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USE OF PERFORATED I-BEAMS OF VARIABLE RIGIDITY IN A STEEL SMALL-ELEMENT FARM AND STUDY OF ITS RATIONALITY

ВИКОРИСТАННЯ ПЕРФОРОВАНИХ ДВОТАВРІВ ЗМІННОЇ ЖОРСТКОСТІ В СТАЛЕВІЙ МАЛОЕЛЕМЕНТНІЙ ФЕРМІ ТА ДОСЛІДЖЕННЯ ЇЇ РАЦІОНАЛЬНОСТІ

Nalepa O.I., Ph.D., Associate Professor, orcid.org/0009-0008-0749-5663; **Romaniuk Y.V., PhD student**, orcid.org/0009-0005-6097-9788**; Neverkovets D.T., student** (National University of Water Management and Environmental Management, Rivne, Ukraine); **Kovtonyuk A.V., Engineer** (State Enterprise "State Research Institute of Building Structures", Kyiv), orcid.org/0009-0000-1990-2467

Налепа О.І., к.т.н., доцент, orcid.org/0009-0008-0749-5663**; Романюк Є.В., аспірант,** orcid.org/0009-0005-6097-9788; **Невірковець Д.Т., студентка,** (Національний університет водного господарства та природокористування, м. Рівне, Україна)**; Ковтонюк А.В., інженер** (Державне підприємство "Державний науково-дослідний інститут будівельних конструкцій", м. Київ), orcid.org/0009-0000-1990-2467

One of the ways to reduce the material consumption of steel trusses is the use of initial systems with a minimum number of elements, the concentration of material in the main bearing elements, the use of highly efficient profiles. The researched truss in the form of a sprengel system, which consists of a two-sloped upper belt, a lower broken belt and two risers connecting the belts, can correspond to such design directions. The upper belt in the areas between the support and ridge nodes is a rigid, inseparable rod that receives all three types of internal forces: bending moment M, longitudinal force N and transverse force Q. The main role here is played by the bending moment, the value of which along the belt varies from zero values to certain extreme values. The possibility of using perforated I-beams of constant and variable stiffness in the upper belt has been studied. The characteristic curves of the bending moment in the upper belt and the structural solutions of the rods for each of the given stiffness change schemes are considered. The final proposed constructive solution of the upper belt of the truss with a span of 18 meters in the form of a perforated I-beam of variable height. The permissible range of changes in the values of the bending moment is obtained. A geometric interpretation of the area of possible moment values is established.

Наведений аналіз роботи малоелементної сталевої ферми прольотом 18 м під навантаженням. Обгрунтований вибір перерізу верхнього поясу у вигляді перфорованого двотавра змінної висоти по довжині поясу.

Keywords:
Beam, truss, H-beam, tee-beam, cutting.
Балка, ферма, двотавр, тавр, різка.

Introduction. One of the directions of reducing the material consumption of steel trusses is the use of initial systems with a minimum number of elements, concentration of material in the main load-bearing elements, use of highly efficient profiles. The truss studied in [1, 2, 3] in the form of a truss system, which consists of a gabled upper belt, a lower broken belt and two risers connecting the belts (Fig. 1), can correspond to such directions in design.

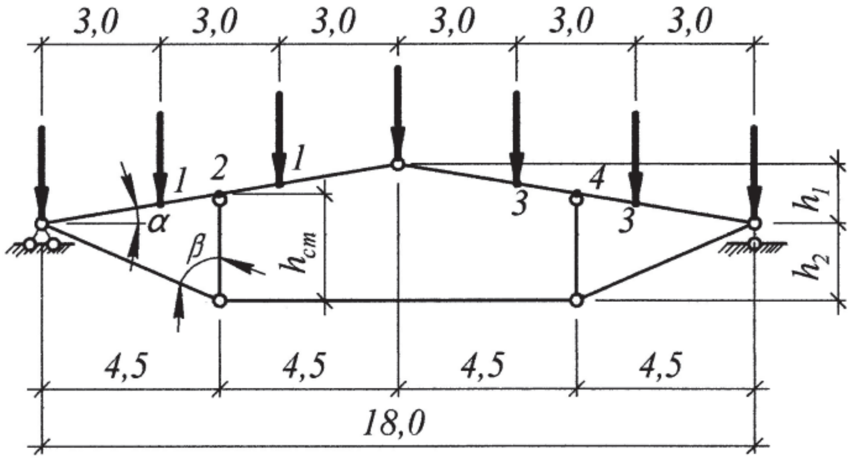

Fig. 1. The initial truss system

The upper chord in the sections between the support and ridge nodes is a rigid continuous rod that perceives all three types of internal forces: bending moment M, longitudinal force N and transverse force Q. The main role here is played by the bending moment, the magnitude of which varies along the chord from zero values to certain extreme values. The possibility of using perforated I-beams of constant and variable stiffness in the upper chord is investigated. The characteristic diagrams of the bending moment in the upper chord and the structural solutions of the rods for each of the given stiffness change schemes are considered. The structural solution of the upper chord of the truss with a span of 18 meters in the form of a perforated I-beam of variable height is finally proposed. The permissible range of bending moment values is obtained. The geometric interpretation of the region of possible moment values is established.

Purpose and objectives of the research. In the adopted distribution of the bending moment and the constructive solution of the upper chord of the truss, there is one important feature that should be investigated in order to prove the effectiveness of using perforated I-beams of variable height in the above-mentioned initial truss system. Its essence is as follows. It is generally accepted to consider the statics of the initial system as primary and, starting from it, to look for constructive solutions for the elements. With this approach to solving the problem, the optimal distribution of the bending moment in the upper chord is an equal-moment distribution. This is fully justified, since in this case the extreme values of the bending moment will be simultaneously the minimum of all possible. Accordingly, the most expedient would be to use a perforated rod with a constant cross-sectional height in the upper chord. However, highly effective types of profiles, which are perforated I-beams with a variable cross-sectional height along the length, forced to solve the issues of the constructive nature and distribution of internal forces simultaneously.

Let us analyze the geometric characteristics of the sections of perforated I-beams with a constant (type A2, Fig. 2) and a variable (type B2, Fig. 3) [2] section height along the length. The maximum possible section height for them will be the same. At the same time, in B2 it smoothly decreases along the length of the rod. The most important for us are the geometric characteristics in sections with extreme values of the bending moment (points 1, 2, 3 and 4 of the geometric diagram, Fig. 4).

In Table. 1 and in the graphs of Fig. 5, their comparison is given for the maximum possible development of the section for the initial I-beam 23B1. The cutting parameters are equal: for a rod with a constant section height hi = 4 cm, cij = 15 cm; for a rod with a variable section height hi = 4 cm, cij = 4 cm. The maximum possible section height in both cases is 38 cm. The values of the cross-sectional area (A), the moment of inertia of the entire section (I), the height of the T-beam in the weakened section (h_T) are compared, as well as the moments of inertia of the T-beams (I_T), the maximum (W_T, max) and minimum (W_T, min) moments of resistance of the T-beams. The characteristics of the rod with a constant section height are taken as 100%.

Analysis of the calculation results shows that the geometric characteristics of the section with the largest height of the rod type B2 far exceed the similar characteristics of the rod type A2. At points 1 and 3 (see Fig. 4), the moment of inertia I of the rod B2 is somewhat smaller, but the geometric characteristics of individual T-sections remain incomparably larger, namely they are decisive in the calculations of perforated elements. The height of the T-sections for a given wall section in the rod A2 is equal to 4 cm along the entire length, and in the rod B2 it varies from 4 cm in the smallest section to 15 cm in the largest. With an increase in the height of the T-sections of the rod A2, the height of the section of the entire rod decreases. Table 2 and Fig. 6 give a comparison of the geometric characteristics of the sections with the height of the T-section of the rod A2 equal to the average height of the T-section of the rod B2 described above. Its height is 9.5 cm, and the height of the entire rod is 27 cm. With such a section, the characteristics of the T-sections have increased significantly, and the value of I has decreased. However, in all sections with extreme values of the bending moment, the geometric characteristics of the rod with a variable cross-section height exceed the characteristics of the rod with a constant height.

Research results. Conclusion. Thus, for the same initial I-beam, the bearing capacity of a perforated rod with a length-variable section height in places with extreme values of bending moment is significantly greater than that of a perforated rod of constant height. The efficiency of using these rods in the upper chord of the truss necessitated the redistribution of the bending moment values in proportion to the values of the geometric characteristics of the sections (see Fig. 4).

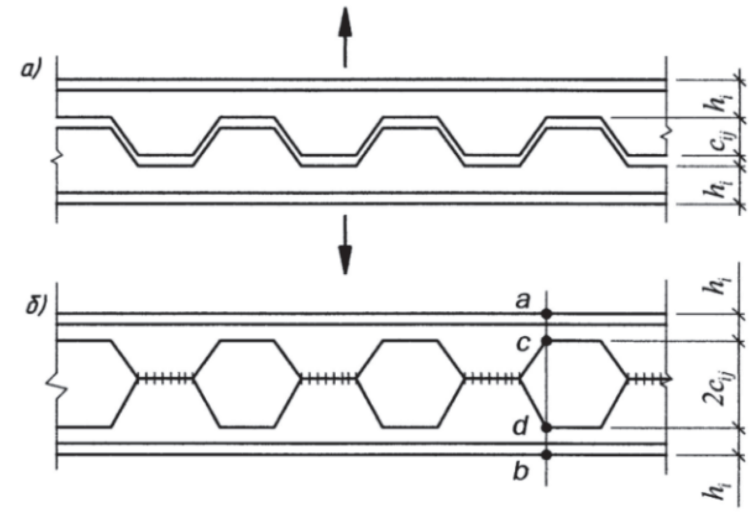

Fig. 2. Scheme of the formation of a perforated I-beam of constant stiffness type A2: a) initial I-beam; b) resulting perforated I-beam

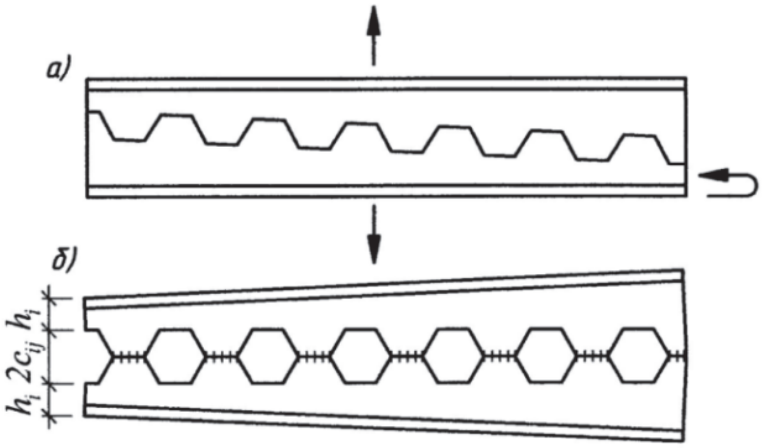

Fig. 3. Scheme of the formation of a perforated I-beam of variable stiffness type B2: a) initial I-beam; b) resulting perforated I-beam

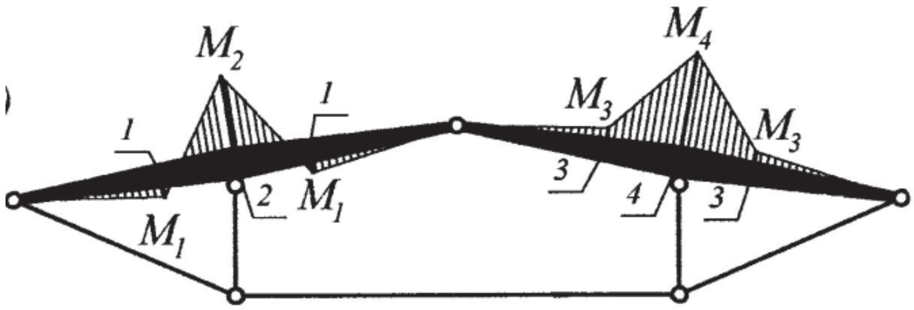

Fig. 4. Scheme of the change in stiffness of the upper chord and sections with extreme values of the bending moment

Table 1

Comparison of geometric characteristics of sections at maximum development of I-beam 23B1

Parameters	A2 type rod cross-section	Maximum cross-section of type B2 rod	Cross-section at points 1 and 3 of a rod of type B2	Minimum cross-section of a type B2 rod
1	*2*	*3*	*4*	*5*
$h_т$, см	4,00 / 100%	15,00 / 375%	11,33 / 283%	4,00 / 100%
A, $см^2$	24,51 / 100%	36,83 / 150%	32,72 / 134%	24,51 / 100%
I, $см^4$	8160,69 / 100%	9396,79 / 115%	5733,80 / 70%	1298,45 / 16%
$I_т$, $см^4$	9,29 / 100%	383,56 / 4129%	173,83 / 1871%	9,29 / 100%
$W_{т, min}$, $см^3$	2,88 / 100%	33,92 / 1178%	19,69 / 684%	2,88 / 100%
$W_{т, max}$, $см^3$	12,00 / 100%	103,87 / 866%	69,43 / 579%	12,00 / 100%

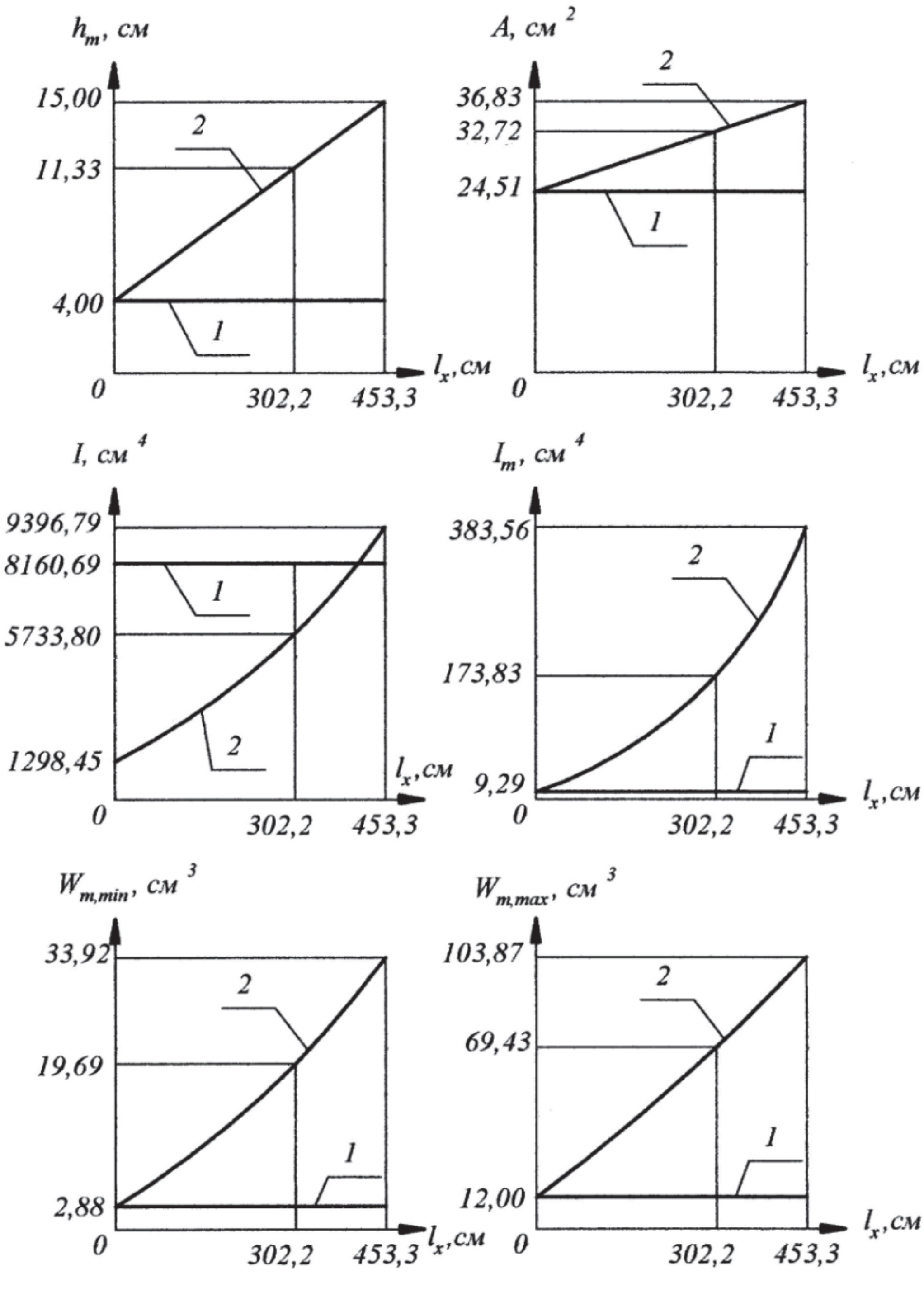

Fig. 5.. Graphs of changes in the values of geometric characteristics of weakened sections of the upper chord in the section from the supporting (or ridge) node to the riser junction node (to Table 1):
1 - rods of constant height; 2 - rods of variable height

Table 2
Comparison of geometric characteristics of sections at the height of the mark of the rod of type A2, which is equal to the average height of the mark of the rod of type B2 (for the original I-beam 23B1)

Parameters	A2 type rod cross-section	Maximum cross-section of type B2 rod	Cross-section at points 1 and 3 of a rod of type B2	Minimum cross-section of a type B2 rod
1	*2*	*3*	*4*	*5*
$h_т$, см	9,50 / 100%	15,00 / 158%	11,33 / 119%	4,00 / 42%
A, $см^2$	30,67 / 100%	36,83 / 120%	32,72 / 107%	24,51 / 80%
I, $см^4$	4284,33 / 100%	9396,79 / 219%	5733,80 / 134%	1298,45 / 31%
$I_т$, $см^4$	104,96 / 100%	383,56 / 365%	173,83 / 166%	9,29 / 9%
$W_{т, min}$, $см^3$	13,95 / 100%	33,92 / 243%	19,69 / 141%	2,88 / 21%
$W_{т, max}$, $см^3$	53,17 / 100%	103,87 / 195%	69,43 / 131%	12,00 / 23%

It should be noted that the value of the bending moment M4 in the upper chord of variable stiffness exceeds the value of the moment at this point in the uniform moment scheme. As numerical studies have shown, this increase is approximately 35%. However, the geometric characteristics of this section during the transition from a rod of constant stiffness to a rod of variable stiffness increase in the range from 2 to 12 times (depending on the values of the section parameters of the original I-beam). The value of the bending moment M1 during the transition from a uniform moment upper chord to a belt of variable stiffness decreases on average by 1.35 times, and the geometric characteristics of the section increase in the range from 1.3 to 5 times. Thus, when transitioning from the uniform bending moment distribution scheme and the corresponding use of perforated rods with constant section height to the scheme under which the condition |M4|>|M1| is fulfilled and which corresponds to the structural solution of the upper chord in the form of a perforated I-beam with a section height variable along the length, the values of both the bending moment

M4 and the geometric characteristics of the sections at points 4 and 1 increase (the value of M1 decreases). However, the increase in the geometric characteristics of the sections at several times exceeds the increase in extreme values of bending moments in critical sections. From this it follows that the use of perforated elements of variable stiffness in such structures is more effective compared to perforated elements of constant stiffness along the length.

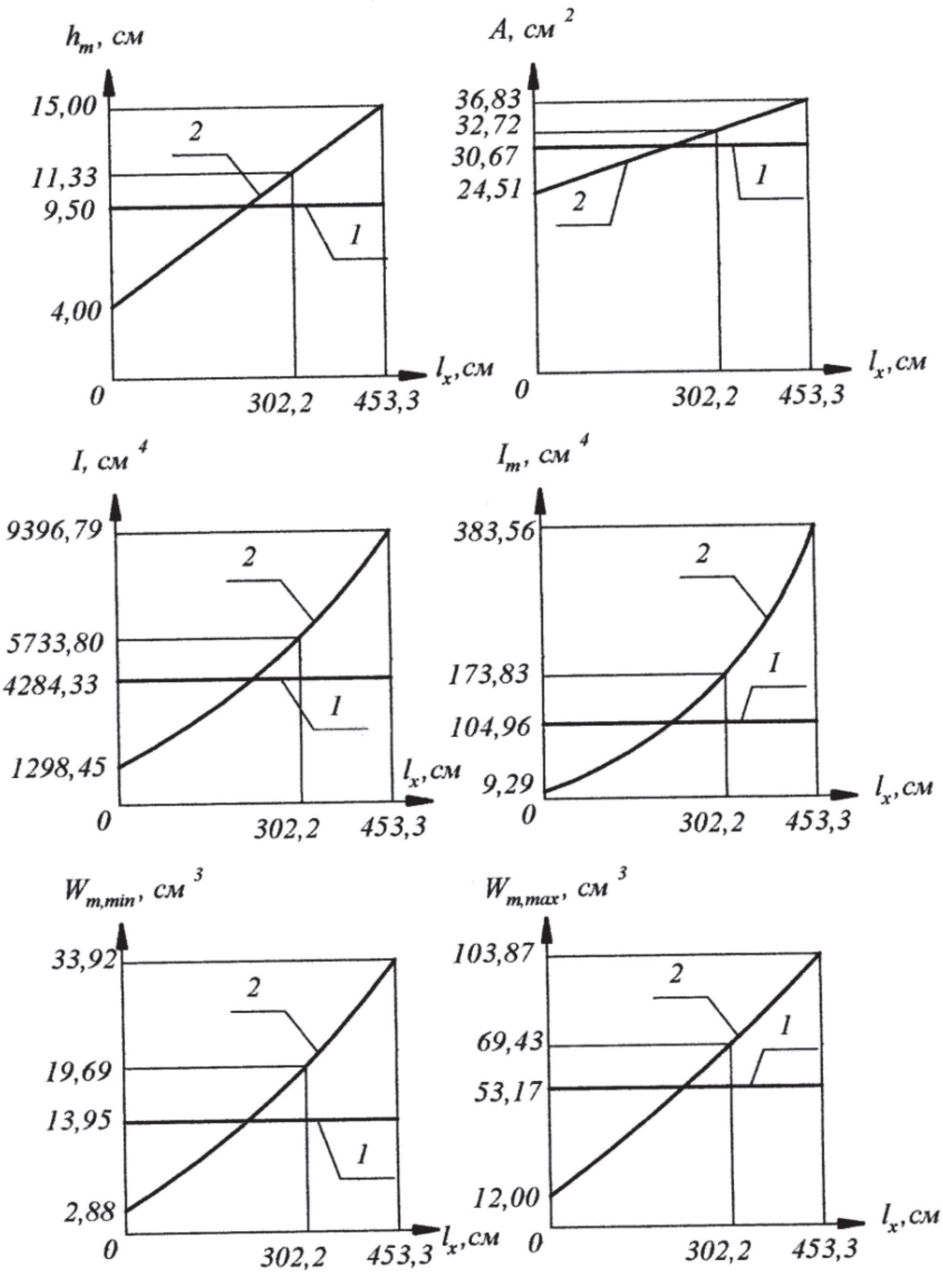

Fig. 6. Graphs of changes in the values of geometric characteristics of weakened sections of the upper belt in the area from the supporting (or ridge) node to the riser junction node (to Table 2): 1 - rods of constant height; 2 - rods of variable height

several times exceeds the increase in extreme values of bending moments in critical sections. From this it follows that the use of perforated elements of variable stiffness in such structures is more effective compared to perforated elements of constant stiffness along the length.

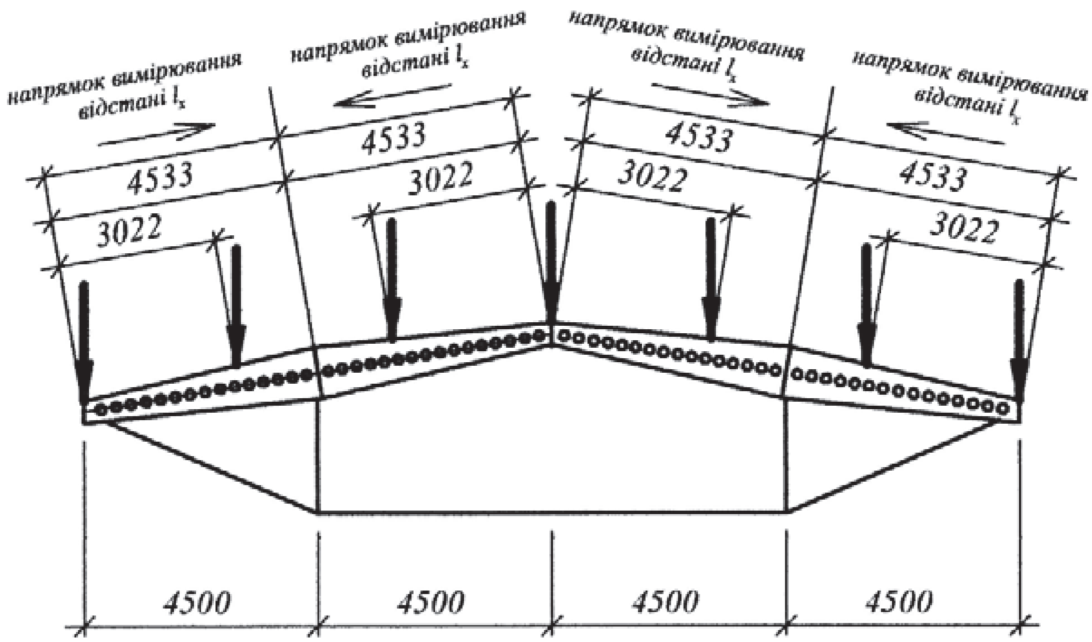

Fig. 7. Before determining the distance on the graphs l_x

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