of coatings that differ in lightness, high technical and economic indicators, and architectural expressiveness (Gogol, 2018; Gogol et al., 2018).

The implementation of advanced materials made it possible to significantly improve the operational characteristics of steel trusses (Hohol et al., 2023; Hohol et al., 2022; Lavrinenko et al., 2019; Shymanovskiy et al., 2018). The modern level of production of rolled profiles makes it possible to produce such cross-sections of the rods of combined trusses that correspond to the work of the elements in compression, tension, bending, compression with bending (Brütting et al., 2019). At the same time, the trusses provide the standard load-bearing capacity, are lighter and cheaper, and are competitive compared to foreign analogues (Brütting et al., 2019; Gogol, 2018; Panagiotis et al., 2002; Pichugin et al., 2013). These materials make it possible to increase spans, reducing the number of supporting columns and increasing architectural freedom. In addition, innovative manufacturing technologies, including 3D printing and robotic welding, allow trusses to be manufactured with increased precision and reduced labor costs (Amir et al, 2016).

The 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 (Fang et al., 2021; Madrazo-Aguirre et al., 2015). The development of steel building structures (roof combined trusses) is connected with the task of increasing their efficiency by reducing mass and, therefore, reducing steel costs. Combined steel structures make it possible to reduce steel consumption by 21–27 % and the cost of their manufacture, which as a result gives a reduction in their actual cost by up to 31 %, compared to typical designs of similar spans (Cazacur et al., 2014; Gogol, 2018; Janušaitis et al., 2012).

But today, in Ukraine and in the world, not enough research has been carried out, which would ensure the purposeful design of rational combined steel structures, make comprehensively justified decisions, which will ensure better design and implementation of competitive solutions. This will contribute to their widespread use in buildings and structures, which will ensure a general economic effect. There are also no general recommendations for determining the technical and economic efficiency of rational combined steel trusses. Therefore, further scientific research is needed to substantiate the effectiveness of such combined systems.

The aim of the work is to analyze and evaluate the technical and economic efficiency of rational combined steel trusses.

Materials and methods

At present, we have developed new rational constructive combined forms of coating systems, with smaller dimensions and material consumption compared to existing analogues (Table 1, *b*). Such rational constructive forms of a combined steel truss (minimum mass) according to geometric parameters (frame outline) and physical (distribution of material between truss elements). They allow to reduce the metal consumption and labor-intensive manufacturing due to the simplification of the design scheme, more rational work, reduction of the number of elements and nodes, which in general increases the reliability of the work of such structures.

Table 1

Schemes of rational steel combined trusses of span 12–30 m

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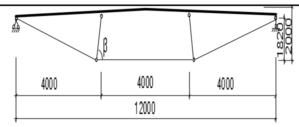
<tr><td>Not specified</td><td>
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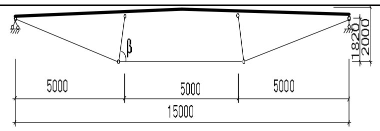
<tr><td>Not specified</td><td>
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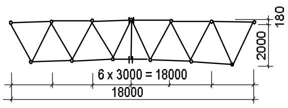
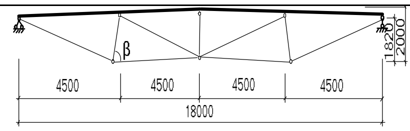
<tr><td>
</td><td>
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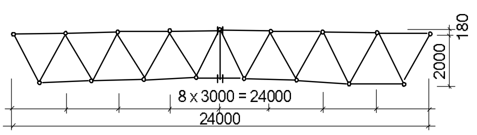
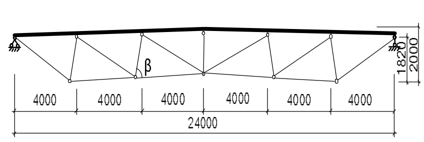
<tr><td>
</td><td>
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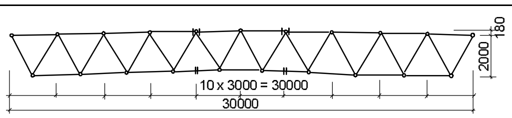
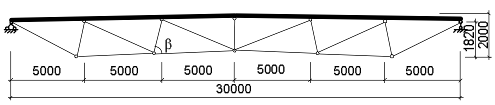
<tr><td>
</td><td>
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A rational roof steel truss consists of a rigid upper chord made of a bent-welded profile of a rectangular cross section, a broken line shaped lower chord connected to it with a slope of the upper and lower belts of 1.5 %, racks, braces connected to the upper and lower belts, contains struts located at an angle of 80°, and the braces are made of high-strength reinforcing rods that form an N-shaped lattice, which is attached to the upper and lower chords by hinges.

The main criterion for the economic efficiency of constructions is mainly the given costs, which include the costs of creating the structure, i.e. reducing costs is the most important condition for choosing a rational structural form (Bouw et al., 2009; Shmukler, 2017). In turn, the decrease of the structure mass is associated with a decrease in the labor intensity of manufacturing and installation. These factors are interrelated, and the effectiveness of their influence on the structural form is greater, the more fully the requirements for ensuring the manufacturability of the structure are taken into account during the design (Zinkova, 2014). So, a rational design is one that has a minimum mass, manufacturability and minimum labor-intensiveness of its manufacture.

Therefore, to evaluate the technical and economic efficiency of rational steel roof trusses, which do not require additional investment costs, we consider it appropriate to apply the criterion of comparative efficiency, which characterizes the technical and economic advantages of one option over others in terms of the rational use of all types of resources and costs.

We will conduct an comparative analysis of the technical and economic efficiency of rational combined steel trusses with spans of 18, 24 and 30 m at different values of uniformly distributed load, which corresponds to the values of DSTU by the method of comparison with typical trusses operating at the same load and the same spans (Fig. 1–3).

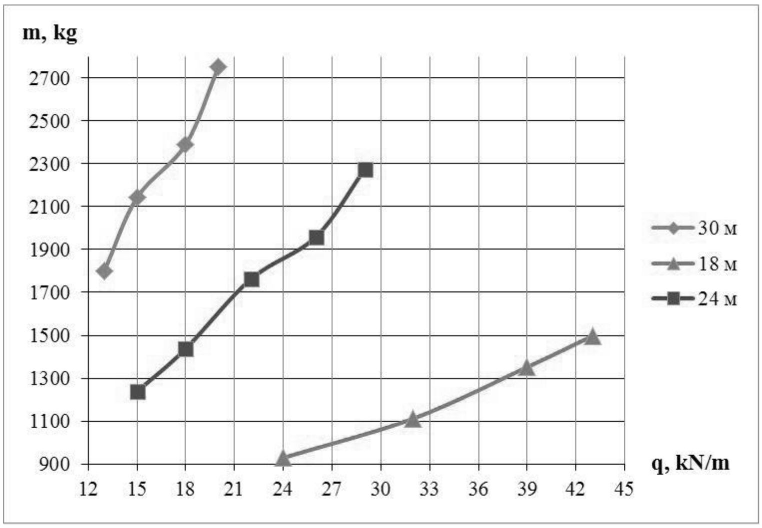

Fig. 1. Dependence of the mass of a typical truss according to DSTU on the value of the uniformly distributed load q

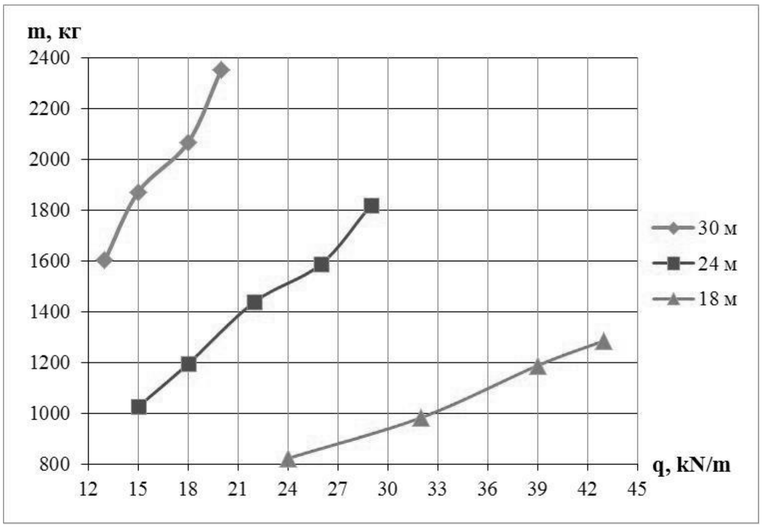

Fig. 2. Dependence of the mass of a rational combined steel truss on the value of the uniformly distributed load q

For a rational combined steel truss, the dependence of the mass on the value of the uniformly distributed load q is shown in Fig. 2.

In Fig. 3 shows the efficiency (comparison of masses) of a rational combined steel truss (in percent) compared to a typical truss according to DSTU.

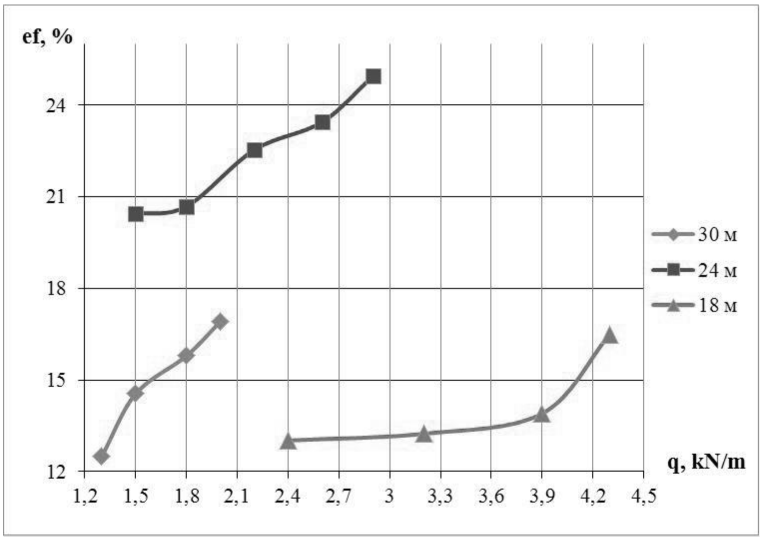

Fig. 3. Efficiency (comparison of masses) of a rational combined steel truss (in percent) compared to a typical truss according to DSTU

As can be seen from Fig. 3, the mass of a rational combined steel truss with a span of 18 m is less than a typical one by 13 % to 16.5 %, depending on the amount of load, for a combined truss with a span of 24 m, the mass is less by 20.5 % to 25 %, and for 30 m – by 12.5 % to 17 %.

For example, for a 30 m rational combined steel truss (Fig. 4) with a linear load q = 17.65 kN/m, the cross-sections of the elements are shown (Table 2).

a

b

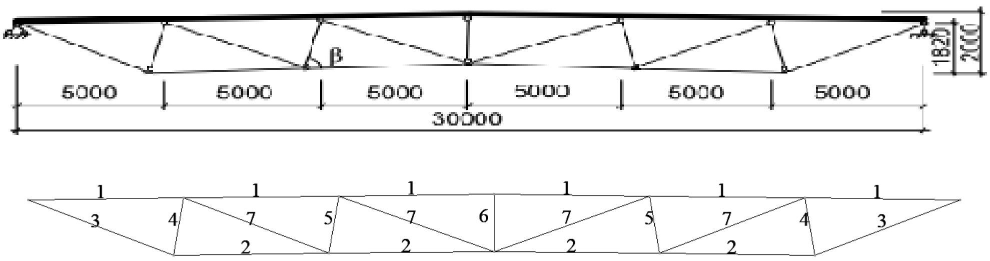

Fig. 4. Rational combined steel truss L = 30 m: a – general view; b – element numbering

Table 2

Elements specification for rational combined steel truss of span 30 m

No.	Element type	Steel	Cross-section	Mass, kg
1	Upper chord	C345	□200×7	1233.1
2	Lower chord	C345	□100×7	394.8
3	Lower chord	C345	□100×4	117.2
4	Stumps	C255	□80×3	26.2
5	Stumps	C255	□60×3	19.2
6	Stumps	C255	□50×3	7.7
7	Braces	A400C	●ø42	223.9
Number of elements 21 psc, weld seam length – 19.8 m				
			Total mass:	2022.1 kg

A comparison of the efficiency of such a truss with a typical benchmark truss is given in Table 3.

Table 3

Comparison of the technical and economicefficiency of a rational combined steel truss L = 30 m and a typical truss according to DSTU

Index	Unit	Truss according to DSTU	Rational truss
Steel cost	UAH	61 973	53 795
Manufacturing cost	UAH	12 865	8 806
Total cost	UAH	74 838	62 601
Truss mass	kg	2455.5	2022.1
Weld seam length	m	39.2	19.8
Number of elements	psc	41	21
Number of joints	psc	23	12
Maximum tension	%	84.7	99.0
Minimum tension	%	0.2	20.2
Energy consumption	kW·h	1102	862
CO_2 emission	t	4.31	3.54

As can be seen from the Table 3, reduced steel consumption by 15.2 %, labor cost by 46 %, truss weight by 21.4 %, number of elements and number of nodes by almost 2 times, as well as energy consumption during manufacturing and carbon dioxide emissions.

Results and discussion

Since the alternative version of the construction of the farm practically does not require additional capital costs, in order to evaluate its effectiveness, it would be appropriate to calculate indicators of comparative technical and economic efficiency, which characterizes the advantages of one option over others in terms of the rationality of using current material and labor costs. For this, it is necessary to compare their manufacturing labor intensity and estimated costs.

Conclusions

New rational constructive combined forms of covering systems (roof trusses) have been developed for spans of 18, 24 and 30 m, with smaller dimensions and material consumption compared to existing analogues.

The technical and economic efficiency of rational combined steel trusses has been established.

The main criterion for the economic efficiency of constructions is general costs.

The mass of a rational combined steel truss with a span of 18 m is less than a typical one by 13 % to 16.5 %, depending on the amount of load, for a combined truss with a span of 24 m, the mass is less by 20.5 % to 25 %, and for a 30 m – from 12.5 % to 17 %.

A comparison of the technical and economic efficiency of a rational combined steel truss and a typical truss that meets the DSTU proves that the option we offer provides a significant saving of material and labor resources, and if it is widely implemented in production, it can provide a significant economic effect for the national economy, which has of particular importance in the conditions of martial law and post-war reconstruction of Ukraine.

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М. В. Гоголь[1], П. К. Динька[3], Д. П. Сидорак[1], М. М. Гоголь[2]

Національний університет “Львівська політехніка”,
[1] кафедра будівельного виробництва,
[2] кафедра автомобільних доріг і мостів,
Національний лісотехнічний університет України,
[3] кафедра менеджменту і маркетингу

ЕФЕКТИВНІСТЬ РАЦІОНАЛЬНИХ КОМБІНОВАНИХ СТАЛЕВИХ ФЕРМ

Наведено порівняльну оцінку техніко-економічної ефективності раціональних комбінованих сталевих ферм із типовими фермами за ДСТУ. Розроблені нові раціональні конструктивні комбіновані форми систем покриттів (кроквяні ферми) для прольотів 18, 24 і 30 м, габарити і матеріаломісткість яких менші порівняно з аналогами. Зокрема, розглянуто комбіновані сталеві ферми прольотом 12 та 15 м. Наведено порівняльну таблицю конструкцій ферм відповідно до ДСТУ та розроблених запропонованих варіантів. Показано, що маса таких раціональних комбінованих сталевих ферм прольотом 18 м менша порівняно з типовою на 13–16,5 % залежно від величини навантаження, для комбінованої ферми прольотом 24 м маса менша на 20,5–25 %, а для 30 м – 12,5–17 %. У формі діаграм показано залежність маси від навантаження для типових ферм за ДСТУ та комбінованих сталевих ферм. Також визначено відсоток ефективності комбінованих ферм залежно від прольоту та величини навантаження. Наведено результати оцінювання техніко-економічної ефективності раціональних комбінованих сталевих ферм, специфікацію елементів та схему їх розташування для комбінованої сталевої ферми прольотом 30 м. Подано техніко-економічне порівняння типової ферми за ДСТУ та комбінованої сталевої ферми на прикладі конструкції прольотом 30 м. Зокрема, розглянуто такі параметри, як витрата та вартість сталі, вартість виготовлення конструкції, загальні витрати, кількість елементів та вузлів, енергетичні затрати, емісія CO_2 тощо. Порівняльний аналіз підтверджує ефективність комбінованих сталевих ферм практично за усіма параметрами. Основним критерієм економічної ефективності конструкцій прийнято приведені затрати. Порівняння техніко-економічної ефективності раціональної комбінованої сталевої ферми і типової ферми, що відповідає ДСТУ, доводить, що запропонований нами варіант забезпечує значну економію матеріальних і трудових ресурсів, і за умови широкого впровадження у виробництво може дати істотний економічний ефект.

Ключові слова: комбінована сталева ферма; раціональна конструкція; маса; металомісткість та трудомісткість виготовлення; критерій економічної ефективності; техніко-економічна ефективність.