STABILITY ANALYSIS OF THIN-WALLED COLD-FORMED SIGMA PROFILES USING THE FINITE STRIP METHOD

Mikuláš Venzara*,[1]

*205804@vutbr.cz
[1]Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00

Abstract

The stability analysis of cold-formed thin-walled profiles often benefits from the effective application of the finite strip method. Among the software tools based on this method is the CUFSM program. This article provides an overview of the principles of the finite strip method and the use of the CUFSM program for conducting parametric studies. Specially, the focus is on investigating the influence of the geometry of web intermediate stiffeners in Sigma-sections on the buckling capacity of flanges with edge stiffeners during distortional buckling. The parametric studies are automated through appropriate modifications of the CUFSM program source code.

Keywords

Thin-walled, sigma profile, buckling, finite strip method, CUFSM software

1 INTRODUCTION

The utilization of constructions made from cold-formed thin-walled elements is increasingly gaining attention from engineers and investors. An undeniable advantage lies in the reduction of construction costs, attributed to material and energy savings, which, particularly in a time marked by the rise in energy and material prices, can significantly impact the overall construction cost. A well-executed design using cold-formed thin-walled profiles provides an economical and reliable solution for load-bearing steel structures. This not only results in cost savings but also contributes to a reduction in negative environmental impacts by using a smaller quantity of steel compared to designs using hot-rolled profiles. Applications of cold-formed thin-walled steel profiles can generally be divided into four main categories: secondary structures of hall buildings (mainly purlins and wall girts), skeletons of multi-story buildings, lightweight frame structures of hall buildings, and structures for storage purposes. The increasing utilization necessitates a closer examination of the behaviour of these profiles to ensure a safer and more cost-effective design [1], [2].

During local buckling (see Fig. 1a), there is a bulging of the compressed slender walls where only a rotation of the centreline points occurs at the corners of the cross-section, and there are no translations. In the presence of edge or internal stiffeners in the profile, distortional buckling may occur (see Fig. 1b). Due to the insufficient stiffness of support by these stiffeners, the entire compressed stiffened part of the cross-section may buckle (for example, compressed flanges with edge stiffener or compressed parts of flanges or webs with internal stiffener). In the case of distortional buckling, some corners of the cross-section not only experience rotation of the centreline points but also simultaneous translation. In the event of global instability (see Fig. 1c), the entire cross-section buckles as a whole (in the case of lateral-torsional buckling, the cross-section both buckles and twists as a whole without deformation of cross-section shape). The design of constructions using cold-formed thin-walled profiles introduces specific characteristics due to the very small thickness of the profile walls. Unlike hot-rolled profiles, thin-walled profiles, need consideration of both global stability issues (buckling of compressed columns and lateral-torsional buckling of bent beams) and local stability problems such as local buckling or distortional buckling.

DOI 10.13164/juniorstav.2024.24069

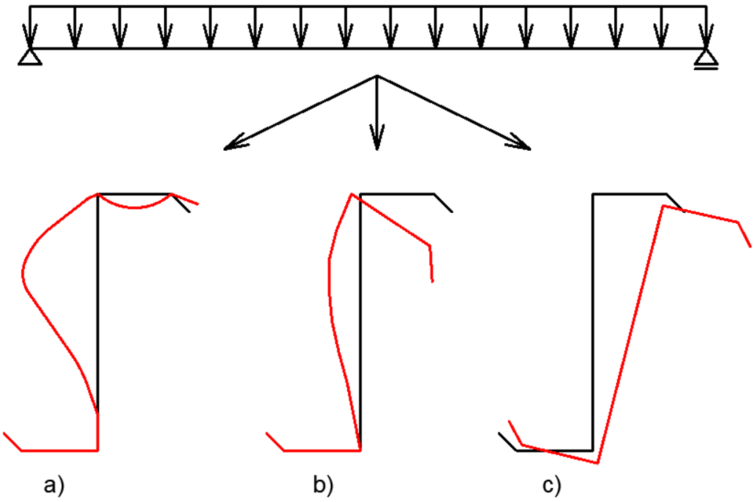

Fig. 1 Buckling modes of thin-walled member loaded in bending.

An effective tool for analyzing stability issues of cold-formed thin-walled sections is the Finite Strip Method (FSM). The principle of this method involves discretizing (dividing) the section along its centreline length into individual finite strips of constant width throughout the length of the profile. In the longitudinal direction of the section, the buckling shape of the strip is assumed to correspond to a single sinusoidal half-wave with a length equal to the strip's length. In the transverse direction (along the centreline of the cross-section), the buckled shape of the strip is described using suitable shape functions (e.g., third-order polynomial functions). As shown in Fig. 2.

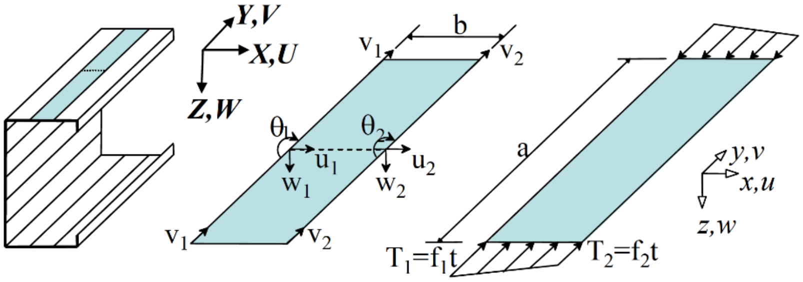

Fig. 2 Discretization of the beam using FSM (Finite Strip Method) [3].

The vector of displacement u = $[\mathrm{u},\ \mathrm{v},\ \mathrm{w}]^T$ is approximated by displacements and rotations at nodes d and selected shape functions N. Shown in more detail in (1), (2) and (3).

$$u = \left[\left(1-\frac{x}{b}\right)\ \left(\frac{x}{b}\right)\right]\begin{Bmatrix}u_1\\u_2\end{Bmatrix}\sin\left(\frac{m\pi y}{a}\right) \tag{1}$$

$$v = \left[\left(1-\frac{x}{b}\right)\ \left(\frac{x}{b}\right)\right]\begin{Bmatrix}v_1\\v_2\end{Bmatrix}\cos\left(\frac{m\pi y}{a}\right) \tag{2}$$

$$w = \left[\left(1-\frac{3x^2}{b^2}+\frac{2x^3}{b^3}\right)\ \mathrm{x}\left(1-\frac{2x}{b}+\frac{x^2}{b^2}\right)\ \left(\frac{3x^2}{b^2}+\frac{2x^3}{b^3}\right)\ \mathrm{x}\left(\frac{x^2}{b^2}+\frac{x}{b}\right)\right]\begin{Bmatrix}w_1\\\theta_1\\w_2\\\theta_2\end{Bmatrix}\sin\left(\frac{m\pi y}{a}\right) \tag{3}$$

where u, v, and w are vectors representing general displacements, a is the length of the strip, and b is the width of the strip.

The CUFSM program [4], based on the Finite Strip Method, has its source code written in the Matlab programming language. This article focuses on the issue of distortional buckling in cold-formed Sigma-shaped thin-walled profiles, characterized by internal stiffeners on the web of the profile.

The aim of this article is to investigate the influence of these internal web stiffeners with various geometries on the overall load-bearing capacity of the profile. Past studies have indicated that internal web stiffeners can have a negative impact on the distortional buckling of the compressed flange with an edge stiffener. The standard

ČSN EN 1993-1-3 [5] assesses Sigma profiles similarly to C profiles; therefore, if this phenomenon is confirmed, it could lead to an incorrect assessment of the profile.

2 METHODOLOGY

A parametric study was conducted using the CUFSM program. To perform automated parametric studies, the source code of the program was modified. The focus of the parametric study is a Sigma profile (geometrical dimensions outlined in Fig. 3).The profile has the following parameters, height h = 150 mm, flange width b = 60 mm, wall thickness t = 2 mm, and variable geometry of internal web stiffeners and edge stiffeners c = 0/6/12/18/24/30/36/42 mm, d = 0/20/25/30 mm, e = 5/10/15/20/25 mm and f = 5/10/15/20/25 mm. The cross-section incorporates rounded corners, with the radius of curvature assumed to be equal to the wall thickness of the profile.

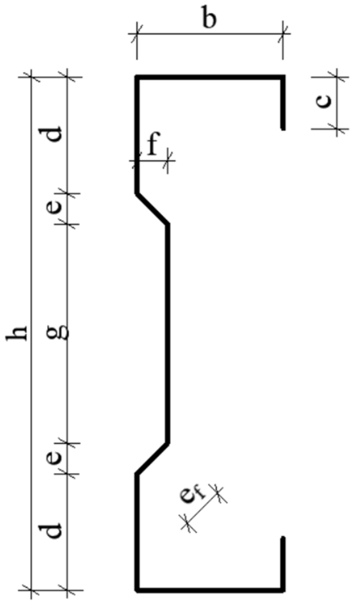

Fig. 3 Geometric description of the Sigma profile in the conducted study.

The study aims to investigate the influence of various geometries of internal web stiffeners and various geometries of edge stiffeners of the compressed flange on their mutual interaction. The primary goal is to determine the load-bearing capacity during distortional buckling.

3 RESULTS

The provided figure illustrates the results. On the horizontal axis of the graph, a sinusoidal half-wave is depicted, while the vertical axis shows the value of the critical stress factor, which is further utilized to determine the critical stress used for assessing the load-bearing capacity of the section undergoing stability loss. For various analysed lengths of the member L, which are predefined in the software, critical stresses are computed for each specific length. These critical stresses are then plotted on the graph as a function of the variable member length.

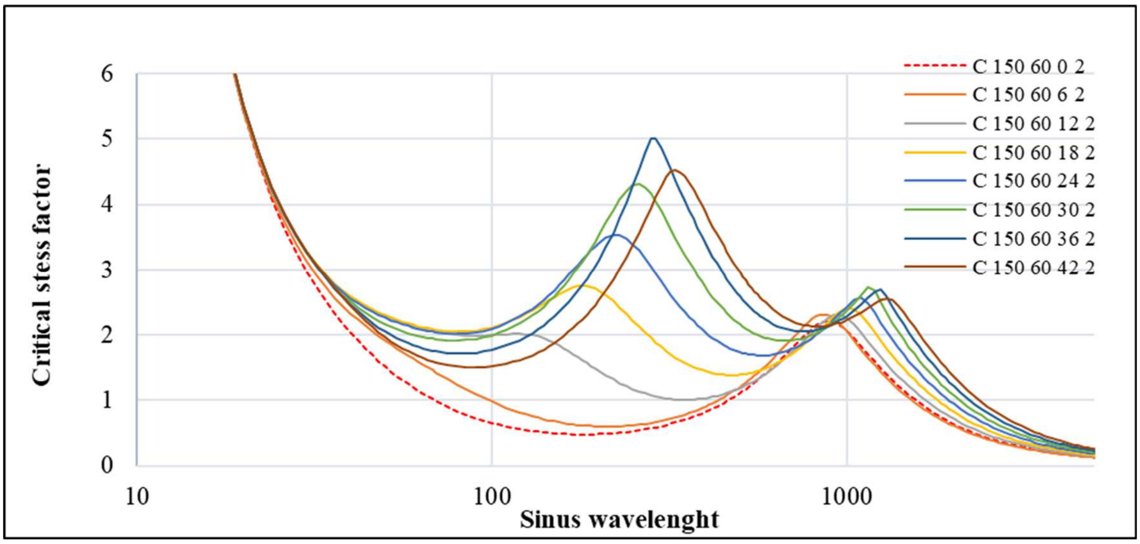

Fig. 4 Results for the case of C profile.

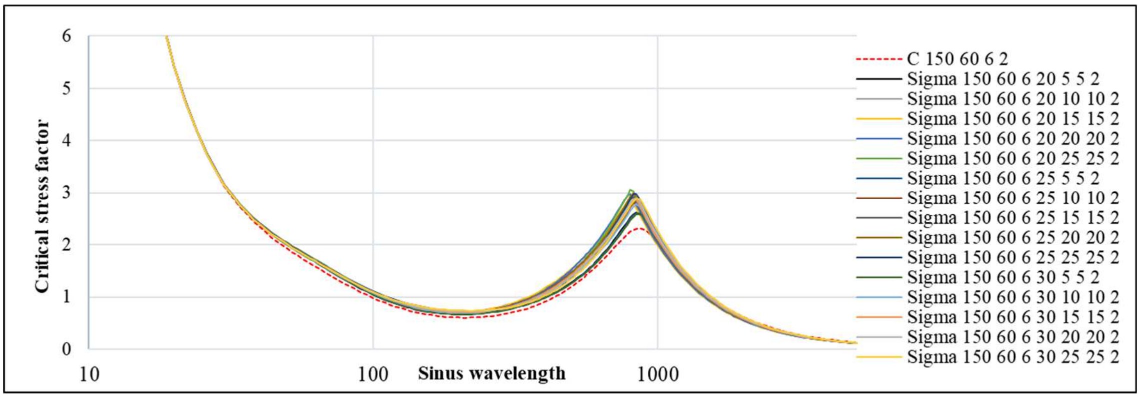

Fig. 5 Results for the case of Sigma profiles, c = 6 mm.

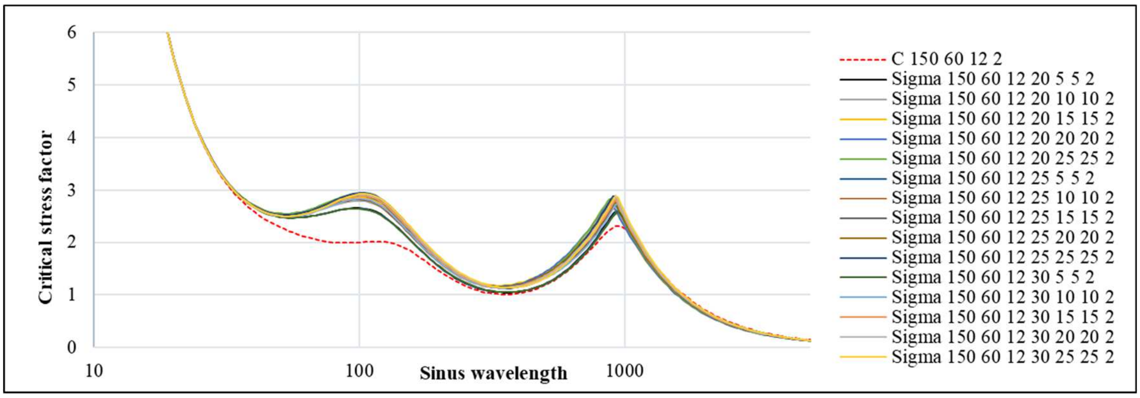

Fig. 6 Results for the case of Sigma profiles, c = 12 mm.

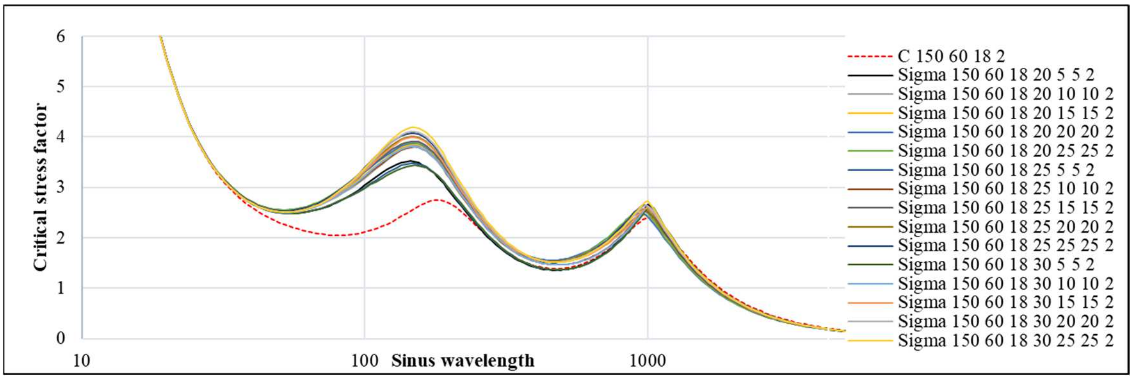

Fig. 7 Results for the case of Sigma profiles, c = 18 mm.

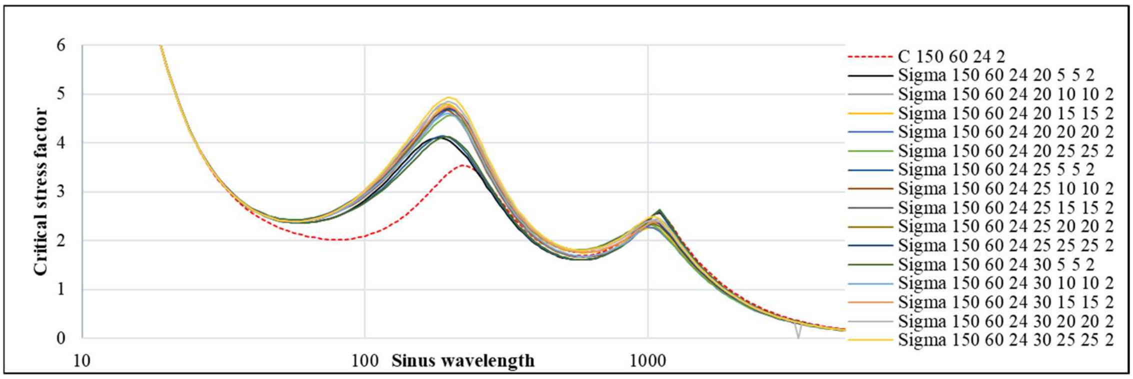

Fig. 8 Results for the case of Sigma profiles, c = 24 mm.

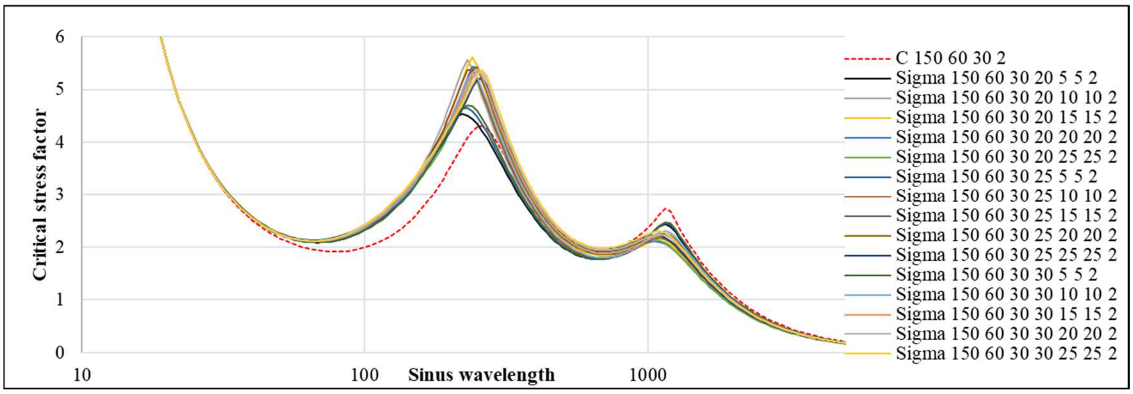

Fig. 9 Results for the case of Sigma profiles, c = 30 mm.

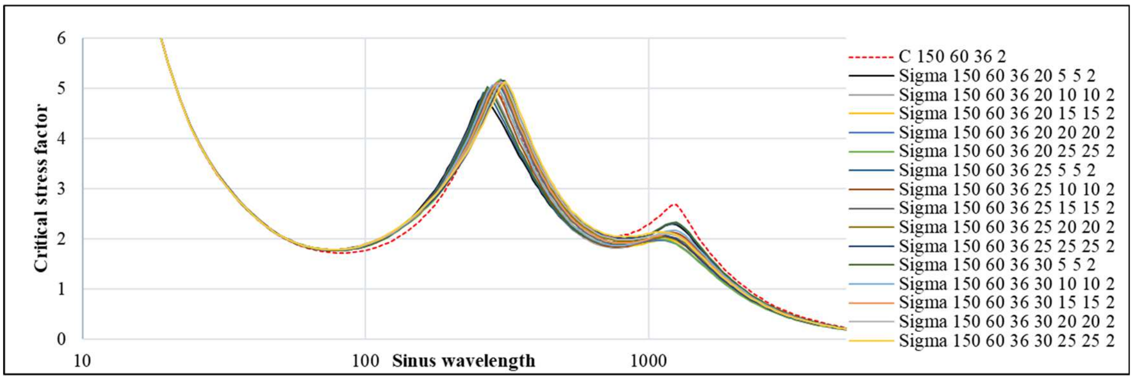

Fig. 10 Results for the case of Sigma profiles, c = 36 mm.

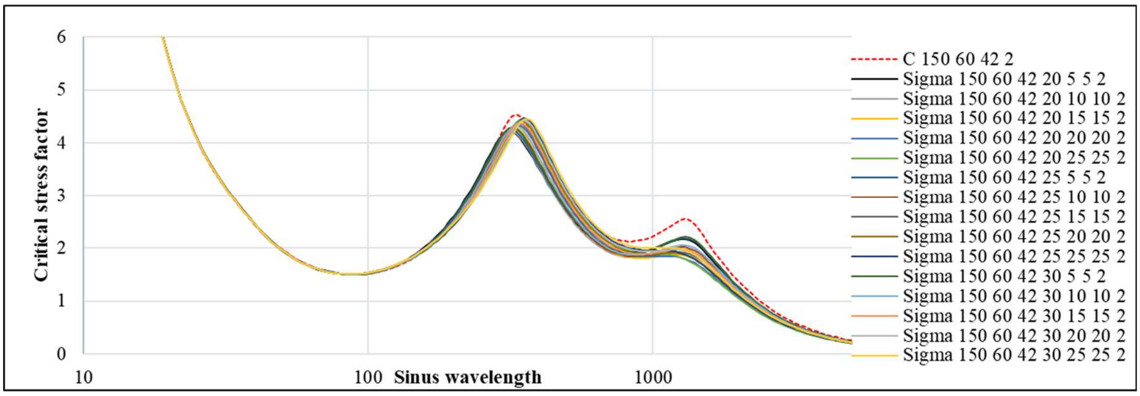

Fig. 11 Results for the case of Sigma profiles, c = 42 mm.

4 DISCUSSION

On Fig. 4, the results for a C profile (i.e., a profile without internal stiffeners) with gradually increasing edge stiffening of the flange are presented. The dashed line represents the case of c = 0 mm, corresponding to a U-shaped section. Due to the absence of stiffeners, U-shaped sections do not undergo distortional buckling, resulting in a single local minimum on the curve corresponding to local buckling mode. However, as the height of the edge stiffener of the compressed flange increases, two local minima begin to form gradually on the curve (for $c \geq 12$ mm) – the first corresponding to local buckling mode, and the second corresponding to distortional buckling mode. It can be said that increasing the height of the edge stiffener of the flange leads to an increase in the load-bearing capacity of the section under distortional buckling (the critical stress factor for distortional buckling increases).

Figures 5 to 11, show the results for a specific length of the edge stiffener of the flange denoted as c. Each curve represents different geometries of the internal web stiffener of the Sigma profile. As seen in Fig. 5 and 6, for profiles with a small height of the edge stiffener of the flange (for example $c \leq 12$ mm, etc), increasing the dimensions of the internal web stiffener results in an increase in the critical stress factor.

Fig. 10 and 11 depict profiles with a higher height of the edge stiffener of the flange (c = 36 mm and c = 42 mm). For these profiles, increasing the dimensions of the internal web stiffener leads to lower values of the critical stress factor for distortional buckling.

For the intermediate cases (Figures 7 to 9), the impact of increasing the stiffener height c is not as straightforward. Some sections exhibit a negative effect, while for others, there is no apparent influenced.

5 CONCLUSION

From the above, it can be inferred that:

- For the C profile, increasing the height of the edge stiffener of the flange enhances the load-bearing capacity of the section under distortional buckling of the compressed flange with edge stiffening.
- If the geometry of the section involves an increase in the height of the edge stiffener of the flange (c) along with an increase in the dimensions of the internal web stiffener, these seemingly beneficial modifications in the geometry of the internal web stiffener of the Sigma profile can lead to a reduction in the critical stress for distortional buckling.
- Increasing the dimensions of the internal web stiffener for sections with a higher height of the edge stiffener of the flange results in a deterioration of the effect of distortional buckling. However, simultaneously, with the increasing size of the internal web stiffener and edge stiffener, there is an increase in the flexural capacity of the gross section (section without the influence of local buckling and distortional buckling). Therefore, it would be necessary to further explore the overall effect of the combination of different geometries of internal web stiffener and edge stiffener of compresed flange on the overall load-bearing capacity of the section in bending.
- Considering the occurrence of the aforementioned, negative influence of a larger size of the flange stiffener combined with a stiffener on the web, according to ČSN EN 1993-1-3 [5], an incorrect design may occur. This observation should be further investigated.

Acknowledgement

This paper has been elaborated within the support of the project No FAST-S-23-8317 of the Ministry of Education, Youth and Sports of the Czech Republic.

References

[1] TILBURGS, Kees. Those peculiar structures in cold-formed steel. Steel Construction [online]. 2013, 6(2), 95–106, ISSN 18670520. DOI 10.1002/stco.201310016
[2] SCHAFER, Benjamin W. Cold-formed steel structures around the world. Steel Construction [online]. 2011, 4(3), 141–149 [accessed 2022-06-14]. ISSN 18670520. DOI 10.1002/stco.201110019
[3] Adany, S., "Buckling Analysis of Cold-formed Steel Members Using CUFSM: Conventional and Constrained Finite Strip Methods" (2006). CCFSS Proceedings of International Specialty Conference on Cold-Formed Steel Structures (1971 - 2018). 2.Finite Strip Methods" (2006). CCFSS Proceedings of International Specialty Conference on Cold-Formed
[4] Steel Structures (1971 - 2018). 2 CUFSM software. Constrained and Unconstrained Finite Strip Method, Cross-section Elastic Buckling Analysis. CUFSM, Thin-walled Structures Group, Civil and Systems Engineering, Johns Hopkins University. [2020] Available at: https://www.ce.jhu.edu/bschafer/cufsm
[5] EN 1993-1-3 Eurocode 3. Design of steel structures: Part 1-3: General rules – Supplementary rules for cold-formed members and sheeting. European Committee for Standardization, 2006. Brussels.

DOI 10.13164/juniorstav.2024.24069