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OPTIMIZATION OF LARGE-SPAN STEEL TRUSSES THROUGH MODIFICATION OF STRUCTURAL FORM

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Abstract:
This study addresses the problem of improving the structural efficiency of large-span steel trusses, which are widely used in construction due to their simplicity and adaptability but are often associated with increased material consumption and complex stress states under non-nodal loading. A key issue arises when concentrated loads act between nodes, generating additional bending moments (M) and shear forces (Q) in the upper chord members, leading to unfavorable stress–strain conditions.

To overcome this limitation, the research proposes a constructive approach based on the local reverse bending of the upper chord panels. The knowledge gap lies in the insufficient exploration of how modifying the geometric form of truss elements can influence internal force distribution and reduce material usage. The study investigates two variants of a 36 m span pentagonal steel truss: a conventional model with a straight upper chord and a modified model with pre-bent upper chord panels.

Using numerical analysis in the LIRA-SAPR 2017 environment, both models were subjected to identical static and dynamic loading conditions. The results demonstrate that reverse bending significantly reduces bending moments and shear forces in the upper chord members, leading to a more efficient stress distribution. The optimal performance was achieved at a bending height of f=12 cm.

The findings confirm that this method enhances load-bearing capacity, reduces structural deformation, and decreases steel consumption by up to 10–11% overall and 20–21% in upper chord elements. The proposed solution offers a practical and economically efficient approach for optimizing large-span steel truss design.

Keywords: large span, concentrated force, upper chord, stress, bending moment, shear force, stress, deformation, bending, diagrams, and efficiency

1. Introduction

Large-span structures in the world exist in various forms, including beam structures, frame systems, arch structures, spatial structures, and suspension structures. Among these, beam structures occupy a distinct position. Large-span beam structures also include large-span trusses.

Large-span trusses are classified into several types according to their structural form, including trapezoidal (quadrilateral and pentagonal), polygonal, segmental, and parallel-chord trusses [1].

There are several methods for improving the efficiency of large-span trusses, including the selection of appropriate structural forms, the selection of an optimal bracing system, the choice of optimal cross-sections for members, fabrication using high-strength steel, and prestressing. In large-span trusses, the length of the upper chord panel may be 3 m or more; in such cases, the applied concentrated load may act at points other than the nodes. As a result, in addition to axial forces, bending moment (M) and shear force (Q) arise in the truss members, leading to a complex stress state in the members [2].

Among the large-span structures used in construction practice, beam structures are considered the simplest and most convenient. They are relatively simple in design and comparatively easy to assemble, and they differ from other large-span structures in that no horizontal thrust (распор) is generated at the supports. However, these structures are also characterized by being somewhat heavier than other types of structures for covering the same span [3].

Based on this, the present study investigates a proposed large-span truss with a modified structural form, which is expected to be lighter than conventional trusses and, accordingly, more efficient.

This article is aimed at addressing these relevant issues by applying a method of bending the upper chord panel of the truss in the direction opposite to the bending moment, with the objective of reducing stresses and deformations in the members, while also decreasing the overall weight of the structure.

2. Materials and Methods

In large-span trusses, in some cases the applied concentrated load is not placed at the node, which leads to the occurrence of local bending moment (M) and shear force (Q) in the upper chord panel, adversely affecting the stress–strain state of the truss members [4][5]. By modifying the structural form of the upper chord panel, that is, by pre-bending the panel in the opposite direction and controlling the distribution of internal forces to achieve their coordination, it is possible to determine the potential for improving the overall efficiency of the structure by reducing the cross-sectional areas of members under stress.

For this purpose, two different structural forms of the truss upper chord are initially selected: one with a straight upper chord panel, and the other with a modified upper chord panel shape, namely with reverse curvature relative to the plane of bending. The geometric parameters of both trusses, including material, loads, types of supports, and boundary conditions, are assumed to be identical [6].

According to the theory of local reverse bending, if reverse curvature is introduced in the upper chord panel, the magnitude of the bending moment and shear force in the members decreases to a certain extent. This, in turn, reduces the stress values in the cross-sections of the elements and enables savings in steel consumption.

Such solutions are analyzed through static calculations using the LIRA-SAPR 2017 program. In this process, the geometric scheme of each truss is developed, all acting loads are applied, the member cross-sections are preliminarily assigned, and the stresses and deformations in the members are calculated [7].

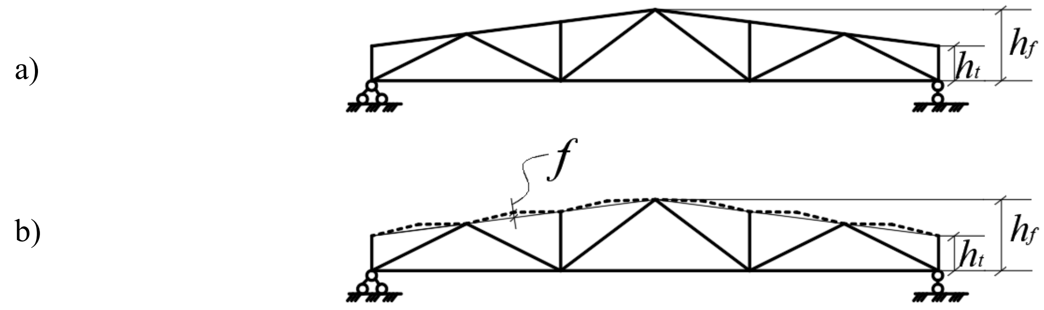
Selected large-span steel trusses with a span of 36 meters are adopted. Their heights are taken within the range of (1/6–1/8)l, and the support heights are within (1/15–1/17)l. The truss material is assumed to be S235 grade steel.

One of the truss supports is selected as a pinned support, while the other is taken as a roller support. The truss spacing is 12 m.

Two types of structural schemes of the trusses are adopted: a conventional pentagonal trapezoidal form (Figure. 1a) and a modified pentagonal form with an altered structural configuration (Figure. 1b). The length of the upper chord panel of the selected trusses is taken as 6 m, while the lower chord length is assumed to be 6–12 m.

For the trusses with modified structural form, the upward bending height of the upper chord panel is examined within the range of f = 8–15 cm [8][9].

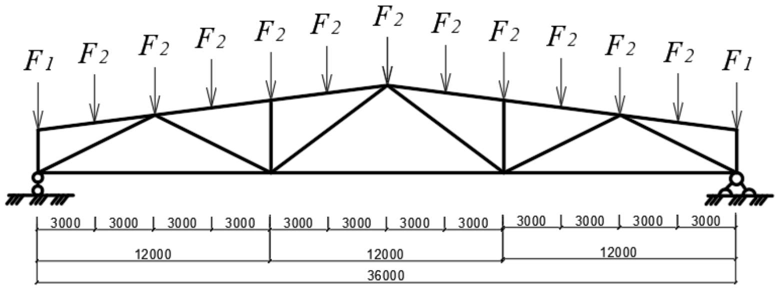
(1.b-figure).



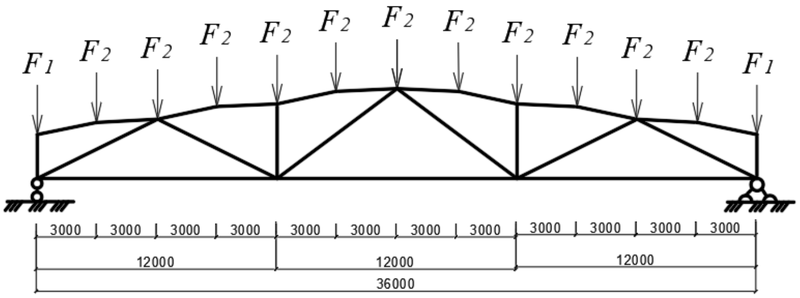
1-figure. Two types of large-span pentagonal trusses with different structural forms: a) conventional pentagonal truss; b) pentagonal truss with a modified structural form.

It is assumed that the concentrated load acts vertically on the upper chord panels of the truss at intervals of 3 meters, with its normative and design values as follows:

F_1^m= 2.42·1.54·12=43.56 kN; F_2^m= 2.42·3·12=87.12 kN;
F_1=3.378·1.5·12=60.8 kN; F_2=3.378·3·12=121.6 kN;



2-figure. Loading scheme of the pentagonal truss with a straight upper chord panel.

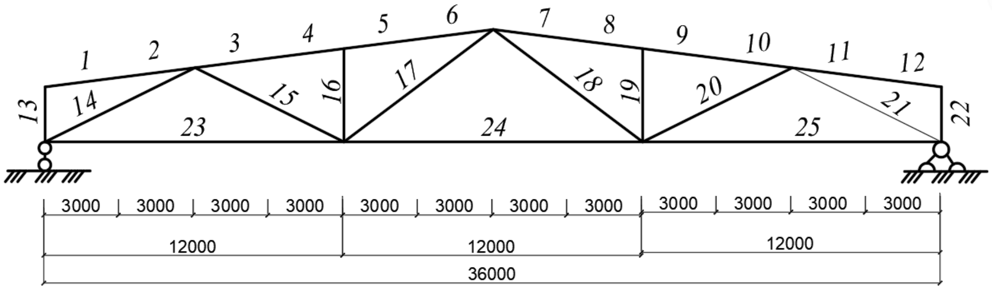


3-figure. Loading scheme of the pentagonal truss with a modified structural form.

3. Results and Discussion

Usually, in truss members with rigidly connected joints, in addition to the axial force (N), a bending moment (M) is also generated; however, since this moment is relatively small, it is generally neglected. As can be seen from Figure 2 above, because the load in the truss is also applied at the mid-panel, the magnitude of the moment in the upper chord becomes significant, which complicates the behavior of the member [10][11]. Therefore, it becomes necessary to take the bending moment into account in the design of the truss. This situation arises when the length of the upper chord panel exceeds 3 meters or when a uniformly distributed load acts on the upper chord (as in roof coverings without purlins).

The adopted truss has a span of 36 m, a height of h_f=4.5 m, and a support height of h_t=2,2 m. The length of the upper chord panel is 6 m, while the length of the lower chord panel is 12 m (Figure 4).



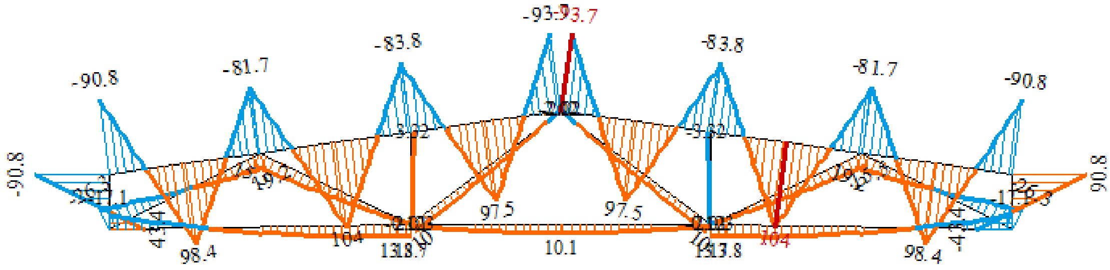
4-figure. Numbering scheme of the elements of a 36-meter span pentagonal truss with a straight upper chord.

The calculation results of the truss under static and dynamic loads were obtained using the LIRA-SAPR 2017 program and are presented in Figures 1 and 2. As can be seen from the table, in addition to the axial force (N), bending moment (M) and shear force (Q) are also generated in the upper chord members.

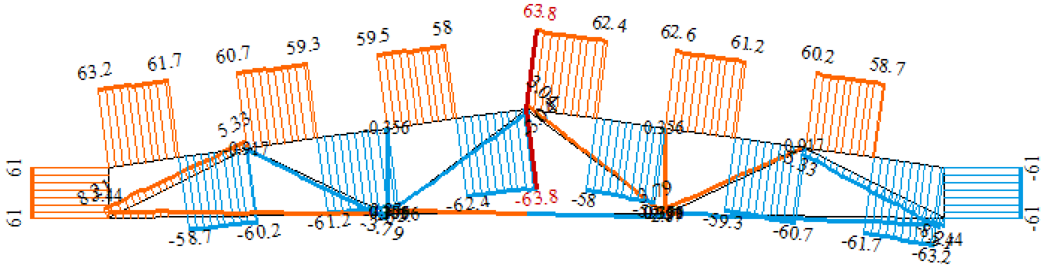
The bending moment (M) mainly reaches significant values in the upper chord. In the lower chord, the magnitude of the bending moment (M) is not considerable [12][13]. In the support column and support brace, the bending moment (M) has relatively higher values, whereas in the other columns and braces, the bending moment (M) is not significant (Table 1).

Table 1. Stresses in the elements of a 36-meter span pentagonal truss with a straight upper chord panel (Figure 5, Figure 6).

I-variant		Stresses		
Member designation		*N (kN)*	*My (kN·m)*	*Qz (kN)*
Upper chord	1	-70,35	-90,75	63,16
	2	-53,42	98,36	-58,72
	3	-1684,21	-81,68	60,70
	4	-1684,33	103,70	-61,18
	5	-1684,13	-83,78	-62,62
	6	-1700,53	97,50	58,04
Lower chord	23	1312,93	-17,10	5,44
	24	1538,02	1,51	2,87
Columns	13	-133,03	-90,75	60,99
	16	-244,81	3,32	-0,36
Braces	14	-1405,43	19,20	5,33
	15	402,00	15,49	-0,92
	17	173,07	10,04	-0,17

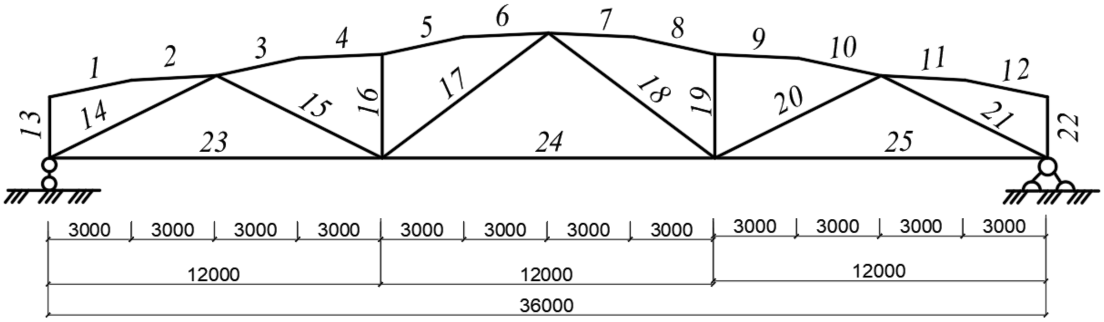


5-figure. Bending moment (M) diagram of a 36-meter span pentagonal truss with a straight upper chord.



6-figure. Shear force (Q) diagram of a 36-meter span pentagonal truss with a straight upper chord.

The upper chord panels of the truss were pre-bent upward at specified intervals within the range of *f*=8-15 cm and a concentrated load of *F=121.6 kN* was applied at the nodes The structure was then analyzed under static and dynamic loads (Figure 3) [14][15]. Analysis of the obtained results showed that when the local bending value of the upper chord panel is *f*=12 sm the values of bending moment (M) and shear force (Q) decrease and reach optimal values (Figure 7).

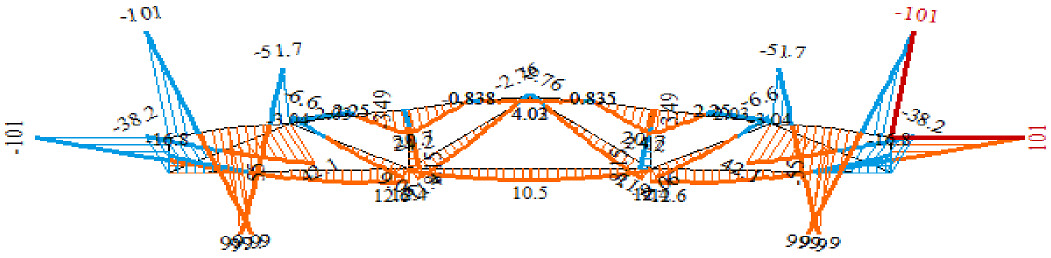


7-figure. Numbering scheme of the elements of a 36-meter span pentagonal truss with the upper chord panel reverse-bent by *f*=12 sm.

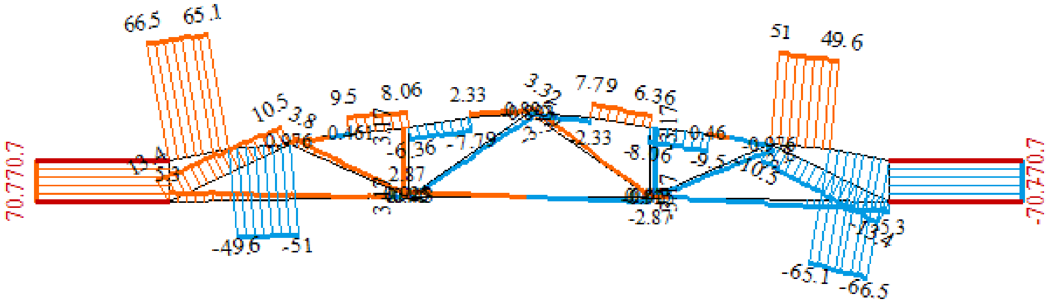
Table 2. Table of stresses in the truss members with the upper chord panel reverse-bent by *f*=12 cm (Figure 8, Figure 9).

(f=12 sm)		Stresses		
Member designation		*N (kN)*	*My (kN·m)*	*Qz (kN)*
Upper	1	-83,76	-100,61	66,52
	2	-66,18	99,94	-49,58
	3	-	-3,04	0,98

chord		1671,42		
	4	-1654,09	-2,25	9,50
	5	-1667,33	20,73	-6,36
	6	-1656,57	-0,84	2,33
Lower chord	23	1265,08	-16,79	5,30
	24	1500,38	1,90	2,87
Columns	13	-141,03	-100,61	70,73
	16	-239,22	-3,49	3,17
Braces	14	-1378,58	-38,21	13,38
	15	389,01	-6,60	3,80
	16	165,24	11,39	-0,45



8-figure. Bending moment (M) diagram of a 36-meter span pentagonal truss with the upper chord panel reverse-bent by *f*=12 cm.



9-figure. Shear force (Q) diagram of a 36-meter span pentagonal truss with the upper chord panel reverse-bent by *f*=12 cm.

The diagram showing the variation of the bending moment in the upper chord panels of a 36-m span *L*=36 m truss, with straight and reverse-bent upper chord panels, as a function of the bending height, is presented below (Figure 10).

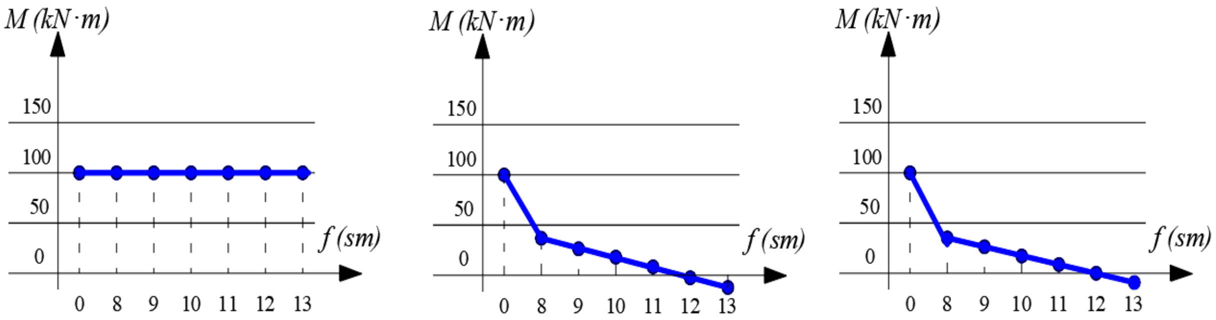
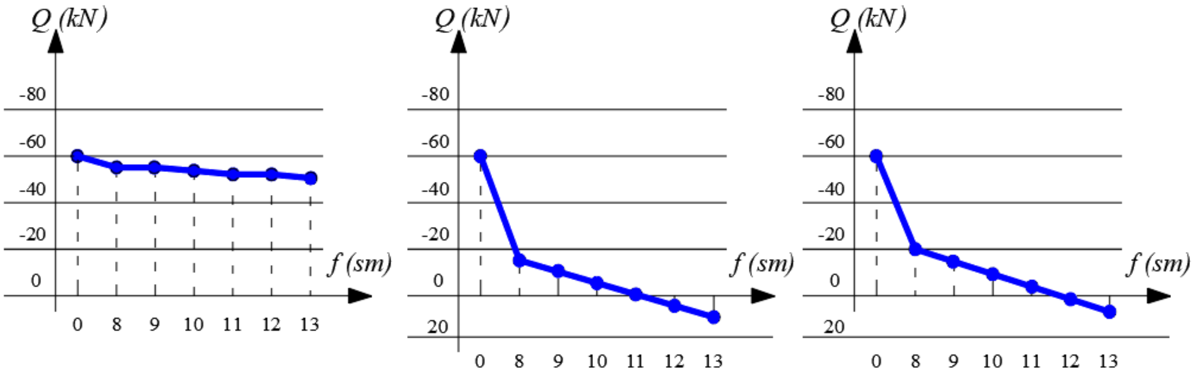


Figure 10. Variation graph of the bending moment (Mx) in the upper chord of trusses with straight and bent upper chord panels as a function of f

a) first panel of the upper chord of the truss;
b) second panel of the upper chord of the truss;
c) third panel of the upper chord of the truss.



a) b) v)

Figure 11. Variation graph of the shear force (Qx) in trusses with straight and reverse-bent upper chord panels (*f*=12 cm) as a function of *f*.

a) first panel of the upper chord of the truss;
b) second panel of the upper chord of the truss;
c) third panel of the upper chord of the truss.

4. Conclusion

In conclusion, it has been established that the constructive solution of locally reverse bending the upper chord in large-span steel trusses is one of the important approaches that contributes to improving the operational efficiency of the truss. In the studies conducted on 36 m span pentagonal (trapezoidal-shaped) steel trusses, the structures were analyzed in two variants using the LIRA-SAPR 2017 program, and their results were compared.

The obtained results showed that in reverse-bent trusses, the values of bending moment (M) and shear force (Q) in the members decrease, which leads to a more favorable distribution of stresses in the structural elements and an overall increase in their performance. In particular, the most optimal result was achieved when the bending height was f=12 cm, at which point the internal stresses reached their minimum values and the overall deformation of the truss was also relatively small.

In general, the conducted analysis scientifically confirmed that by applying the method of reverse bending of the upper chord, it is possible to increase the load-bearing capacity of trusses, optimize material consumption, and reduce stresses in the members. This demonstrates that the proposed structural solution can achieve efficiency when applied in practical construction. The results of the study also indicate that, in trusses with a reverse-bent upper chord panel, material consumption can be significantly reduced compared to conventional trusses. In particular, the comparison results show that steel consumption decreased by approximately 10–11% for the entire truss and by up to 20–21% for the upper chord elements, leading to improved economic efficiency of the structure and more rational use of materials.

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