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APPLICATION OF MONOSYMMETRICAL I-BEAMS
IN LIGHT METAL FRAMES WITH VARIABLE STIFFNESS

І.О. Скляров. **Застосування моносиметричних двотаврових перерізів у легких сталевих рамах змінної жорсткості.** Стаття присвячена дослідженню ефективності використання моносиметричних двотаврів з гнучкою стінкою в рамних конструкціях змінного перерізу, особливостям їх розрахунку і конструювання. *Мета:* Метою дослідження є підтвердження доцільності застосування двотаврів з гнучкою стінкою як легких несучих металевих каркасів будівель універсального призначення. *Матеріали і методи:* Для зменшення витрат металу рама умовно розбивається на кілька окремих ділянок відповідно до епюри згинальних моментів так, щоб у стиснутій або більш напруженій зоні перерізу було розташовано пояс з більшою площею, а у розтягнутій або менш напруженій полиці — пояс з меншою площею. Отримані таким чином перерізи мають меншу площу порівняно з симетричними профілями. Додаткове зменшення згинальних моментів забезпечується також внаслідок зміщення осей елементів змінного перерізу. *Результати:* Проведені розрахунки і підбір перерізів елементів рами показали, що шляхом використання моносиметричних перерізів можна досягти зменшення маси несучих елементів на 10 % порівняно з симетричними профілями змінної жорсткості. Ефективність запропонованого конструктивного рішення підтверджується порівнянням маси спроектованої рамної конструкції з існуючим аналогом — рама симетричного профілю легша на 15,3 %, моносиметричного профілю — на 27 %. *Висновки:* Аналіз напружено-деформованого стану конструкцій показав: по-перше, через несиметричність профілю відбувається зміщення центра ваги перерізу, що призводить до перерозподілу внутрішніх зусиль у рамі; по-друге, через малу площу перерізу розтягнутих поличок складніше забезпечити стійкість плоскої форми згину ригелів, що призводить до необхідності розкріпляти карнизні ділянки ригелів в'язями з меншим кроком.
Ключові слова: моносиметричні двотаври, тонкостінні конструкції, рами змінного перерізу, легкі сталеві конструкції.

I.O. Sklyarov. **Application of monosymmetrical I-beams in light metal frames with variable stiffness.** The article is devoted to effectiveness of using of monosymmetrical I-beams with flexible wall frame structures of variable section, features of their calculation and design. *Aim:* The aim of research is to confirm the feasibility of I-beams with flexible wall bearing as light metal skeletons for buildings of the universal assignment. *Materials and Methods:* In order to reduce the metal consumption a frame is conventionally divided into several sections according to bending moment diagrams so that in the more compressed zone section the belt of great area was located, and in the stretched or less intense zone the lesser belt was installed. The resulting sections have smaller area in compare to symmetric profiles. Additional reduce bending moments provided as a result of displacement of elements axes with variable cross section. *Results:* The calculations and selection of sections of the frame have shown that it can be achieved the reducing of bearing elements weight by 10 % compared to the symmetrical profiles of variable stiffness due to using monosymmetrical sections. The effectiveness of the proposed constructive solution is confirmed by compare of the projected weight frame construction with existing analogue. The symmetrical frame profile is 15.3 % lighter; the monosymmetrical frame profile is 27 % lighter. *Conclusions:* Analysis of stress-strain state structures shown: first, through asymmetrical profile there is a shifting of the center of gravity section, which leads to a redistribution of internal forces in the frame; secondly, because of the small cross-sectional area of the stretched zones more difficult to ensure the stability of the plane form of bending beams, which leads to the necessity to disconnect areas curtain beams by constraints of smaller steps.
Keywords: monosymmetrical I-beams, thin-walled structures, variable cross section frame, lightweight steel structures.

Introduction. One of the priorities of the capital construction industry is increasing the effectiveness of structures by improving the structural forms and methods of calculation. I-beam elements with a flexible wall have broad prospects for application: beams and cover, frame, arch system — all these structures at low values cut efforts can be made of the thin-walled profile. The efficiency of these elements caused by higher values of the inertia moments in relation to cross-sectional area due to the concentration of material in the shelves. In the overwhelming action of the bending moments it provides a significant economic benefit and achieves frame weight reducing by 30 % in compare to traditional welded sections.

Operating the light frames with thin I-beam sections has certain characteristics. First, rack and crossbars of single-span frames have quite stable distribution of internal forces (of the bending moments especially) (Fig. 1), so that it can be produced of profiles with variable stiffness. Of course, taking into account the presence of structural constraints, so-called "beam of equal resistance" is impossible in the frame elements, but to minimize the material consumption is possible by changing

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the cross-section. Second, there are longitudinal efforts in the columns and frame bolts except of the bending moments and leading to uneven stresses in the compressed and stretched shelves section. Because of this, the logical step is to perform asymmetric profiles, advanced compressed shelf beams (Fig. 2).

The study of variable stiffness constructions, including the frame skeletons, dedicated work by V. Katyushin [1], G. Nasser [2], O. Glitin [3], S. Bilyk [4] and etc. It should be noted that all these works study the stress-strain state, durability and strength frame structures of variable section, but, unfortunately, the results of all the studies have not been definitively formulated the calculation method for thin-walled elements with action the compression of the bend.

The aim of research is to confirm the usefulness of I-beams with flexible wall bearing as light metal skeletons of buildings universal assignment.

Materials and Methods. In order to reduce the metal consumption a frame is conventionally divided into several sections according to bending moment diagrams so that in the more compressed zone section the belt of great area was located, and in the stretched or less intense zone the lesser belt was installed (Fig. 2). The area of the shelf at length of each section is not changed.

Thus, obtained sections have smaller area compared to symmetric profiles. Additional reducing of the bending moments is provided by the displacement of axes elements of variable section. In addition, compressed shelves can lead to loss of stability, so use shelf with larger area will help improve the stiffness of frame.
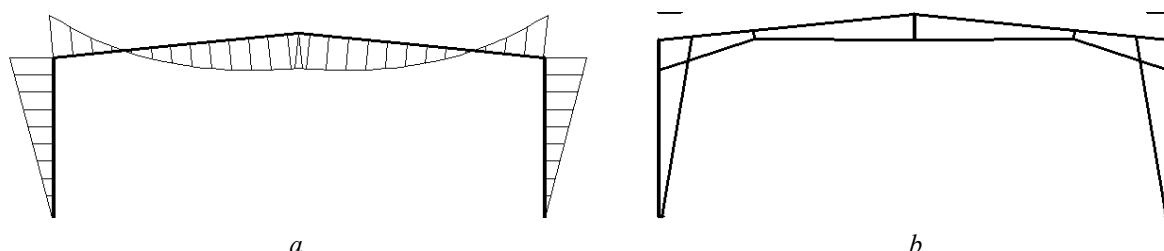

a   *b*

Fig. 1. The principle of design of variable stiffness elements:
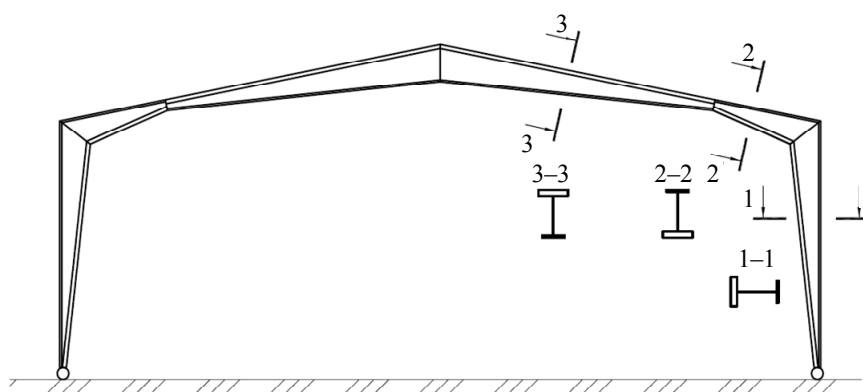*a — bending moment diagrams, b — rational design of variable stiffness frame*

Fig. 2. Steel two-hinges frame with variable stiffness with monosymmetrical I-beam and flexible wall

Calculations and selection of sections of the frame elements via the example frame warehouse building with span of 36 m have shown that by using monosymmetrical sections can be achieved by reducing the bearing elements weight by 10 % in compare to the symmetrical profiles of variable stiffness. Calculated load for cover of the buildings was 2.85 kN/m^2 (including snow load — 1.55 kN/m^2 and own weight constructions for covering fences — 1.3 kN/m^2).

As a result of the selection section were offered such dimensions of structures:
1. Symmetric profiles:

— Cornice node — the wall is 1600×6 mm, shelf is 270×14 mm;

— Flange node — the wall is 1200×6 mm, shelf is 140×14 mm.

2. Monosymmetrical profiles:

— Cornice node — the wall is 1600×6 mm, shelf is 270×14 mm (in compressed mode) and 220×12 mm (in stretched state);

— Flange node — the wall is 1200×6 mm, shelf is 140×14 mm (in compressed mode) and 100×12 mm (in stretched state).

The weight bearing structures per square meter of building area is about 19.87 kg/m^2 for symmetric profiles and 17.98 kg/m^2 for monosymmetrical profiles.

Results. Evaluate the effectiveness of the proposed constructive solution is possible by comparing the weight of the frame with the analog frame presented by V. Trofimov [5] (see Table).

Table

Comparing the projected weight with analogue design

Group of constructions	Span, m	Step, m	Calculated load on the floor, kN/m^2	Weight of construc-tions of frames, kg/m^2
Frame analog [5]	24	6	2.4	22.92
Designed frame of sym-metrical profile	36	6	2.85	19.87
Designed frame of mono-symmetrical profile	36	6	2.85	17.98

Trofimov noted that using more advanced thin profiles will reduce the weight of constructions for another 5...12 % compared to the structural solution proposed in [5], which we see in the table — weight frame construction symmetrical profile lighter on 15.3 %; and monosymmetrical profile on 27 %.

We showed [6...9] that considering the critical work of flexible thin-walled plate of I-beams can increase the carrying capacity of structures. For these profiles is recommended to carry out checks the bearing capacity of elements of frames sections with relative eccentricity $m_{ef} \geq 15$ by:

$$\left| \frac{N}{N_u} \right| + \left(\frac{M_x}{M_{u\varphi}} \right)^2 + \left(\frac{Q}{Q_u} \right)^4 \leq \gamma_c , \tag{1}$$

where M_x, N, Q — bending moment, longitudinal and cross section efforts of the calculation section frame;

$M_{u\varphi}$, N_u, Q_u — limit value of bending moment, longitudinal and transverse effort under simultaneous actions in the calculation section;

γ_c — coefficient of working conditions.

The critical shear stress τ_{cr} and limit value of transverse forces Q_u are calculated using the formulas from section 22 of State Standard DBN V.2.6-198:2014 for I-beams with flexible wall.

The coefficient of working conditions γ_c, taking into account the complex mode of deformation elements of variable stiffness steel frame with a flexible wall, must be limited to 0,95.

Experimental studies that have been conducted by Sklyarov and Bilyk [9] found that in the supercritical phase of a flexible wall shelves work in the section there are additional strain due the actions of local bending moments. Bending moments in compressed shelves are result of deformation of walls and "settling" of shelf, which works as a beam on elastic foundation bed with variable coefficients subgrade resistance (depending on the nature of the deformation of the wall). Thus, the maximum normal stresses in the compressed zone of the frame with a flexible wall may be defined as follows:

$$\sigma_\Sigma = \frac{N}{A_{red}} + \frac{M}{W_{red}} + \frac{M_{fc} k_c}{I_{fc}} y_0 \leq R_y \gamma_c , \tag{2}$$

where N, M — squeezing force and bending moment of the action of external loads;

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A_{red}, W_{red} — area and resistance moment of weakened cross section with flexible wall;

M_{fc} — additional bending moment that occurs in a belt when buckling wall;

I_{fc} — inertia moment of section, formed compressed shelf and part of the wall with height h_{wred};

y_0 — distance from the center of gravity of section of compressed zone to the brink of the belt;

R_y — steel estimated resistance;

$$k_c = \begin{cases} 1, & \overline{\lambda_w} > 9; \\ \dfrac{\overline{\lambda_w}}{\overline{\lambda_{wu}}}, & \overline{\lambda_w} \leq 9 \end{cases}$$ — coefficient for accounting the redistribution of loading bending moment

and depends on the flexibility of the wall;

$$\overline{\lambda_w} = \frac{h_w}{t_w}\sqrt{\frac{R_y}{E}}$$ — conditional flexibility of I-section wall, where h_w — wall height, t_w — wall thickness;

E — elastic modulus of steel;

$\overline{\lambda_{wu}} = 12$ — experimentally established limit of the flexibility of the wall, where shelf does not lose stability in the plane of the wall.

To check the calculation regulations of proposed method for calculation of these structures there was conducted mathematical modeling of the frame by the software system «LIRA-SAPR» (Fig. 3).
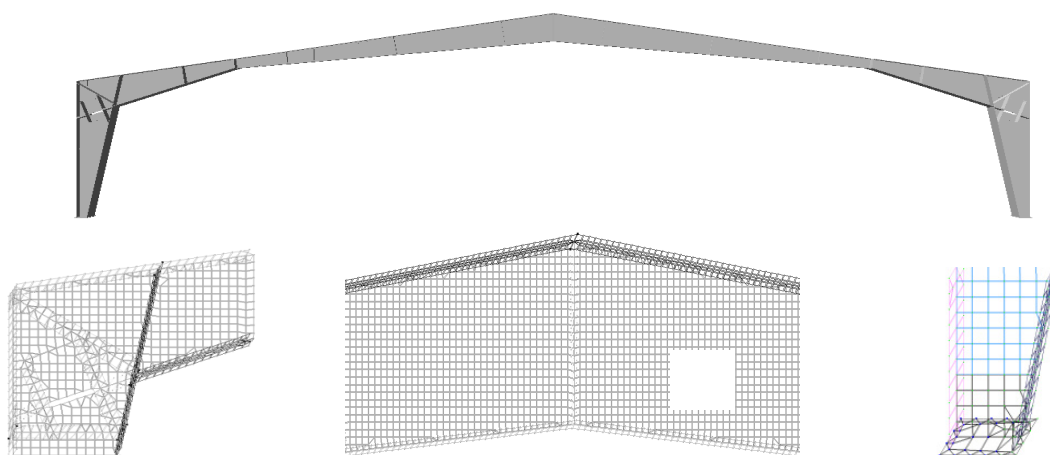

Fig. 3. Finite element model with flew 36 m with welded monosymmetrical I-beam with flexible wall

Conclusions. Analysis of stress-strain state structures showed some features of the frames mono-symmetrical I-beams in compare to symmetric profiles: first, due to asymmetrical type of profile the shift of the gravity section center appears, which leads to a redistribution of internal forces in the frame, that requires to adjust rod design scheme frames after sections selecting; secondly, because of the small cross-sectional area it is difficult to ensure the stability of the plane form of bending beams, which leads to the necessity to disconnect the areas curtain beams by the constraints with smaller steps.

In a market economy and the transition from design of typical mass to individual work with a particular customer, using highly efficient steel structures is a prerequisite for preserving competitiveness as designers of metal structures and steel industry as well. The conducted research of lightweight frames designs based on monosymmetrical profiles indicates the significant prospects for their use in this area. Operations of these structures are still understudied and needs further theoretical analysis as well as series of additional experimental tests.

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