



New Effective Combined Steel Structures

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Abstract

In the article, based on the generalization of the experience of adjusting efforts in steel combined structures, it is shown, that the most rational method of regulation is calculated in the design process. This method does not require any additional material costs. It is shown that the beam on elastic intermediate supports and solid extremes is a generalized type of all possible types of beams. It was emphasized that the problem of calculating building structures, including combined, first of all should be regarded as a problem of their rational design. The results of experimental studies of combined steel truss with calculated regulation in their internal efforts are presented. Experimental studies confirmed the hypothesis about the possibility of regulating the stress deformation state (SDS) in combined structures with resilient support - system of springs and achieving an equally stressed state in the calculated cross-sections. The sufficient consistency of the experiment results with theoretical calculations is shown and the efficiency of such systems compared with the typical reaches up to 27%. The proposed nomenclature series of effective new light, with a small number of elements trussed structures. Effective combined steel structures with rational geometric parameters and calculated value adjustments of SDS were used during the construction and reconstruction of many buildings:

Keywords: calculation method of regulation, combined steel truss, experimental research, rational design.

1. Introduction

One of the most important directions of progress in the construction industry is to increase reliability and durability, reduction of material consumption of construction structures on the basis of maximum use of all reserves of strength. This causes the special relevance of the development of new lightweight and, at the same time, reliable and durable engineering structures, in the first place steel structures of covers, overlappings and bridge transitions.

In this regard, the most promising, and often the only possible one, is the approach, which is based on the development of existing and the development of new constructive forms and methods for their calculation, which does not require any additional material expenses [1-5].

One of the ways to solve this problem is to use the calculation of stress deformation state (SDS) regulation in steel combined structures during the design process, which would meet these requirements [6,7].

The main task when designing the building structures, with which the engineer encounters, is to get the most rational system with equal stresses in its cross-sections. Therefore, the problem of calculating building structures, including combined, first of all should be regarded as a problem of their rational design. In this paper, a method is developed [11], which allows simultaneously with the solution of the inverse problem - rational design, to obtain and solve the direct task of calculating the SDS of the structure. As the criterion of rationality stands the energy criterion of rational design, as well as SDS requirements: stress equality, of deformation of the intermediate supports of the rigidly beam on the ratio of the supporting and spans moments [7]. This raises the

bending moment equality, maximal inflexibility, or minimum mass of structure. The main advantage of combined structures the concentration of materials and the possibility of designing them with a small number of elements [9]. In most steel combined structures, the main (65-85%) mass of material is concentrated in the beam of rigidity, from the design and metal content of which - the technical and economic indicators of the entire system depend to a large extent. The calculation of each type of such structures by the existing method [10] has its own peculiarities. The results of such calculations give an uneven tense state along the length of the main element - beams of rigidity, which consists of a significant difference in reference and flying moments. This makes the existing combined structures always rational [12-14]. Therefore, improving the method of calculating combined steel structures, which would reflect their actual work, is currently a actual problem.

An analysis of existing design and construction experience has shown, compared with traditional beam and frame structures, combined systems have a number of advantages [16-18].

At the same time, their main drawback is the use of pre-stressing [15]. However, the use of such systems is small due to the lack of detailed theoretical and experimental studies of their real work.

2. The Main Material

The proposed method of designing and calculating rational combined steel structures reduces to taking into account the effect

need to develop a methodology for selecting rational geometric parameters of combined steel structures. The area of

application of combined systems is a span of 6-60 m. To calculate rational combined steel structures, a unified computational model of application of combined systems is a span of 6-60 m. To calculate rational combined steel structures, a unified computational model of combined systems (on the basis of the method of decomposition of the system) in the form of a beam on elastic supports (Figure 1), in which a beam simulates a beam of rigidity, and elastic supports- a reinforcement system [10]. That the design model was able to number of elements of reinforcement, i.e. elastic supports, it is possible to create the maximum number of calculated cross sections in the stiffening beam.

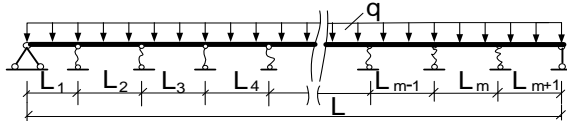


Fig.1. Chart of the generalized calculation model

2.1. Experimental Research

In order to verify the results of theoretical studies and to identify the real work of rational metal combined structures, complex experimental studies were performed. Preparation of experiments of steel farms was carried out for combined structures, which were designed and calculated according to the proposed method.

2.1.1. Subject, purpose and tasks of research

For the experimental verification and refinement of the results of theoretical studies of regulation of efforts in combined structures with a given ratio of stiffenings of their elements, a model of a combined truss was made, which had the same dimensions with the model of a typical farm (standard) - a run of 3.2 m, a height of 0.4 m. The ratio of the stiffness of the upper belt (stiffening beams) and the sprenkel combined fermium (lower belt and slopes) were calculated theoretically according to the authors' theory. The mentioned ratio of rigidity of the combined truss allows to provide the calculated rational parameters of regulation, that is, the equality of stresses in the calculated sections of the beam of rigidity (upper belt).

The geometric parameters of the lower belt and the tread bars of the rigidity were designed so that the upper belt of the truss worked as an unbroken beam on elastic supports. The upper belt of the balconies is designed and made of rolling double-leaf № 10 (Figure 2), the lower belt - from the corner number 45x4, slopes that, along with the lower belt, worked as elastic supports, with angles 45x3.

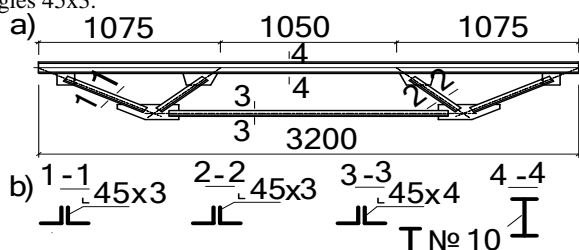


Fig.2. Constructive scheme of the combined truss:
a) a general view; b) cross-sections

The purpose of the experimental study was to identify the actual parameters of the regulation of the SDS of the combined system and the comparison with the theoretical results.

The objectives of the study were consistent with the goals set, namely:

- estimation of the possibility of calculation regulation of SDS in the beam of rigidity – equalization of stresses;
- studying the behavior of the farm as a system in the case of symmetric and asymmetric load;
- comparison of the experimental results of the actual work of the combined and standard truss with the results of theoretical studies.

2.1.2. Constructive Parameters of the Investigated Models. Test Bench and Equipment

A pilot sample of a typical (reference) of a 3.2 m span model, which modeled a 24-meter stepped truss, was made from equidistant paired angles (Figure 3).

The constructive parameters of the experimental model of the combined truss were taken from the equality with standard. For the load bearing capacity of both truss were the same, but the weight of the combined truss was significantly different from the typical truss, the weight of which was 70 kg, and the weight of the combined truss - 57 kg, which was almost 20% less. The geometric and constructive parameters of a typical truss are shown in fig.3. To test the experimental models of typical and combined truss, a special booth with a powerful power beam was designed and manufactured.

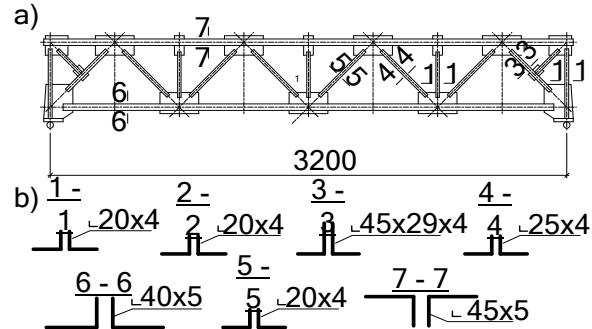


Fig.3. Constructive scheme of the model of a standard truss a) general view; b) cross-sections

The loads on experimental models were transmitted at seven points in the form of equidistant distributed concentrated forces, which was a simulation of a uniformly distributed load. One-sided load was transmitted so as to simulate the most unfavorable asymmetric.

To create an external load on the samples on the stand were arranged screw traction, which, with the help of nuts, were connected with the upper and lower traverse. The lower crossbar hinged and centrally (in the middle) rested in the power beam from below, and through the upper traverses, under which the dynamometers were installed, the load on the prototype was carried out. Models were fixed from the power plane. In the characteristic points of experimental models glued strain gauges, as well as installed gauges. Load on the experimental samples step by magnitude to 1 kN.

Load on the farm was applied to the upper belt through the traverse and traction system using specially designed screw devices for this purpose. The load control was carried out by the model dynamometers installed at the places of application of this load.

A sample of a typical farm was tested on the same test bench, on the same load, and under the same conditions as the sample of the combined truss. The load on the pilot sample of a typical truss was transmitted according to the scheme the combined truss was tested, that is, according to the scheme which simulated evenly distributed load, which was applied to the upper belt of the truss. The general view of the combined and typical truss during its testing is shown in Figure 4,5.

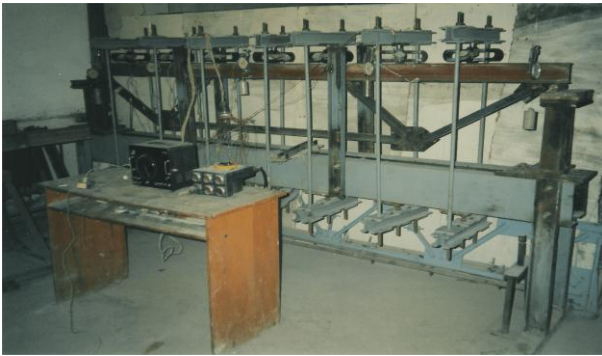


Fig.4. Tests of a combined farm on a symmetrical load



Fig.5. Typical - standard farms tests on a power stand

2.1.3. Results of experimental studies

As a result of the measurements, the relative fibrous deformation (ϵ) of the experimental models in the areas of gluing of strain gauges with a base of 20 mm were obtained during the study. According to these indicators, the corresponding stresses and efforts in the elements of truss were determined. Boundary bearing capacity of models was determined by a sharp increase in their deflections when applying the next degree of external load, after which the test of the models was discontinued. The load carrying capacity was determined by the applicable norms for the combined truss [8].

In order to evaluate and compare the deformability and bearing capacity of the truss, estimation of the possibility of the calculation of SDS regulation in the beam of stiffness - equalization of stresses, according to the measurements during the deformation tests, the graphs of the change of deflections (f) from the magnitude of the uniformly distributed load (q) in kN / m were constructed, graphs of the change of fibrous deformations $\epsilon \times 10^{-5}$ in the beam of rigidity of the combined farm, depending on the magnitude of the symmetric loading (q), as well as the distribution of fibrous deformations $\epsilon \times 10^{-5}$ with a maximum load $q = 54 \text{ kN} / \text{m}$ in the beam of rigidity of the combined truss from the symmetrical load in the stretched and compressed zones.

At the same time, was tested the influence of the asymmetric load on the change in the operation of the elements of the truss from compression to stretch, or vice versa. Diagrams deflections of the combined truss after each degree of application of the external load are shown in Figure 6, and the parameters of the SDS on Figure 7. As can be seen from diagrams of the deflections, the deflections along the length of the farm increased in proportion to the load to the maximum load of $54 \text{ kN} / \text{m}$.

From the diagrams graphs of the change of fibrous deformations in the beam of rigidity of the combined truss, depending on the symmetric load (Figure 8), that at the maximum load $q = 54 \text{ kN} / \text{m}$, fiber deformations in the calculated sections (on average and in the reference sections of the runway) differed slightly from each other.

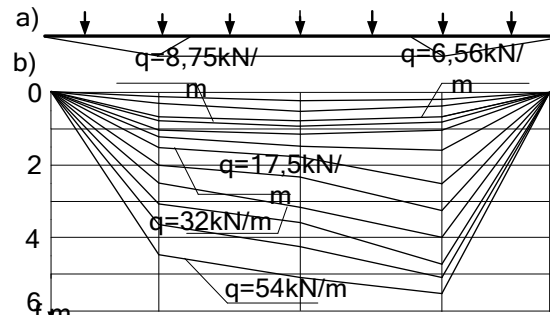


Fig.6.. Diagrams of the deflections of the combined truss with the calculation of the effort: (symmetric load) a) the scheme of the farm; b) the diagrams of the deflections along the length.

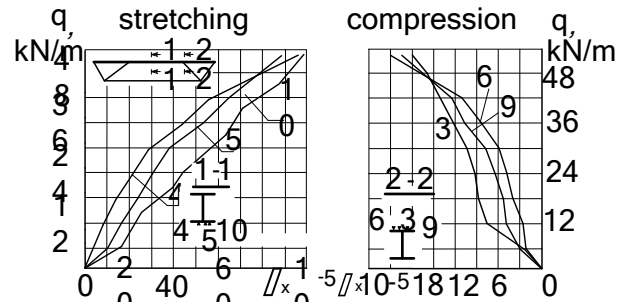


Fig.7. Diagrams of fiber strain changes in the beam of the rigidity of the combined truss, depending on the symmetric load

The difference was (Figure 8, a): for compressed zones from $\epsilon = 101 \times 10^{-5}$ to $\epsilon = 107 \times 10^{-5}$ (corresponding to the tension $\sigma_{\text{max, exp.}} = 212.1 \text{ MPa}$ at $\sigma_{\text{max, theor}} = 237.2 \text{ MPa}$ to $\sigma_{\text{max, exp.}} = 224.7 \text{ MPa}$ at $\sigma_{\text{max, theor}} = 230.3 \text{ MPa}$), ie 6%. This maximum discrepancy is consistent with the accuracy of the experiments.

Consequently, practically stress equality was obtained for the calculated cross sections, which indicates the effectiveness and reliability of the proposed method of calculation regulation of SDS. For stretched zones from $\epsilon = 11 \times 10^{-5}$ to $\epsilon = 31 \times 10^{-5}$, but only maximum stress is taken into account (Figure 8, b).

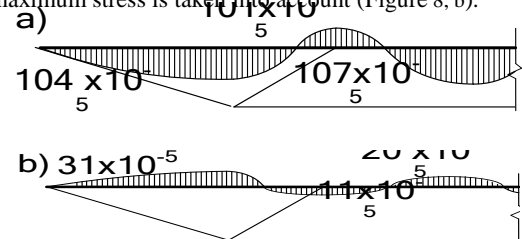


Fig.8. Experimental distribution of fibrous deformations $\epsilon \times 10^{-5}$ at $q = 54 \text{ kN} / \text{m}$ in the beam of rigidity of the combined truss from symmetrical loading: a) in compressed zones; b) in stretched zones

Comparison of maximum experimental and theoretical deflections of a combined truss (mm) at $q = 54 \text{ kN} / \text{m}$ is given in Table 1.. As can be seen from Table 1, experimental relative bends of the combined truss $f_{\text{exp}} / l = 1 / 640$, equal to 5 mm, approximately twice smaller than the allowed deflections according to the norms [8] - $[f] = 1 / 300 l = 1 / 300 \cdot 3200 = 10.66 \text{ mm}$. The maximum difference between the experimental and theoretical deflections is 10.66%, which is consistent with the accuracy of the experiments. The results of combined truss tests on an asymmetric load are given in Figure 8. Studies have shown that the load carrying capacity of the combined farm corresponded to the same load as with symmetric loading, equal to $q = 54 \text{ kN} / \text{m}$ with a lower deflection $f = 4.7 \text{ mm}$ with a clearly expressed asymmetric deflection.

Table 1: Maximum deflections of the combined farm with the calculated control forces (mm) at $q = 54 \text{ kN/m}$

Type of load	Experimental deflections		Theoretical deflections		
	Absolute (mm) f_{exp}	Relative f_{exp} / l	Absolute (mm) f_{theor}	Relative f_{theor} / l	% deviation from f_{exp}

1	2	3	4	5	6
Symmetrical throughout the length of the upper belt	5,00	1/640	5,533	1/578	10,66
Unsymmetric half-length of the upper belt	4,71	1/679	4,98	1/642	5,73

According to the measurements in the process of testing by fibrous deformations in the trussed system of the combined truss, a scheme of normal forces at a non-symmetric load $q = 54 \text{ kN/m}$ (Figure 9) was constructed. As can be seen from Fig. 9, normal forces in the bars of the trussed, in the case of asymmetrical load of the combined truss have the same signs as for the symmetric, as well as installed on the displays of strain gages, that in the process of loading compression changes on tension, or vice versa did not happen. The loss of stability and geometric unalterability of the combined truss were not observed during tests for asymmetric loading.

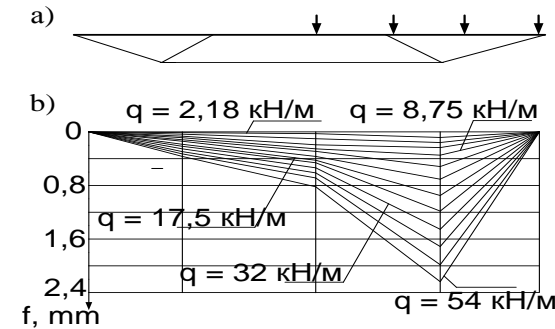


Fig. 9. Burns of a combined truss in case of an asymmetric load: a) the scheme of the truss; b) deflection

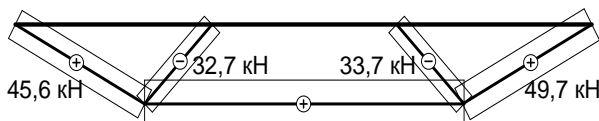
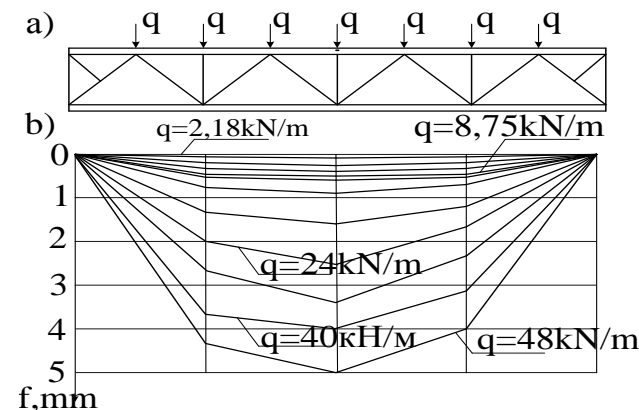


Fig. 10. Normal forces in the trussed system of the combined girder in case of asymmetric loading: + tension; - compression

The results of tests of the typical truss (Figure 11) showed that its bearing capacity $q = 48 \text{ kN/m}$ less than the carrying capacity of the combined truss at 11%, but the weight of the combined truss was 57 kg, and the typical was 70 kg, that is almost 20% less. At the same time, its deflections are close to the values of the combined truss deflections (the difference is up to 7%, Figure 5



and Figure 10).
Fig. 11. Test results of the standard truss: a) the scheme of the truss; b) the diagrams of the deflections

From the graphs of the change of fibrous deformations during the test of the standard truss, shown in Figure. 12, it is evident that their values ($\epsilon_{max} = 72 \times 10^{-5}$) are significantly smaller than the values for the combined truss ($\epsilon_{max} = 107 \times 10^{-5}$, Fig. 6). This is explained by the lower efficiency of using the strength characteristics of the element material of the standard truss compared to the combined truss. Studies have shown that the

deformability of the standard truss and the combined truss with symmetric loading practically coincided, and the difference with theoretical deflections was 5.7-14%, which testifies to the authenticity of the developed calculation method of regulation of SDS (Figure 13).

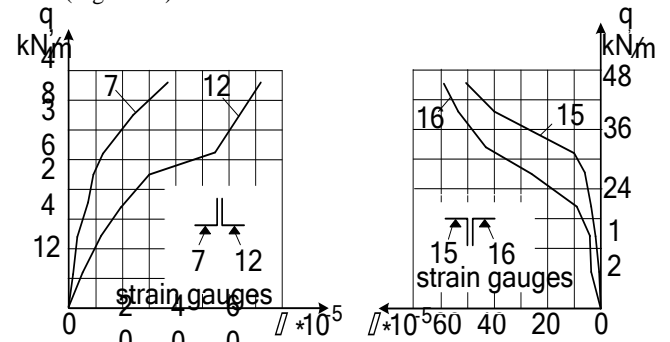


Fig. 12. Charts of fibrous deformations in elements of a standard truss with symmetrical loading

On the basis of the analysis of the results of work proposed and developed new constructive forms of combined steel trussed beam and trusses (Table 2), which take into account the peculiarities of the calculated regulation in their stresses during the design process and the achievements in the process of these stress equality number of calculated cross sections.

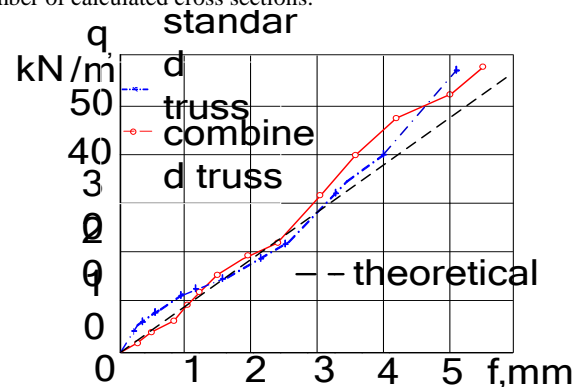


Fig. 13. Comparison of experimental and theoretical variables of the trenches of the truss in the middle of the span (symmetric loading)

Ensuring the rationality of such systems is achieved by minimum number of elements and by the method of transforming diagrams of bending moments of the beam of stiffness and the principle of minimizing technological costs.

Implementation of calculation regulation in combined steel trussed beam and truss is carried out at the initial stages of designing by transforming their topology and with the provision of a rational number of supports, rational angles of inclination of strut and suspension and height of combined structures. It is also rational to use the supporting eccentricities to create bending moments that are opposite to the external load [12]. The area of use of such constructive systems is most rational with spans less than 40-45 m for industrial and civil buildings. Techno-economic comparison of the effectiveness of the new design [9] with the typical truss was performed (Table 3). The area of use of such constructive systems is most rational with spans less than 40-45 m for industrial and civil buildings. Techno-economic comparison of the effectiveness of the new design [21] with the typical truss was performed (Table

3). Saving of materials compared to a typical 18m truss reaches 27% with a significant simplification of manufacturing technology. The result of the work was the publication of recommendations on the use of the results of research in the designs to cover and block the houses [19-22] practical

development a program and algorithm for calculating the efforts of the calculation method on the computer.

Effective combined steel structures with rational geometric parameters and calculated regulation of SDS were used during the construction and reconstruction of many buildings: trussed truss

with a span of 18 m at the construction of the 5-star sanatorium-hotel complex Royal Hotels & SPA Resort, building "Geneva" in Truskavets, Lviv region (Figure 14), Lviv factory of experimental mechanical tests (Figure 15) and others

Table 2. Types of combined trussed truss

S.No	Scheme of combined trussed truss	S.No	Scheme of combined trussed truss
1		5	
2		6	
3		7	
4		8	

Table 3. Technical – economics indexes for 1 element

S.No	Indexes	Measure	Typical truss L=18m	Combined truss L=18m	Correlation, %
1	Structure mass	kg	3000	2189	73
2	Labor time of production	hour	59	14,5	24,5
3	Cost of production and transporting	uah	1350	560	42
4	Labor time of erecting	hour	6,0	6,3	105
5	Cost of installing	uah	520	550	106
6	Cost of installed construction	uah	7536,6	5198,3	69
7	Economical effect	uah		2338,3	



Fig.14. Installing of low element sub diagonal truss with span L=18m, Sanatorium "Zeneva" Truskavets, Ukraine



Fig.15. Trussing beam-truss L=12m. Experimental research factory, Lviv, Ukraine

3. Conclusion

This experimental work studied the possibility of achieving an equally stressed state in the beam of rigidity of a combined truss by the calculation of SDS verification of the proposed method of calculation, evaluation of the effectiveness of such structures, and made the following conclusions.

1. The results of experiments reflecting the real work of the combined truss are in good agreement with the theoretical ones.
2. The conducted experimental researches confirmed the hypothesis about the possibility of regulating SDS in combined structures with elastic-supportive supports.
3. The theoretically calculated intensity of inclusion in the work of metal on the length of elements at the expense of the calculation regulation of SDS is confirmed, that is, a rational structures is obtained

4. The work of combined truss is characterized by the uniform distribution of stresses in the sections on the length of the upper belt and high rigidity.

5. The maximum experimental deflections of the combined truss were 14% less than the theoretical, which indicates a sufficient consistency of the results of the experiment with theoretical calculations.

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