IOP Conference Series: Materials Science and Engineering

Innovative Cold-formed GEB Section under Bending

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Abstract. This paper is concerned with the numerical bending capacity study of the innovative cold-formed GEB sections. Both linear buckling analysis and non-linear static analysis incorporating geometric and material nonlinearity were carried out employing a shell structural model. The magnitudes of buckling load and limit load with respect to GEB section depth and thickness were obtained. The opened cold-formed section was tested assuming two structural positions. The influence of battens on structural load-bearing capacity was investigated in the work.

1. Introduction

In recent years cold-formed steel sections have been frequently designed for metal structures. The innovative GEB section was invented as a primary load-bearing member in fabricated steel panels and trusses. Stability of typical cold-formed open steel sections has recently been studied [1], however, according to the European Standard requirements every new section shape should be tested [2-4]. The optimal configuration of the dimensional parameters of the cross section may act definitely on the profile bearing capacity and the production possibilities [5]. The GEB member stability was investigated in [6-8]. Both numerical analysis and experimental tests for the sample GEB profile under bending were presented in [9].

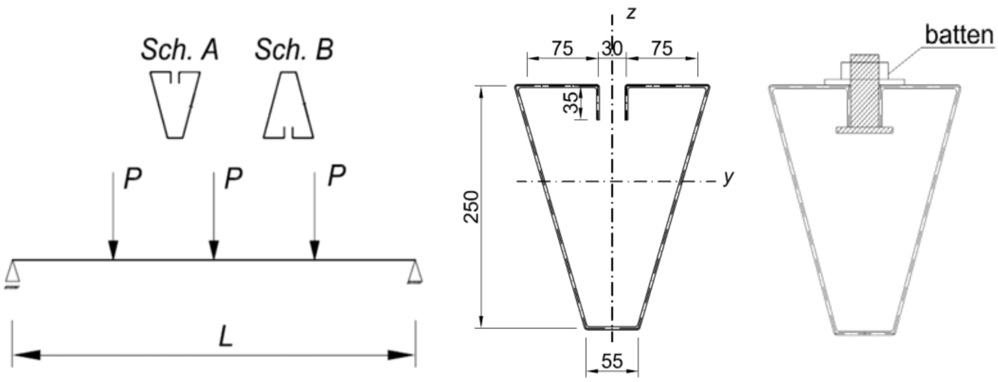
The paper continues the previous research, presented in [9]. Linear buckling analysis and non-linear static analysis (geometric and material non-linearity) were performed applying a shell structural model. In numerical research, the cross-sectional depth was considered variable. The considered profile did not include side braces along the element length.

2. Description of the GEB profile

The GEB profile was made of DC04 steel grade. A separate testing procedure was used to estimate material parameters [6]. The Young's modulus and the yield strength were equal to 178 GPa and 206 MPa, respectively. The element was 6.0 m long, loaded every 1.5 m (figure 1). The thickness values applied in the analysis were 2.0 mm, 3.0 mm, 4.0 mm and 5.0 mm. In the tests, the distance between vertical parallel walls (30 mm) and the wall width (55 mm) were assumed constant (figure 1). The GEB section depth was variable, from 100 mm to 500 mm. Two alternative profile situations are presented in Scheme A and Scheme B (figure 1). The loading was applied only to the horizontal walls of width equal to 2×75 mm (the GEB, depth 250 mm, figure. 1b), in structural position A. For the GEB section situated in position B (figure 1a) the shortest horizontal wall (55 mm wide) was the only one subjected to loading.

Numerical analysis in the Sch. B position considers the structure with or without battens (figure 1c). In each Sch. A case, the battened structure was considered. It was assumed that the GEB profile was pinned at the end supports, torsion was restrained.

In the numerical analysis, an approximate number of 20000 shell elements QUAD4 [10] of a GEB sections 100 mm deep (or a number of 50 000 elements due to 500 mm depth) was assumed (figure 2). The loading was applied (arc-length method) in the form of point forces situated at each node along the horizontal wall width (top of the section). The structure was battened at three loaded joints (Sch. A or Sch. B, figure. 1a). In the numerical model the battens were situated between the vertical parallel section walls only (the width equal 35 mm). These elements were modelled by RIGID links [10] and situated at each node along the parallel wall width.



(a) (b) (c)

Figure 1. Static model of a profile at bending (a), the cross-sectional details for GEB depth 250 mm (b), the batten invented for the opened GEB cross section

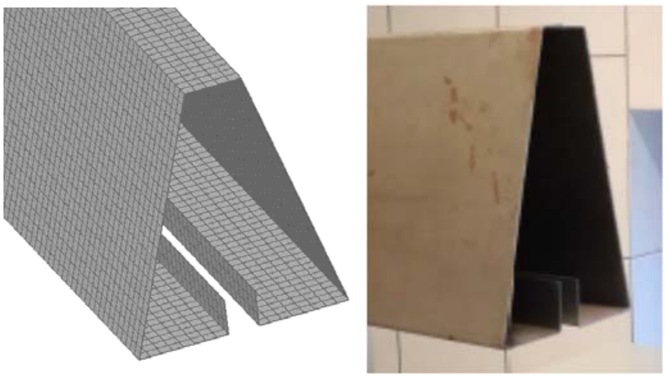


Figure 2. The GEB profile shell model (a) and the real structural model, depth 215 mm, the Sch. B structural position (b)

3. Linear buckling analysis results

Based on linear buckling analysis (LBA), the critical load (the sum of all point forces) was computed in the case of a GEB profile subjected to bending. Figure 3 presents the results of a GEB profile element situated in the Sch. A. structural position. The threshold GEB section depth was detected to ensure the maximum magnitude of buckling load. This threshold depth was equal to 200 mm for the thickness of 2.0 mm or 300 mm for the thickness of 3.0 mm. In these cases, the increase of GEB section depth (above the threshold value) led to the buckling load reduction. The global lateral-torsional buckling modes (global deformation of an entire structure) appeared in the following cases: the section depth 150 mm (or lower) and thickness 2.0 mm, the section depth 250 mm (or lower), thickness 3.0 mm or 4.0 mm, and the section depth 300 mm (or lower), thickness 5.0 mm. In all other cases the structure was subjected to local buckling (local deformations in the mid-span only). The buckling modes are presented in figure. 4.

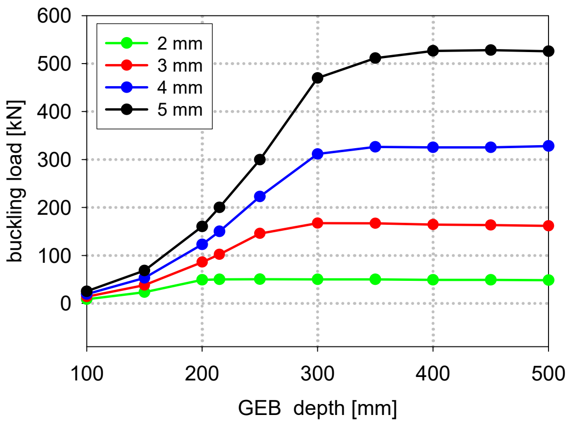
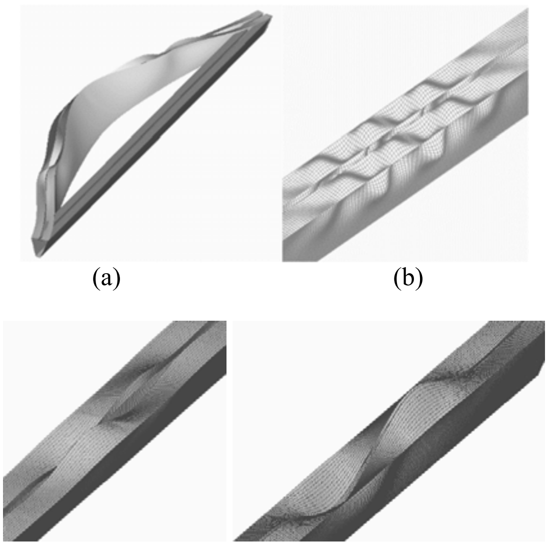


Figure 3. The buckling load vs section depth relation with respect to wall thickness, the GEB profile situated in Sch. A.



(a) (b)

(c) (d)

Figure 4. The buckling modes in the following cases (depth, thickness) [mm]: (150, 2), (250, 3), (250, 4), (300, 5) (a), (200, 2), (300, 3) (b), (300, 4), (400, 5) (c), (450, 4), (450, 5) (d).

The LBA results for the GEB profile elements situated in Sch. B structural position are presented in figure 5. The differences between the results of the structures without battens (figure 5a) and with battens (figure 5b) were up to 5%. In most cases, local buckling modes appeared (figure 6). The threshold GEB depth was 200 mm (thickness of 4.0 mm or 5.0 mm). In the cases of deeper sections, the magnitudes of buckling loads decreased significantly (up to 20%). Based on the analysis, the buckling load magnitudes of the Sch. B situation were much lower compared to Sch. A. Large variations occurred between the threshold section depth values in both structural positions.

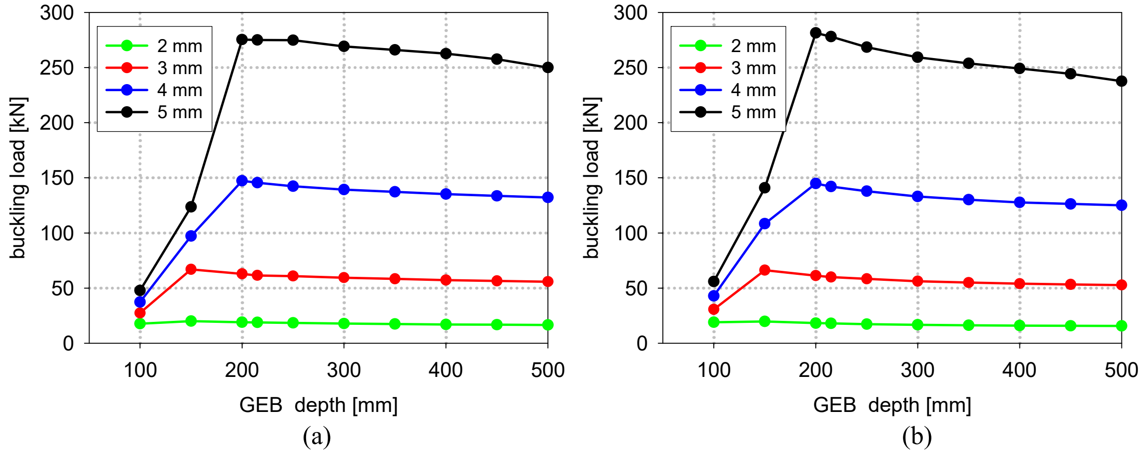


Figure 5. The buckling load vs section depth relation with respect to wall thickness, the GEB profile situated in Sch. B – structure without battens (a) and structure with battens (b).

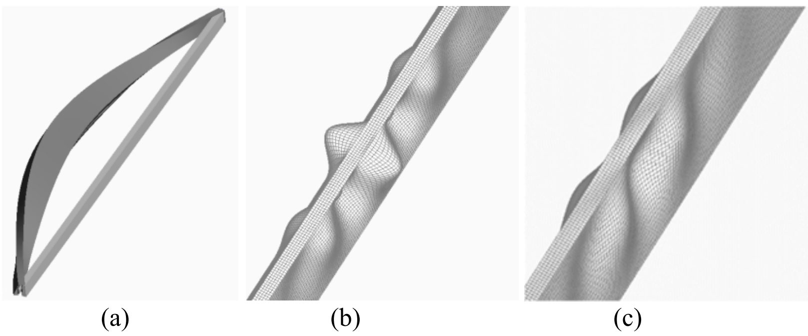
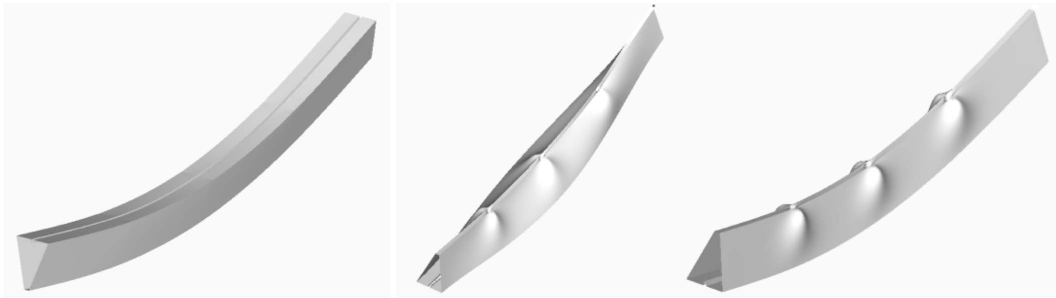


Figure 6. Buckling modes, the considered cases: the profile depth of 100 mm, structure without battens - all thickness values, structure with battens - thickness equal to 3.0 mm, 4.0 mm, 5.0 mm (a), the section depth of 250 mm (or higher) - without battens, all thickness values (b), the section depth of 200 mm (or higher) - with battens, all thickness values (c).

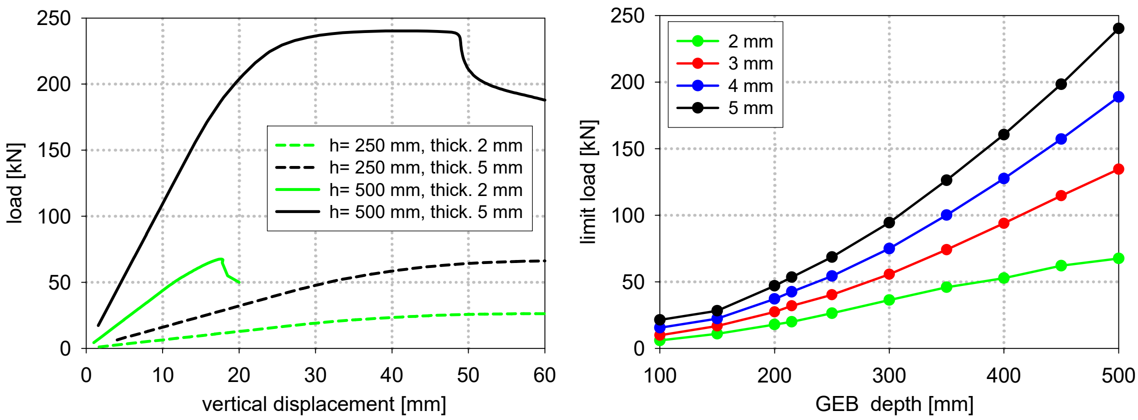
4. Nonlinear static analysis results

Nonlinear static analysis (geometric and material nonlinearity – GMNIA) was conducted considering initial geometric imperfections (figure 7). In each case, the bi-linear elastic-plastic body model was assumed. The imperfection shape was obtained from the results of linear static analysis with respect to the structural position (Sch.A or Sch.B) and the effect of additional battens. The maximum magnitude of imperfection (total displacement) was equal to 12.0 mm (L/500).



(a) (b) (c)

Figure 7. Initial geometric imperfections of a GEB profile in the following structural positions: Sch.A (a), Sch.B – without battens (b), Sch.B – with battens (c).



(a) (b)

Figure 8. Relation of GEB loading (Sch. A) vs vertical displacement (in the mid-span – bottom wall), regarding section depth and thickness (a), relation of limit load (Sch. A) vs section depth, regarding thickness (b).

The results of the GEB profile situated in the Sch.A structural position are presented in figure 8. The equilibrium paths show that the structural stiffness is significantly affected by GEB depth. In all cases, the limit load (maximum magnitude of loading – the sum of all point forces) rose with the increase of section depth (figure 8b). In most cases, the limit state deformation mode was the global arch curvature (figure 9a). The cases of section depth equal to 400 mm, 450 mm, 500 mm and thickness equal to 2.0 mm were the only ones triggering local deformations in the form of few half-waves located in the mid-span (figure 9b).

The GMNIA results according to the profile situated in the Sch. B structural position are presented in figure 10 (without battens) and figure 11 (with battens). The limit load of the battened profile is up to 5% higher than the limit load of the GEB without battens (except the cases of section depth 250 mm and 300 mm). The limit load of the GEB section 300 mm deep (without battens, thickness 3.0 mm) was about 15% higher than the case of 350 mm section depth. In these cases, the plastic range changed significantly, figure 12a illustrates the lower section depth case, while figure 12b shows the higher profile case. The deformations and the stress state – plate top HMH stress (at the limit state) for the battened cross section (Sch. B) are presented in figure 13. It is worth noting that the battened cross-section makes the distance between the diagonal walls (along the profile length) slightly rise in the loading course, compared to the structural case without battens.

Based on the nonlinear analysis, the differences between the limit loads for the GEB profiles (thickness 5.0 mm) in Sch. A or Sch. B structural positions, were up to 20%, while the section depth did not exceed 300 mm. Deeper GEB sections showed the differences up to 110%.

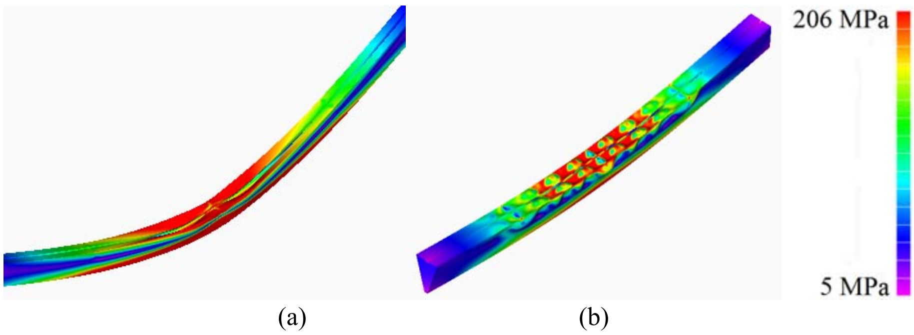


Figure 9. The GEB limit state deformation (Sch.A), dimension variants: section depth of 250 mm, thickness of 2.0 mm or 5.0 mm (a), section depth of 500 mm, thickness of 2.0 mm (b).

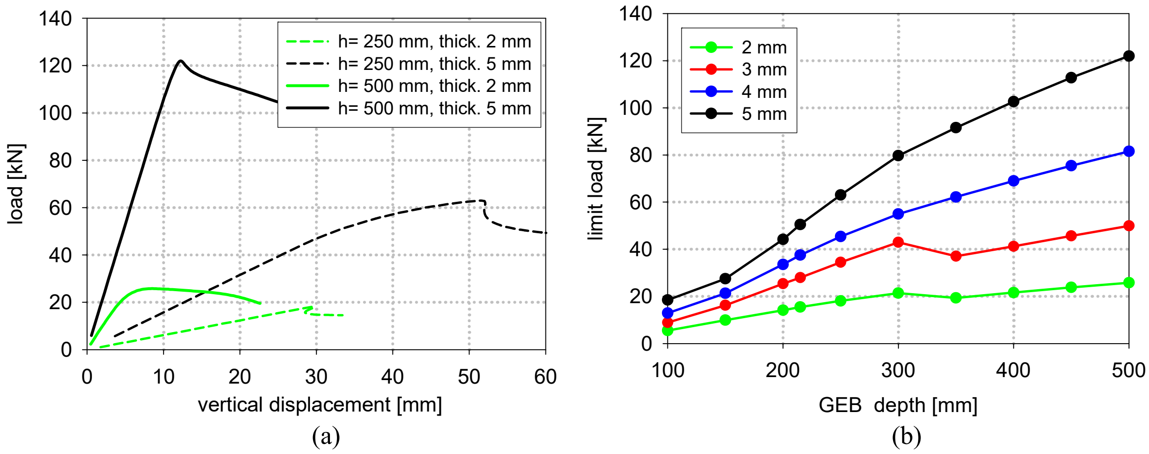
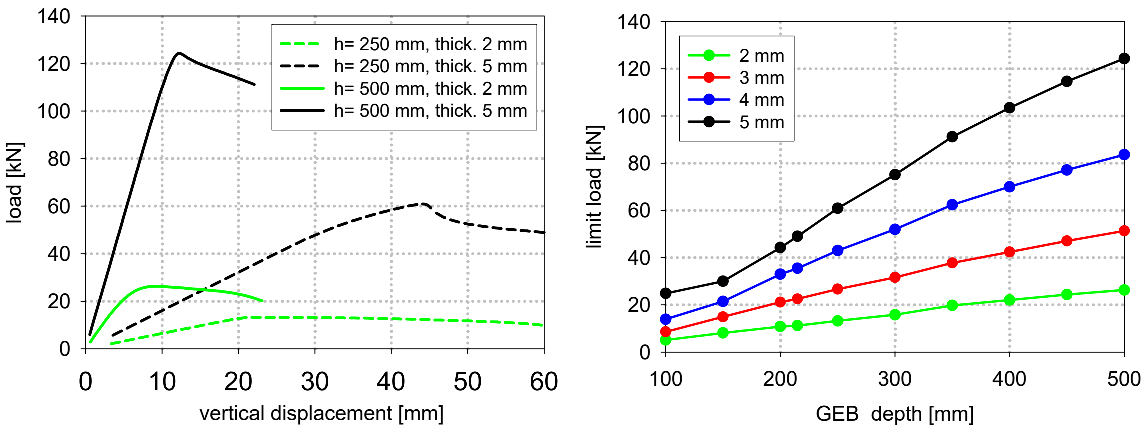
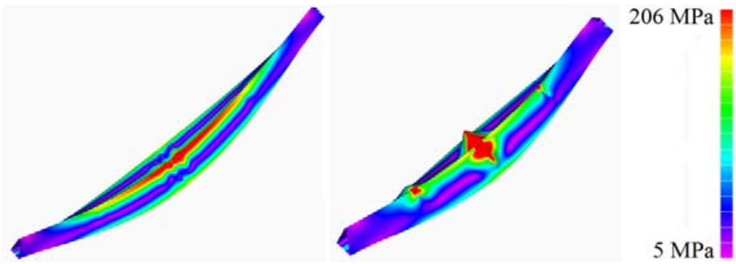


Figure 10. Relation of GEB loading (Sch. B – without battens) vs vertical displacement (in the mid-span – bottom wall), regarding section depth and thickness (a), relation of limit load (Sch. B – without battens) vs section depth, regarding thickness.



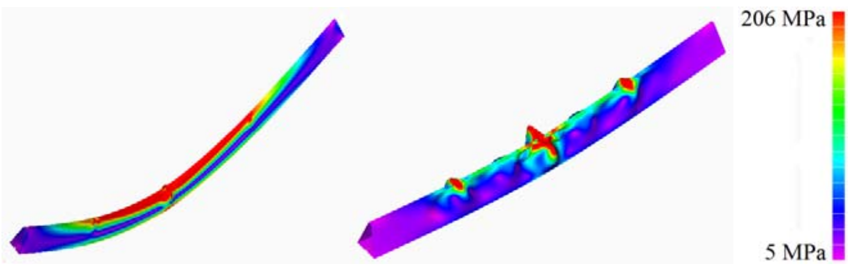
(a) (b)

Figure 11. Relation of GEB loading (Sch. B – with battens) vs vertical displacement (in the mid-span – bottom wall), regarding section depth and thickness (a), relation of limit load (Sch. B – with battens) vs section depth, regarding thickness.



(a) (b)

Figure 12. The GEB limit state deformation (Sch.B – without battens), dimension variants: section depth of 250 mm, thickness of 2.0 mm or 5.0 mm (a), section depth of 500 mm, thickness of 2.0 mm or 5.0 mm (b).



(a) (b)

Figure 13. The GEB limit state deformation (Sch.B – with battens), dimension variants: section depth of 250 mm, thickness of 5.0 mm (a), section depth of 500 mm, thickness of 2.0 mm or 5.0 mm (b).

5. Conclusions

Based on the LBA results, a threshold (minimum) GEB section depth was determined to limit the maximum magnitudes of buckling loads (the section thickness of 2.0 mm or 3.0 mm). The buckling loads obtained in the case of 300 mm section depth (thickness 4.0 or 5.0 mm) were up to 8% less compared to the maximum GEB depth results. Considering the structural position at Sch.A, the local buckling modes appeared for the GEB depth equal to 350 mm (or higher) in the entire thickness range. Most cases of Sch. B. structural position showed local buckling of GEB profiles. The effect of additional battens (Sch.B) made the buckling load rise at about 5%.

The bending capacity of the GEB profile (GMNIA) situated in the first structural position (Sch.A) was higher (up to 110%) compared to the Sch. B. In most cases, the increase of wall thickness and section depth made a significant limit load increase. The differences between the maximum structural loading magnitudes in two cases: with or without battens (structural position B) were usually low (up to 5%)

Future research is planned on the full-scale experimental tests of the structural types analysed in the paper.

References

[1] B. W. Schafer, "Local, distortional, and Euler buckling of thin-walled columns", *Journal of Structural Engineering,* 128(3),pp. 289-299,2002.
[2] PN-EN 1993-1-1: 2006, "Eurocode 3 – Design of steel structures - Part 1-1: General rules and rules for buildings", 2006.
[3] PN-EN 1993-1-3: 2006, "Eurocode 3 – Design of steel structures - Part 1-3: General rules - Supplementary rules for cold formed members and sheeting", 2006.
[4] PN-EN 1993-1-5: 2006, "Eurocode 3 – Design of steel structures - Part 1-5: General rules - Plated structural elements", 2006.
[5] A. Łukowicz, E. Urbańska-Galewska, P. Deniziak and M. Gordziej-Zagórowska, "Classification of restraints in the optimization problem of a cold-formed profile", *Advances in Science and Technology*, 9(28), pp.61-67, 2015.
[6] A. Łukowicz A, E. Urbańska-Galewska, "Deformations of innovative cold-formed GEB sections", *7th European Conference on Steel Composite Structures, Eurosteel 2014 Naples, Conference Proceedings*, edited by R. Landolfo and F.M. Mazzolani, pp. 348-350, 2014.
[7] A. Łukowicz, P. Deniziak, W. Migda, M. Gordziej-Zagórowska and M. Szczepański, "Innovative cold formed GEB section under compression", *Proceedings of the XIII International Conference on Metal Structures - ICMS 2016 Zielona Góra, Recent Progress in Steel and Composite Structures*, CRC Press/Balkema, pp.76-77,2016.
[8] A. Łukowicz and M. Krajewski,"Stability of an innovative cold-formed GEB section", *Engineering Transactions*, 65(1), pp. 45–51, 2017.
[9] A. Łukowicz A, E. Urbańska-Galewska and M. Gordziej-Zagórowska,"Experimental testing of innovative cold-formed GEB section", *Civil and Environmental Engineering Reports*, 16(1), pp.129-140, 2015.
[10] Femap with NX Nastran. Siemens Product Lifecyde Management Software Inc., 2009.