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SEARCHING FOR A COMPROMISE SOLUTION IN CROSS-SECTION SIZE OPTIMIZATION PROBLEMS OF COLD-FORMED STEEL STRUCTURAL MEMBERS

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A parametric optimization problem of cross-sectional sizes for cold-formed steel lipped channel structural members subjected to axial compression has been considered by the paper. An optimization problem is formulated as to define optimum cross-sectional sizes of cold-formed structural member taking into account post-buckling behavior (web and flange local and distortional buckling) of the member as well as structural requirements when the profile perimeter (strip width), profile thickness, design lengths of the structural member as well as material properties are constant and specified in advance. Maximization of the load-carrying capacity of the cold-formed structural member has been assumed as purpose function. The formulated parametric optimization problem has been solved by exhaustive search method using the software written in Python. As optimization results the cold-formed steel lipped channels with optimum cross-sectional dimensions have been obtained depending on the profile thickness and design lengths of the structural member. In order to obtain optimum solutions for cross-sectional dimensions of the CFS lipped channel structural members which are independent from the design flexural lengths and profile thickness, searching for a compromise solution has been performed by exhaustive search method. The obtained cold-formed steel lipped channel structural members with optimum cross-sectional sizes have higher design buckling resistance under the axial compression at the same material consumption (stripe width) comparing with the cold-formed steel lipped channels proposed by the manufacturer. Web local buckling phenomenon has been occurred in all obtained CFS lipped channel cross-sections with optimum sizes.

Keywords: cold-formed steel, buckling resistance, torsional-flexural buckling, parametric optimization, exhaustive search method, compromise solution

Introduction. Previously, the use of cold-formed thin-walled profiles was limited to cases where reducing the weight of the structure was a priority, such as in the aviation or automotive industries. However, due to the development of production technology, corrosion protection, product availability as well as implementation of the design code the use of thin-walled structural elements, including cold-formed profiles is gradually expanding [1].

Today, various structural systems made from cold-formed steel (CFS) structural members used widely in the construction industry are imported intensively to the Ukrainian market of steel structures. Implementation of steel structures made from thin-walled cold-formed profiles in building practice is relevant and economically reasonable. There are specific fields of application where their efficiency is the highest. However, the widespread application of the structures made from thin-walled cold-formed profiles of the domestic production is delayed due to the lack of domestic experience in economic and reliable design of such structures [1, 2].

Literature review and problem statement. In the papers [3] the authors said that "A high degree of flexibility in the manufacturing of various cross-sectional shapes provides a unique opportunity to further improve the load-carrying capacity of these structural elements through an optimization process, leading to more efficient and economical structural systems". A brief review of optimization problem formulation, calculation techniques and algorithms, including gradient-based methods, stochastic search, artificial intelligent methods, and ant colony methods, have been discussed in the paper [4]. The optimization methodologies for CFS structural members have been also summarized and presented systematically in the paper [5, 6].

Lots of papers presented the results of shape optimization of cold-formed steel columns (see for example [7, 8, 9]). In the paper [10] the optimization problem formulation included fabrication and geometric enduse constraints. Shape optimization of manufacturable and usable cold-formed steel singly-symmetric and open columns has been also considered by the paper [11].

An optimization methodology intended to find the optimum cross-section sizes for CFS beam structural members with maximum flexural resistance has been provided by the paper [12]. Geometrical requirements according to EuroCode 3 as well as a number of manufacturing and practical constraints have been considered in scope of the optimization procedure. The flexural resistance of the CFS structural members has been determined based on the effective width approach regulated by EuroCode. The proposed optimization procedure has been performed based on the particle swarm optimization method.

In the paper [13] authors considered the optimal design problems for cold-formed steel lipped channel beams subjected to combined action of bending, shear, and web crippling. CFS beam structural member has been also considered by the papers [14, 15] where Big Bang-Big Crunch optimization and micro Genetic Algorithm have been used. In the paper [16] authors used the particle swarm optimization method in order to obtain optimum cross-section dimensions for lipped channels, folded-flanges, and super-sigma profiles used in modular building applications as beam structural members. Comparing to the conventional CFS sections the load-carrying flexural capacity of the structural members with optimum cross-sectional sizes has been improved significantly.

In the paper [3] a practical optimization methodology for the CFS beam-column structural members with different design lengths and thicknesses, subjected to various combinations of longitudinal force and bending moment has been proposed. The optimization procedure has been performed using a genetic algorithm, when the optimization problem has been formulated as maximization the buckling resistances of CFS structural members with specified and constant material consumption.

The paper [17] presents an optimization procedure to obtain optimum dimensions for CFS channel cross-sections in structural members subjected to compression or bending. An optimization problem has been formulated as maximization of the load-carrying capacity and solved using genetic algorithms. Optimization has been performed for the different column design lengths taking into account the shift of the centroid of its effective cross-sections caused by the local buckling effects.

The paper [18] has been devoted to the shape optimization of cold-formed steel beam-columns with practical and manufacturing constraints. CFS beam-column structural member has been also considered by the papers [19, 20] in scope of unconstrained and constrained optimization procedures.

Particular attention has been paid to the optimal folding of the CFS structural members. In the paper [1] a parametric optimization problem for single edge fold size in CFS structural members subjected to axial compression has been considered. The purpose function and constraints of the mathematical model has been formulated as continuously differentiable functions, then the parametric optimization problems has been successfully solved using the gradient projection non-linear methods [21, 22].

The similar optimization problem has been also considered in the paper [23], where a genetic algorithm has been used with further improvement of the optimal decision based on the gradient descent method. As a result CFS structural member with optimal single edge folds have higher load-carrying capacity comparing to the original designs.

In order to increase the widespread application of the structures made from CFS profiles of the domestic production, effective national ranges of assortments of CFS profiles have to be developed. In this paper, CFS lipped channel structural members subjected to axial compression are considered as research object, which investigated for the searching for optimum cross-sectional dimensions. The following research tasks are formulated: to develop a mathematical model and a numerical technique to solve an optimization problem for cross-sectional sizes of CFS structural members; to perform numerical investigations in order to obtain optimal solutions for considered research object; to develop a guide for designers relating to the optimum material distribution in the cross-sections of the CFS structural members.

The aim and objectives of the study. In order to increase the widespread application of the structures made from CFS profiles of the domestic production, effective national ranges of assortments of CFS profiles have to be developed. In this paper, CFS lipped channel structural members subjected to axial compression are considered as research object, which investigated for the searching for optimum cross-sectional dimensions. The following research tasks are formulated: to develop a mathematical model and a numerical technique to solve an optimization problem for cross-sectional sizes of CFS structural members; to perform numerical investigations in order to obtain optimal solutions for considered research object.

Material and methods. Applied optimum design problems for structures in some cases are formulated as parametric optimization problems, namely as searching problems for unknown structural parameters, which provide an extreme value of the specified purpose function in the feasible region defined by the specified constraints [24]. The mathematical model of the parametric optimization problems includes a set of design variables, an objective function, as well as constraints, which reflect generally non-linear dependences between them.

Let formulate a parametric optimization problem as follow: to find optimum values of cross-sectional sizes for CFS lipped channel structural members subjected to axial compression when the profile perimeter (strip width), profile thickness, steel properties as well as design lengths of the structural member are constant and specified in advance.

The formulated parametric optimization problem can be stated in the following mathematical terms: to find unknown structural parameters:

$$\vec{X} = \{X_\iota\}^T, \ \iota = \overline{1, N_X}; \tag{1}$$

providing the maximum value of the determined objective function:

$$f^* = f\left(\vec{X}^*\right) = \max_{\vec{X} \in \Im} f\left(\vec{X}\right); \tag{2}$$

in feasible region (search space) $\Im$ defined by the following system of constraints:

$$\boldsymbol{\varphi}\left(\vec{X}\right) = \left\{\varphi_\eta\left(\vec{X}\right) \le 0 \mid \eta = \overline{1, N_{IC}}\right\}; \tag{3}$$

where $\vec{X}$ – vector of the design variables (unknown structural parameters); N_X – total number of the design variables; f, φ_η – continuous functions of the vector argument; $\vec{X}^*$ – optimum solution (the vector of optimum values of the structural parameters); f^* – optimum value of the objective function; N_{IC} – number of constraints-inequalities $\varphi_\eta\left(\vec{X}\right)$, which define a feasible region in the design space $\Im$.

Overall cross-section dimensions of a CFS lipped channel, namely web height h, flange width b and single edge fold length c (Fig. 1) are considered as *design variables*. Initial data for optimization are profile thickness t, internal bend radius $r = 1.5t$, material properties (base yield strength f_{yb} and modulus of elasticity E), design length of the structural member corresponded to the flexural buckling modes $l_{ef} = l_{ef,y} = l_{ef,z}$. The torsional buckling length $l_{ef,T}$ is equals to the flexural buckling length $l_{ef,z}$.

Let us introduce in the plane of thin-walled cross-section a Cartesian coordinate system $y_C O z_C$ with the origin in the center of mass C of the section, the direction of the coordinate system axes $y_C O z_C$ coincides with the direction of principle axes of inertia. Let us also describe the considered section of thin-walled bar by a set of sectional points

$\mathbf{P}=\left\{\mathbf{p}_j=\left\{y_j,z_j\right\} \mid j=\overline{0,n}\right\}$ (y_j and z_j are the coordinates of j^{th} sectional point in the coordinate system $y_C O z_C$ introduced above) and by a set of sectional segments $\mathbf{S}=\left\{\mathbf{s}_i=\left\{\mathbf{p}_{i-1},\mathbf{p}_i\right\} \mid i=\overline{1,n}\right\}$, which connect to adjacent sectional points, where n is quantity of the sectional segments and $n+1$ is quantity of the sectional points. It should be noted that the coordinates of the sectional points depend on the design variables of the formulated optimization problem $\mathbf{P}=\mathbf{P}\left(\vec{X}\right)$.

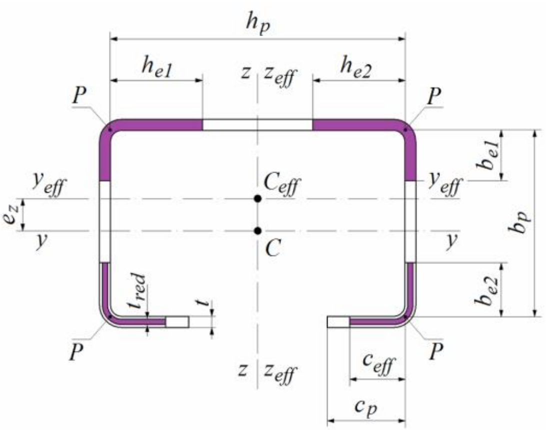

Fig. 1. Cross-section of the CFS lipped channel structural member

The following integral geometrical properties of considered cross-section can be calculated on the determined set $\mathbf{P}$ of sectional points and set $\mathbf{S}$ of sectional segments (see Annex C [25]): A_g is the gross cross-sectional area; I_y, I_z are the second moments of inertia relative to the main axis of inertia, which coincide with the axes of global Cartesian coordinate system $y_C O z_C$; i_y, i_z are the radiuses of inertia relative to the main axis of inertia; I_ω is the sectorial moment of inertia; I_t is the second moment of area for pure torsion. As the coordinates of the sectional points depend on the design variables, then the integral geometrical properties of the gross cross-section depends on the design variables as well.

Design sizes of plane cross-sectional elements (Fig. 1) for CFS lipped channel structural member are calculated according to [25] depending on the design variables h, b and c as well as on the constant internal bend radios r and profile thickness t as presented below:

$$h_p=h-2R+r_m\sqrt{2}\,; \qquad (4)$$

$$b_p=b-2R+r_m\sqrt{2}\,; \qquad (5)$$

$$c_p=c-R+0.5r_m\sqrt{2}\,; \qquad (6)$$

where h_p – design web height; b_p – design flange width; c_p – single edge fold design length; r_m –middle bend radius, $r_m=r+0.5t$; R – external bend radius, $R=r+t$.

Relative slenderness $\bar{\lambda}_{ph}$ of the web, relative slenderness $\bar{\lambda}_{pb}$ of the flanges and relative slenderness $\bar{\lambda}_{pc}$ of the single edge fold for CFS lipped channel are calculated according to [25, 26] as follow:

$$\bar{\lambda}_{ph} = \frac{h_p}{56,8t\varepsilon}; \tag{7}$$

$$\bar{\lambda}_{pb} = \frac{b_p}{56,8t\varepsilon}; \tag{8}$$

$$\bar{\lambda}_{pc} = \frac{c_p}{28,4t\varepsilon\sqrt{\tilde{\mathbf{k}}_{\boldsymbol{\sigma}\mathbf{c}}\left(c_p/b_p\right)}}; \tag{9}$$

where ε – material factor, $\varepsilon = \sqrt{\frac{235}{f_{yb}[\text{MPa}]}}$; $\tilde{\mathbf{k}}_{\boldsymbol{\sigma}\mathbf{c}}\left(c_p/b_p\right)$ – buckling factor calculated according to the dependency proposed by [25].

Cross-section flanges and web of CFS lipped channel structural member are subjected to post-buckling behavior (when local buckling occurs) in the case when its slenderness exceed limit value, namely web slenderness $\bar{\lambda}_{ph} > 0,673$ and/or flange slenderness $\bar{\lambda}_{pb} > 0,673$. In this case effective widths of the web h_{eff} and flanges b_{eff} as well as effective cross-sectional sizes h_{e1}, h_{e2}, b_{e1}, b_{e2} are defined according to [25, 26] as presented below:

– if $\bar{\lambda}_{ph} > 0,673$:

$$h_{e1} = h_{e2} = \frac{h_{eff}}{2} = \frac{h_p}{2\bar{\lambda}_{ph}}\left(1 - \frac{0,22}{\bar{\lambda}_{ph}}\right) = 28,4t\varepsilon\left(1 - \frac{12,496t\varepsilon}{h_p}\right); \tag{10}$$

– if $\bar{\lambda}_{ph} \le 0,673$:

$$h_{e1} = h_{e2} = \frac{h_p}{2}; \tag{11}$$

– if $\bar{\lambda}_{pb} > 0,673$:

$$b_{e1} = \frac{b_{eff}}{2} = \frac{b_p}{2\bar{\lambda}_{pb}}\left(1 - \frac{0,22}{\bar{\lambda}_{pb}}\right) = 28,4t\varepsilon\left(1 - \frac{12,496\varepsilon t}{b_p}\right); \tag{12}$$

$$b_{e2} = \frac{b_{eff}}{2} = \frac{b_p}{2\bar{\lambda}_{pb}\sqrt{\chi_d}}\left(1 - \frac{0,22}{\bar{\lambda}_{pb}\sqrt{\chi_d}}\right) = \frac{28,4t\varepsilon}{\sqrt{\chi_d}}\left(1 - \frac{12,496t\varepsilon}{b_p\sqrt{\chi_d}}\right); \tag{13}$$

– if $\bar{\lambda}_{pb} \le 0,673$:

$$b_{e1} = b_{e2} = \frac{b_p}{2}, \tag{14}$$

where χ_d – reduction factor for the distortional buckling cross-section resistance calculated as presented below.

Single edge fold of CFS lipped channel cross-section is subjected to post-buckling behavior (when local buckling occurs) in case when it slenderness exceeds limit value ($\bar{\lambda}_{pc} > 0,748$).In this case effective single edge fold width c_{eff} is determined according to [25] as follow:

– if $\bar{\lambda}_{pc} > 0,748$:

$$c_{eff} = \frac{28,4t\varepsilon}{\sqrt{\chi_d}} \sqrt{\tilde{\mathbf{k}}_{\mathbf{\sigma c}}\left(\frac{c_p}{b_p}\right)}\left(1 - \frac{5,3392t\varepsilon}{c_p\sqrt{\chi_d}} \sqrt{\tilde{\mathbf{k}}_{\mathbf{\sigma c}}\left(\frac{c_p}{b_p}\right)}\right); \tag{15}$$

– if $\bar{\lambda}_{pc} \le 0,748$:

$$c_{eff} = c_p . \tag{16}$$

Let us also describe the considered effective cross-section of thin-walled bar by a set of sectional points $\mathbf{P}_{eff} = \left\{\mathbf{p}_{eff,j} = \left\{y_{eff,j}, z_{eff,j}\right\} \mid j = \overline{0, n_{eff}}\right\}$ ($y_{eff,j}$ and $z_{eff,j}$ are the coordinates of j th sectional point in the coordinate system $y_C O z_C$ introduced above) and by a set of sectional segments $\mathbf{S}_{eff} = \left\{\mathbf{s}_{eff,i} = \left\{\mathbf{p}_{eff,i-1}, \mathbf{p}_{eff,i}\right\} \mid i = \overline{1, n_{eff}}\right\}$, which connect to adjacent sectional points, where n_{eff} is quantity of the sectional segments and $n_{eff}+1$ is quantity of the sectional points. It should be noted that the coordinates of the sectional points depend on the design variables of the formulated optimization problem as well as on the effective cross-sectional sizes h_{e1}, h_{e2}, b_{e1}, b_{e2}, c_{eff} : $\mathbf{P}_{eff} = \mathbf{P}_{eff}\left(\vec{X}, h_{e1}, h_{e2}, b_{e1}, b_{e2}, c_{eff}\right)$.

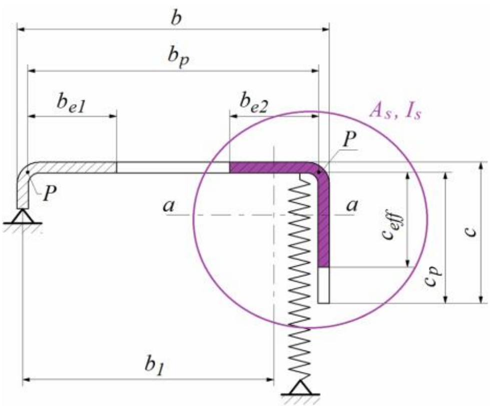

Fig. 2. Flange plane element of the CFS lipped channel stiffened by the single edge fold

The area A_{eff} of the effective cross-section of CFS lipped channel structural member subjected to axial compression can be calculated on the determined set $\mathbf{P}_{eff}$ of sectional points and set $\mathbf{S}_{eff}$ of sectional segments (see Annex C [25]). As the coordinates of the effective cross-sectional points depend on the design variables, then the area A_{eff} of the effective cross-section of CFS lipped channel structural member subjected to compression depends on the design variables as well.

Single edge folds in CFS lipped channel structural members ensure partial restraint for plane flanges. In order to estimate such restraint, the design cross-section of the stiffener (Fig. 2) should be introduced into the further consideration. The design cross-section of the stiffener consists of single edge fold with effective width c_{eff} together with effective adjacent part of the flange with effective width b_{e2}. The thickness of the stiffener's design cross-section is equals to the profile thickness t in case when the distortional buckling does not occur ($\chi_d = 1$). Otherwise, the reduced thickness t_{red} of the stiffener's design cross-section allowing for reduced stiffener resistance due to flexural buckling of the stiffener is determined according to [25] as follow:

$$t_{red} = \chi_d t . \tag{17}$$

Let us also describe the design cross-section of the stiffener by a set of sectional points $\mathbf{P}_s = \left\{ \mathbf{p}_{s,j} = \left\{ y_{s,j}, z_{s,j} \right\} \mid j = \overline{0, n_s} \right\}$ ($y_{s,j}$ and $z_{s,j}$ are the coordinates of j th sectional point in the coordinate system $y_C O z_C$ introduced above) and by a set of sectional segments $\mathbf{S}_s = \left\{ \mathbf{s}_{s,i} = \left\{ \mathbf{p}_{s,i-1}, \mathbf{p}_{s,i} \right\} \mid i = \overline{1, n_s} \right\}$, which connect to adjacent sectional points, where n_s is quantity of the sectional segments and $n_s + 1$ is quantity of the sectional points. It should be noted that the coordinates of the sectional points depend on the design variables of the formulated optimization problem as well as on the effective cross-sectional sizes b_{e2}, c_{eff} and reduced thickness t_{red}: $\mathbf{P}_s = \mathbf{P}_s\left(\vec{X}, b_{e2}, c_{eff}, t_{red} \right)$.

The following geometrical properties of the design cross-section of the stiffener can be calculated on the determined set $\mathbf{P}_s$ of sectional points and set $\mathbf{S}_s$ of sectional segments: A_s is the area of the stiffener's design cross-section; I_s is the second moment of inertia for the stiffener's design cross-section; $b_{c,s}$ is the distance from the web-to-flange junction to the gravity center of the effective area of the edge stiffener.

The partial restraint for plane flanges provided by the single edge folds in CFS lipped channel structural members can be simulated using a linear spring. In case of the axial compression stiffness for such a linear spring can be estimated according to [25] as presented below:

$$K = \frac{E}{3,64} \cdot \frac{t^3}{b_{c,s}^2 \left(b_{c,s} + 1.5h - 3t \right)} . \tag{18}$$

It should be noted that analytical expression for stiffness of the linear spring presented above is restricted by the case of cold-formed structural members with flanges stiffened by single or double edge folds only and cross-section symmetrical relatively to the main axes of inertia which is perpendicular to the web plane.

Then relative slenderness of the stiffener $\bar{\lambda}_d$ corresponded to the flexural buckling of the stiffener is calculated according to [25] as follow:

$$\bar{\lambda}_d = \sqrt{\frac{f_{yb} A_s}{2\sqrt{KEI_s}}} . \tag{19}$$

The reduction factor χ_d for the flexural buckling of the stiffener (or reduction factor for the distortional buckling cross-section resistance) is determined iteratively depending on relative slenderness $\bar{\lambda}_d$ using dependency (5.12) proposed by [25]:

$$\chi_d = \Xi\left(\bar{\lambda}_d\right). \tag{20}$$

The maximization criterion of the minimum design buckling resistance of the structural member subjected to axial compression can be considered as the purpose function (2) of the optimization problem and can be written as follow:

$$N_{bRd,\min} = \min\left\{N_{byRd}, N_{bzRd}, N_{bT,Rd}, N_{bTF,Rd}\right\} \to \max ; \tag{21}$$

where $N_{bRd,\min}$ – minimum design buckling resistance; $N_{by,Rd}$, $N_{bz,Rd}$ are the design buckling resistance for flexural buckling of the cold-formed structural member relative to the main axis of inertia $y-y$ and $z-z$ determined according to [25, 27]; $N_{bT,Rd}$, $N_{bTF,Rd}$ are the design buckling resistance corresponded to the torsional and flexural-torsional buckling of the structural member calculated according to [25, 27].

Then the purpose function can be rewritten as follow:

$$N_{bRd,\min} = \frac{A_{eff} f_{yb}}{\gamma_{M1}} \times \min\left\{\chi_y, \chi_z, \chi_T, \chi_{TF}\right\} \to \max ; \tag{22}$$

where χ_y , χ_z, χ_T , χ_{TF} – buckling factors allowing for the flexural buckling of the CFS structural member relative to the main axis of inertia $y-y$ and $z-z$, as well as for the torsional and flexural-torsional buckling.

The buckling factors χ_y , χ_z, χ_T , χ_{TF} are determined from the relevant buckling curve b according to [25, 27] as:

$$\chi = \frac{1}{0.466+0.17\bar{\lambda}+0.5\bar{\lambda}^2+\sqrt{\left(0.466-0.83\bar{\lambda}+0.5\bar{\lambda}^2\right)\left(0.466+1.17\bar{\lambda}+0.5\bar{\lambda}^2\right)}}; \tag{23}$$

with substitution instead of $\bar{\lambda}$ the relevant non-dimensional slendernesses $\bar{\lambda}_y$, $\bar{\lambda}_z$, $\bar{\lambda}_T$, $\bar{\lambda}_{TF}$ corresponded to the considered buckling modes and calculated taking into account geometrical properties of the effective cross-section of the structural member subjected to the axial compression according to [25, 27] as presented below:

$$\bar{\lambda} = \sqrt{\frac{A_{eff} f_{yb}}{N_{cr}}};\qquad(24)$$

where N_{cr} – elastic critical force for the relevant buckling mode calculated depending on the design lengths and taking into account gross cross-section geometrical properties of the structural member and design lengths according to [27].

The non-dimensional slendernesses $\bar{\lambda}_y$, $\bar{\lambda}_z$, $\bar{\lambda}_T$, $\bar{\lambda}_{TF}$ are determined with substitution in (24) instead of N_{cr} the corresponded elastic critical force $N_{cr,y}$, $N_{cr,z}$, $N_{cr,T}$ or $N_{cr,TF}$, here $N_{cr,y}$ and $N_{cr,z}$ are the elastic critical forces for the flexural buckling mode relative to the main axes of inertia $y-y$ and $z-z$ respectively; $N_{cr,T}$, $N_{cr,TF}$ are the elastic critical forces for the torsional and torsional-flexural buckling mode respectively.

System of constraints (3) for the formulated optimization problem consists of a constraint on the profile perimeter or on a strip width which can be written as presented below:

$$\frac{h+2b+2c}{P_{\max}} - 1 \le 0;\qquad(25)$$

where $P_{\max}$ – maximum value of the cross-section perimeter for CFS lipped channel.

The constraints reflected design code requirements [25] for the ultimate slenderness of the cross-section elements of the CFS channel with flanges stiffened by single edge folds are also included in the system of constraints (3) and presented below:

$$\frac{h}{500t} - 1 \le 0;\qquad(26)$$

$$\frac{b}{60t} - 1 \le 0;\qquad(27)$$

$$\frac{c}{50t} - 1 \le 0;\qquad(28)$$

$$0.2 - \frac{c}{b} \le 0;\qquad(29)$$

$$\frac{c}{b} - 0.6 \le 0.\qquad(30)$$

Additionally, a constraint on the minimum gap between single edge folds ends allowing for providing an access to the internal surface of the CFS lipped channel (for example, in order to organize a bolted connection on the profile flanges [28, 29]) is included to the system of constraints (3) as well and written as below:

$$\frac{h-2c}{d_{\min}} - 1 \le 0;\qquad(31)$$

where $d_{\min}$ is the minimum gap between single edge folds ends.

Thus, the optimization problem of cross-sectional sizes for CFS lipped channel structural member subjected to axial compression is formulated as follow: to find optimum cross-sectional sizes of CFS lipped channel (web height h, flange width b and single edge fold length c) providing the maximum value of the determined objective function (21) in the feasible region defined by the system of constraints (25) –(31), when the profile perimeter (strip width), profile thickness, design lengths of the structural member as well as material properties are constant and specified in advance.

Optimization results. The following CFS lipped channels from the whole profile assortment range manufactured by the company «Blachy Pruszyński» [30] have been chosen to further optimization: C100×48×18 and C100×60×19. Other lipped channels have the same flange widths (48 mm and 60 mm) and have deeper web height simultaneously indicating their more rational usage as beam-column or beam structural members. The strip widths for the chosen CFS lipped channels are 23.2 cm and 25.8 cm respectively.

The following design flexural buckling length has been considered as initial data for optimization: 1.5 m, 2.0 m and 2.5 m. The use of single profiles for long-length CFS structural member with the design length greater than 2.5 m as well as short-length CFS structural members with the design length smaller than 1.5 m is not rational.

Taking into account small dimensionality the formulated parametric optimization problem has been solved by exhaustive search method using the software written in Python. As optimization results the CFS lipped channels with optimum cross-sectional dimensions have been obtained depending on the profile thickness and design lengths of the structural member. The obtained CFS lipped channel structural members with optimum cross-sectional sizes have higher design buckling resistance under the axial compression comparing with the CFS lipped channels with the same stripe width proposed by the manufacturer [30]. The increasing of the load-carrying capacity up to and including 12.14% (for the strip width 23.2 cm) and 19.01% (for the strip width 25.8 cm) has been achieved (Tab. 1 and Tab. 2).

Table 1

CFS lipped channel structural members with optimum cross-sectional sizes (strip width is $P_{max} = 23.2$ cm)

Buckling length, m	t, [cm]	Optimum cross-sectional sizes of the lipped channel, [cm]	$N_{bRd,\min}$, [kN]	Buckling mode	Web local buckling	Flange local buckling	Distor-sional buckling	Load-carrying capacity increasing, %
1.5	0.100	8.8×4.5×2.7	31.696	tors.-flex.	Yes	Yes	Yes	12.14
	0.125	8.8×4.5×2.7	41.871	tors.-flex.	Yes	Yes	Yes	10.81
	0.150	8.8×4.5×2.7	51.664	tors.-flex.	Yes	No	Yes	9.65
	0.175	9.8×4.2×2.5	63.914	tors.-flex.	Yes	No	No	12.66
	0.200	9.8×4.2×2.5	73.285	tors.-flex.	Yes	No	No	10.92
	0.225	9.8×4.2×2.5	82.890	tors.-flex.	Yes	No	No	9.40
	0.250	9.6×4.3×2.5	92.140	tors.-flex.	Yes	No	No	5.55
	0.275	9.6×4.3×2.5	102.099	flex. minor axis	Yes	No	No	5.88

Buckling length, m	t, [cm]	Optimum cross-sectional sizes of the lipped channel, [cm]	$N_{bRd,\min}$, [kN]	Buckling mode	Web local buckling	Flange local buckling	Distor-sional buckling	Load-carrying capacity increasing, %
	0.300	9.2×4.4×2.6	111.737	tors.-flex.	No	No	No	3.37
2.0	0.100	9.8×4.2×2.5	21.941	tors.-flex.	Yes	Yes	Yes	11.04
	0.125	9.8×4.2×2.5	28.539	tors.-flex.	Yes	Yes	Yes	10.32
	0.150	9.8×4.2×2.5	35.164	tors.-flex.	Yes	No	Yes	9.50
	0.175	9.8×4.2×2.5	43.189	tors.-flex.	Yes	No	No	11.35
	0.200	9.6×4.3×2.5	49.898	tors.-flex.	Yes	No	No	9.38
	0.225	9.2×4.4×2.6	56.837	tors.-flex.	Yes	No	No	7.30
	0.250	9.2×4.4×2.6	64.433	flex. minor axis	Yes	No	No	5.03
	0.275	9.0×4.5×2.6	71.707	tors.-flex.	No	No	No	3.04
	0.300	9.0×4.6×2.5	78.879	flex. minor axis	No	No	No	1.26
2.5	0.100	9.8×4.2×2.5	15.699	tors.-flex.	Yes	Yes	Yes	10.72
	0.125	9.8×4.2×2.5	20.445	tors.-flex.	Yes	Yes	Yes	10.11
	0.150	9.8×4.2×2.5	25.446	tors.-flex.	Yes	No	Yes	9.39
	0.175	9.6×4.3×2.5	31.099	tors.-flex.	Yes	No	No	9.53
	0.200	9.2×4.4×2.6	36.385	tors.-flex.	Yes	No	No	7.22
	0.225	9.2×4.5×2.5	41.836	flex. minor axis	Yes	No	No	4.39
	0.250	9.4×4.7×2.2	47.263	tors.-flex.	Yes	No	No	1.18
	0.275	9.8×5.0×1.7	53.058	tors.-flex.	Yes	No	No	5.36
	0.300	9.2×5.0×2.0	59.257	flex. minor axis	No	No	No	9.68

Table 2

CFS lipped channel structural members with optimum cross-sectional sizes (strip width is $P_{max} = 25.8$ cm)

Buckling length, m	t, [cm]	Optimum cross-sectional sizes of the lipped channel, [cm]	$N_{bRd,\min}$, [kN]	Buckling mode	Web local buckling	Flange local buckling	Distor-sional buckling	Load-carrying capacity increasing, %
1.5	0.100	9.8×5.0×3.0	37.761	tors.-flex.	Yes	Yes	Yes	18.80
	0.125	9.8×5.0×3.0	50.890	tors.-flex.	Yes	Yes	Yes	17.31
	0.150	9.8×5.0×3.0	64.073	tors.-flex.	Yes	Yes	Yes	16.32
	0.175	10.8×4.7×2.8	80.942	tors.-flex.	Yes	No	No	19.66
	0.200	10.8×4.7×2.8	92.314	tors.-flex.	Yes	No	No	17.72
	0.225	10.8×4.7×2.8	103.775	tors.-flex.	Yes	No	No	16.20
	0.250	10.8×4.7×2.8	115.367	tors.-flex.	Yes	No	No	14.88
	0.275	10.8×4.7×2.8	127.125	tors.-flex.	Yes	No	No	13.71
	0.300	10.8×4.7×2.8	139.079	tors.-flex.	Yes	No	No	12.83
2.0	0.100	9.8×5.0×3.0	27.611	tors.-flex.	Yes	Yes	Yes	18.71
	0.125	10.8×4.7×2.8	36.181	tors.-flex.	Yes	Yes	Yes	17.97
	0.150	10.8×4.7×2.8	44.738	tors.-flex.	Yes	No	Yes	17.22
	0.175	11.4×4.5×2.7	55.376	flex. minor axis	Yes	No	No	19.60
	0.200	10.8×4.7×2.8	63.852	tors.-flex.	Yes	No	No	18.44
	0.225	10.8×4.7×2.8	72.675	tors.-flex.	Yes	No	No	17.50
	0.250	10.6×4.8×2.8	81.223	tors.-flex.	Yes	No	No	15.96
	0.275	10.6×4.8×2.8	90.040	flex. minor axis	Yes	No	No	14.45
	0.300	10.2×4.9×2.9	99.673	tors.-flex.	Yes	No	No	13.51

Buckling length, m	t, [cm]	Optimum cross-sectional sizes of the lipped channel, [cm]	$N_{bRd,\min}$, [kN]	Buckling mode	Web local buckling	Flange local buckling	Distor-sional buckling	Load-carrying capacity increasing, %
2.5	0.100	10.8×4.7×2.8	20.192	tors.-flex.	Yes	Yes	Yes	19.01
	0.125	10.8×4.7×2.8	26.228	tors.-flex.	Yes	Yes	Yes	18.53
	0.150	10.8×4.7×2.8	32.448	tors.-flex.	Yes	No	Yes	17.96
	0.175	10.8×4.7×2.8	39.897	tors.-flex.	Yes	No	No	19.40
	0.200	10.8×4.7×2.8	46.532	flex. minor axis	Yes	No	No	18.38
	0.225	10.6×4.8×2.8	53.195	flex. minor axis	Yes	No	No	16.85
	0.250	10.2×4.9×2.9	60.157	tors.-flex.	Yes	No	No	15.22
	0.275	10.0×5.0×2.9	67.017	tors.-flex.	Yes	No	No	12.97
	0.300	10.0×5.1×2.8	74.037	flex. minor axis	Yes	No	No	10.62

Table 1 and Table 2 present the optimum cross-sectional sizes for CFS lipped channel structural members depending on the profile thickness as well as on the different design lengths corresponded to the flexural buckling modes. As you can see from the Table 1 and Table 2 the torsional-flexural buckling resistance of CFS lipped channel structural members has been determinative for the majority of the optimum decisions. Web local buckling phenomenon has been occurred in all obtained CFS lipped channel cross-sections with optimum sizes. Flange local buckling phenomenon as well as distortional buckling phenomenon has been occurred in obtained optimum CFS lipped channel cross-sections with small profile thicknesses only (up to and including 0.15 mm – for flange local buckling phenomenon and 0.175 mm – distortional buckling phenomenon).

In order to obtain optimum solutions for cross-sectional dimensions of the CFS lipped channel structural members which are independent from the design flexural lengths and profile thickness, searching for a compromise solution has been performed by exhaustive search metod with the following criterion:

$$\sum_{l_{ef}}\left(\sum_{t}1-\frac{\tilde{N}_{bRd,\min}(t,l_{ef})}{N_{bRd,\min}}\right)\rightarrow \min\,; \qquad (32)$$

where $N_{bRd,\min}$ – minimum design buckling resistance of the lipped channel structural members with optimum cross-sectional sizes according to the Tables 1 and 2; $\tilde{N}_{bRd,\min}\left(t,l_{ef}\right)$ – minimum design buckling resistance of the lipped channel structural members with “compromise” cross-sectional dimensions calculated depending on the profile thickness and flexural design length.

As optimization results there are two “compromise” solutions have been obtained: C88×45×27 (for the strip width 23.2 cm corresponded to the initial profile C100×48×18) and C98×50×30 (for the strip width 25.8 cm corresponded to the initial profile C100×60×19). The obtained CFS lipped channel structural members with „compromise” cross-sectional sizes have higher design buckling resistance under the axial compression comparing with the CFS lipped channels with the same stripe width proposed by the manufacturer [30]. The increasing of the load-carrying capacity has been achieved in range 9.0…18.9% (for the strip width 25.8 cm) and up to and including 12.14% (for the strip width 23.2 cm) (Tab. 3 and Tab. 4).

Table 3

CFS lipped channel structural members with optimum cross-sectional sizes (strip width is P_{max} = 23.2 cm corresponded to the initial profile C100×48×18)

Buckling length, m	t, [cm]	Optimum cross-sectional sizes of the lipped channel, [cm]	$N_{bRd,\min}$, [kN]	Compromise solution, [cm]	$\tilde{N}_{bRd,\min}$, [kN]	Load-carrying capacity decreasing relating to the optimum solution, %	Load-carrying capacity increasing relating to the initial solution, %
	0.100	8.8×4.5×2.7	31.696		31.696	–	12.14
	0.125	8.8×4.5×2.7	41.871		41.871	–	10.81
	0.150	8.8×4.5×2.7	51.664		51.664	–	9.65
	0.175	9.8×4.2×2.5	63.914		63.053	1.35	11.47
1.5	0.200	9.8×4.2×2.5	73.285	8.8×4.5×2.7	72.135	1.57	9.50
	0.225	9.8×4.2×2.5	82.890		81.384	1.82	7.72
	0.250	9.6×4.3×2.5	92.140		90.836	1.41	4.20
	0.275	9.6×4.3×2.5	102.099		100.524	1.54	4.41
	0.300	9.2×4.4×2.6	111.737		110.471	1.13	2.26
	0.100	9.8×4.2×2.5	21.941		21.856	0.39	10.70
	0.125	9.8×4.2×2.5	28.539		28.326	0.74	9.65
	0.150	9.8×4.2×2.5	35.164		34.834	0.94	8.65
	0.175	9.8×4.2×2.5	43.189		42.180	2.34	9.23
2.0	0.200	9.6×4.3×2.5	49.898	8.8×4.5×2.7	48.941	1.92	7.61
	0.225	9.2×4.4×2.6	56.837		56.060	1.37	6.02
	0.250	9.2×4.4×2.6	64.433		63.575	1.33	3.75
	0.275	9.0×4.5×2.6	71.707		71.513	0.27	2.78
	0.300	9.0×4.6×2.5	78.879		77.413	1.86	–0.62
	0.100	9.8×4.2×2.5	15.699		15.522	1.13	9.71
	0.125	9.8×4.2×2.5	20.445		20.111	1.63	8.62
	0.150	9.8×4.2×2.5	25.446		24.917	2.08	7.47
	0.175	9.6×4.3×2.5	31.099		30.361	2.37	7.34
2.5	0.200	9.2×4.4×2.6	36.385	8.8×4.5×2.7	35.771	1.69	5.62
	0.225	9.2×4.5×2.5	41.836		41.616	0.52	3.88
	0.250	9.4×4.7×2.2	47.263		46.259	2.12	–0.96
	0.275	9.8×5.0×1.7	53.058		49.805	6.13	–0.82
	0.300	9.2×5.0×2.0	59.257		53.163	10.28	–0.67

Table 4

CFS lipped channel structural members with optimum cross-sectional sizes (strip width is P_{max} = 25.8 cm corresponded to the initial profile C100×60×19)

Buckling length, m	t, [cm]	Optimum cross-sectional sizes of the lipped channel, [cm]	$N_{bRd,\min}$, [kN]	Compromise solution	$\tilde{N}_{bRd,\min}$, [kN]	Load-carrying capacity decreasing relating to the optimum solution, %	Load-carrying capacity increasing relating to the initial solution, %
1.5	0.100	9.8×5.0×3.0	37.761	9.8×5.0×3.0	37.761	–	18.80
	0.125	9.8×5.0×3.0	50.890		50.890	–	17.31
	0.150	9.8×5.0×3.0	64.073		64.073	–	16.32
	0.175	10.8×4.7×2.8	80.942		80.182	0.94	18.90
	0.200	10.8×4.7×2.8	92.314		91.342	1.05	16.85
	0.225	10.8×4.7×2.8	103.775		102.548	1.18	15.20
	0.250	10.8×4.7×2.8	115.367		113.834	1.33	13.74
	0.275	10.8×4.7×2.8	127.125		125.231	1.49	12.40
	0.300	10.8×4.7×2.8	139.079		136.768	1.66	11.36
2.0	0.100	9.8×5.0×3.0	27.611	9.8×5.0×3.0	27.611	–	18.71
	0.125	10.8×4.7×2.8	36.181		36.085	0.26	17.76
	0.150	10.8×4.7×2.8	44.738		44.646	0.20	17.05
	0.175	11.4×4.5×2.7	55.376		54.463	1.65	18.25
	0.200	10.8×4.7×2.8	63.852		62.643	1.89	16.86
	0.225	10.8×4.7×2.8	72.675		71.084	2.19	15.65
	0.250	10.6×4.8×2.8	81.223		79.830	1.72	14.49
	0.275	10.6×4.8×2.8	90.040		88.914	1.25	13.36
	0.300	10.2×4.9×2.9	99.673		98.367	1.31	12.36
2.5	0.100	10.8×4.7×2.8	20.192	9.8×5.0×3.0	20.065	0.63	18.50
	0.125	10.8×4.7×2.8	26.228		25.962	1.01	17.70
	0.150	10.8×4.7×2.8	32.448		32.066	1.18	16.99
	0.175	10.8×4.7×2.8	39.897		38.968	2.33	17.48
	0.200	10.8×4.7×2.8	46.532		45.341	2.56	16.21
	0.225	10.6×4.8×2.8	53.195		52.088	2.08	15.08
	0.250	10.2×4.9×2.9	60.157		59.246	1.51	13.92
	0.275	10.0×5.0×2.9	67.017		66.846	0.26	12.75
	0.300	10.0×5.1×2.8	74.037		72.718	1.78	9.00

Discussion of results. The optimum length of the single edge fold in all optimum CFS lipped channel cross-sections was greater comparing with the single edge fold length of CFS lipped channels proposed by the manufacturer. The average optimum ratio of the single edge fold length to the flange width c/b has been obtained as 0.58. The average optimum ratio of the flange width to the web height b/h has been received equal to 0.46. It should be noted, that the optimum ratio between the second moments of inertia relatively to the minor and major axis of inertia respectively has been received for all optimum solutions in range 0.2…0.29 due to the type of the cross-section and post-buckling behavior of the lipped channel web. The radiuses of inertia with respect to the main axes of inertia have been obtained for all CFS lipped channel with optimum cross-sectional domensions as follow: $i_y = (0.38...0.39)h$, $i_z = (0.37...0.41)b$.

Conclusion. Searching for optimum cross-sectional sizes of CFS lipped channel structural members taking into account post-buckling behavior and structural requirements has been realized. The obtained CFS lipped channel structural members with optimum cross-sectional sizes have higher design buckling resistance under the axial compression comparing with the CFS lipped channels with the same stripe width proposed by the manufacturer.

The torsional-flexural buckling resistance of CFS lipped channel structural members has been determinative for the majority of the optimum decisions. Web local buckling phenomenon has been occurred in all obtained CFS lipped channel cross-sections with optimum sizes. The optimum length of the single edge fold in all optimum CFS lipped channel cross-sections was greater comparing with the single edge fold length of CFS lipped channels proposed by the manufacturer.

Presented results of the performed optimization calculation allow developing guides for designers relating to the optimum material distribution in the cross-sections of CFS structural members as well as are base to develop effective national ranges of assortments of cold-formed profiles.

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ПОШУК КОМПРОМІСНОГО РОЗВ’ЯЗКУ В ЗАДАЧАХ ОПТИМІЗАЦІЇ РОЗМІРІВ ПОПЕРЕЧНИХ ПЕРЕРІЗІВ ЕЛЕМЕНТІВ КОНСТРУКЦІЙ ІЗ ХОЛОДНОГНУТИХ ПРОФІЛІВ

У статті розглядається задача параметричної оптимізації розмірів поперечних перерізів для стержневих елементів конструкцій із С-подібних холодногнутих профілів, які підлягають дії поздовжнього стиску. Задача оптимізації сформульована як задача пошуку оптимальних розмірів перерізів стержневих елементів конструкцій з врахуванням їх закритичної роботи (втрати місцевої стійкості стінки та полиць та/або втрати стійкості форми перерізу), а також конструктивних вимог за умов, що периметр профілю (ширина штрипси), товщина профілю, розрахункові довжини стержневого елемента конструкції та механічні характеристики сталі приймались постійними та наперед заданими. Як критерій оптимальності розглядалася максимізація несучої здатності елемента конструкції на втрату загальної стійкості. Сформульована задача оптимізації розв’язана за допомогою методу вичерпного пошуку з використанням програмного забезпечення, розробленого мовою Python. Як результат були отримані холодногнуті С-подібні профілі з оптимальними розмірами поперечного перерізу залежно від товщини профілю та розрахункових довжин стержневого елемента конструкції. З метою отримання оптимальних розмірів поперечних перерізів С-подібних холодногнутих профілів, що не залежатимуть від розрахункових довжин і товщини профіля, здійснено пошук компромісного розв’язку. Отримані холодногнуті С-подібні профілі з оптимальними розмірами поперечних перерізів характеризуються вищою несучою здатністю на втрату загальної стійкості при осьовому стисканні при тій самій витраті сталі (ширини штрипси) порівняно з С-подібними холодногнутими профілями, що пропонуються виробником профілів. Для усіх оптимальних розв’язків характерним є явище втрати місцевої стійкості стінки профіля.

Ключові слова: холодногнута сталь, несуча здатність щодо втрати стійкості, згинально-крутильне випучування, параметрична оптимізація, метод вичерпного пошуку, компромісний розв’язок.

Yurchenko V.V., Peleshko I.D.

SEARCHING FOR A COMPROMISE SOLUTION IN CROSS-SECTION SIZE OPTIMIZATION PROBLEMS OF COLD-FORMED STEEL STRUCTURAL MEMBERS

A parametric optimization problem of cross-sectional sizes for cold-formed steel lipped channel structural members subjected to axial compression has been considered by the paper. An optimization problem is formulated as to define optimum cross-sectional sizes of cold-formed structural member taking into account post-buckling behavior (web and flange local and distortional buckling) of the member as well as structural requirements when the profile perimeter (strip width), profile thickness, design lengths of the structural member as well as material properties are constant and specified in advance. Maximization of the load-carrying capacity of the cold-formed structural member has been assumed as purpose function. The formulated parametric optimization problem has been solved by exhaustive search method using the software written in Python. As optimization results the cold-formed steel lipped channels with optimum cross-sectional dimensions have been obtained depending on the profile thickness and design lengths of the structural member. In order to obtain optimum solutions for cross-sectional dimensions of the CFS lipped channel structural members which are independent from the design flexural lengths and profile thickness, searching for a compromise solution has been performed by exhaustive search method. The obtained cold-formed steel lipped channel structural members with optimum cross-sectional sizes have higher design buckling resistance under the axial compression at the same material consumption (stripe width) comparing with the cold-formed steel lipped channels proposed by the manufacturer. Web local buckling phenomenon has been occurred in all obtained CFS lipped channel cross-sections with optimum sizes.

Keywords: cold-formed steel, buckling resistance, torsional-flexural buckling, parametric optimization, exhaustive search method, compromise solution.

Юрченко В.В., Пелешко И.Д.

ПОИСК КОМПРОМИССНОГО РЕШЕНИЯ В ЗАДАЧАХ ОПТИМИЗАЦИИ РАЗМЕРОВ ПОПЕРЕЧНЫХ СЕЧЕНИЙ ЭЛЕМЕНТОВ КОНСТРУКЦИЙ ИЗ ХОЛОДНОГНУТЫХ ПРОФИЛЕЙ

В статье рассматривается задача параметрической оптимизации размеров поперечных сечений для стержневых элементов конструкций из С-образных холодногнутых профилей, подлежащих действию продольного сжатия. Задача оптимизациисформулирована как задача поиска оптимальных размеров сечений стержневых элементов конструкций сучетом их закритической работы (потери местной устойчивости стенки и полоки/илипотери устойчивости формы сечения), а также конструктивных требований при условии, что периметр профиля (ширина штрипсы), толщина профиля, расчетные длины стержневого элемента конструкциии механические характеристики стали принимались постояннымии наперед заданными. В качестве критерия оптимальностирассматривалась максимизация несущей способности элемента конструкции на потерю общей устойчивости. Сформулированная задача оптимизациирешена при помощи методаисчерпывающего поиска с использованием программного обеспечения, разработанного на языке Python. В качестве результатов были получены холодногнутые С-образные профилис оптимальными размерами поперечных сечений в зависимости от толщины профиля ирасчетных длин стержневого элемента конструкции. С целью получения оптимальных размеров поперечных сечений С-образных холодногнутых профилей, не зависящих от расчетных длин и толщины профиля, реализован поиск компромиссного решения. Полученные холодногнутые С-образные профилис оптимальными размерами поперечных сечений характеризуются большей несущей способностью на потерю общей устойчивости при продольном сжатии при том же расходе стали (ширине штрипсы) по сравнению с С-образными холодногнутыми профилями, предлагаемыми изготовителем профилей. Для всех оптимальных решений характерноявление потери местной устойчивости стенки профиля.

Ключевые слова: холодногнутая сталь, несущая способностьотносительно потери устойчивости, изгибно-крутильное выпучивание, параметрическая оптимизация, метод исчерпывающего поиска, компромиссное решение

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Юрченко В.В., Пелешко І.Д. **Пошук компромісного розв'язку в задачах оптимізації розмірів поперечних перерізів елементів конструкцій з холодногнутих профілів** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2022. – Вип. 109. – С. 72-92.

У статті розглядається задача пошуку оптимальних розмірів перерізів стержневих елементів конструкцій з врахуванням їх закритичної роботи (втрати місцевої стійкості стінки та полиць та/або втрати стійкості форми перерізу), а також конструктивних вимог за умов, що периметр профіля (ширина штрипси), товщина профіля, розрахункові довжини стержневого елемента конструкції та механічні характеристики сталі приймалися постійними та наперед заданими. Як критерій оптимальності розглядалася максимізація несучої здатності елемента конструкції на втрату загальної стійкості. Як результат були отримані холодногнуті С-подібні профілі з оптимальними розмірами поперечного перерізу залежно від товщини профіля та розрахункових довжин стержневого елемента конструкції. З метою отримання оптимальних розмірів поперечних перерізів С-подібних холодногнутих профілів, що не залежатимуть від розрахункових довжин і товщини профіля, здійснено пошук компромісного розв'язку. Отримані холодногнуті С-подібні профілі з оптимальними розмірами поперечних перерізів характеризуються вищою несучою здатністю на втрату загальної стійкості при осьовому стисканні при тій самій витраті сталі порівняно з С-подібними холодногнутими профілями, що пропонуються виробником профілів.

Іл. 2. Табл. 4. Бібліог. 30назв.
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Yurchenko V.V., Peleshko I.D. **Searching for a compromise solution in cross-section size optimization problems of cold-formed steel structural members** // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2022. – Issue 109. – P. 72-92.

The paper considers asearching problem for optimum cross-sectional sizes of cold-formed structural member taking into account post-buckling behavior (web and flange local and distortional buckling) of the member as well as structural requirements when the profile perimeter (strip width), profile thickness, design lengths of the structural member as well as material properties are constant and specified in advance. Maximization of the load-carrying capacity of the cold-formed structural member has been assumed as purpose function. As optimization results the cold-formed steel lipped channels with optimum cross-sectional dimensions have been obtained depending on the profile thickness and design lengths of the structural member. In order to obtain optimum solutions for cross-sectional dimensions of the cold-formedlipped channel structural members which are independent from the design flexural lengths and profile thickness, searching for a compromise solution has been performed by exhaustive search method. The obtained cold-formed steel lipped channel structural members with optimum cross-sectional sizes have higher design buckling resistance under the axial compression at the same material consumption (stripe width) comparing with the cold-formed steel lipped channels proposed by the manufacturer.

Figs. 2. Tabs. 4. Refs. 30.

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Юрченко В. В.,Пелешко И. Д. **Поиск компромиссного решения в задачах оптимизации размеров поперечных сечений элементов конструкций из холодногнутых профилей//** Сопротивление материалов и теория сооружений: науч.- тех. сборн. – К.: КНУСА, 2022. – Вып. 109. – С. 72-92.

В статье рассматривается задача поиска оптимальных размеров сечений стержневых элементов конструкций сучетом их закритической работы (потери местной устойчивости стенки и полоки/илипотери устойчивости формы сечения), а также конструктивных требований при условии, что периметр профиля (ширина штрипсы), толщина профиля, расчетные длины стержневого элемента конструкциии механические характеристики стали принимались постояннымии наперед заданными. В качестве критерия оптимальностирассматривалась максимизация несущей способности элемента конструкции на потерю общей устойчивости. В качестве результатов были получены холодногнутые С-образные профилис оптимальными размерами поперечных сечений в зависимости от толщины профиля ирасчетных длин стержневого элемента конструкции. С целью получения оптимальных размеров поперечных сечений С-образных холодногнутых профилей, не зависящих от расчетных длин и толщины профиля, реализован поиск компромиссного решения. Полученные холодногнутые С-образные профилис оптимальными размерами поперечных сечений характеризуются большей несущей способностью на потерю общей устойчивости при продольном сжатии при том же расходе стали (ширине штрипсы) по сравнению с С-образными холодногнутыми профилями, предлагаемыми изготовителем профилей.

Ил. 2. Табл. 4. Библиог. 30 назв.

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