

EXPERIMENTAL TESTING OF INNOVATIVE COLD-FORMED "GEB" SECTION

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Abstract

One of the major advantages of light gauge steel structures made of cold-formed steel sections is their low weight so the production of typical single-storey steel structures of this kind of profiles is still rising. The well known profiles, e.o. Z-sections, C-sections and the so called hat-sections studied and described in the literature, are used mainly as purlins or truss components. A new profile GEB was patented for the use for primary load-bearing member in fabricated steel frames. According to the code [1] every novel cross section should be tested to assign the deformation shape and bearing capacity. The paper deals with the numerical and experimental research of bearing capacity of cold formed GEB profiles. The deformation shape and limit load was obtained from bending tests. The GEB cross section bearing capacity was also determined according to codes [1, 2].

Keywords: cold-formed sections, steel structures, experimental research, bending capacity

1. INTRODUCTION

Typical steel structures are usually made of hot rolled profiles like I-sections and channel-sections or seamless steel pipes. The weight of steel structures due to enlisted species of elements is often high motivating the designers to use thin cold-formed sections thus to reduce the construction weight. The members of cold-formed cross sections are commonly used as

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secondary elements like purlins or sheeting or as a truss components in typical single-storey structures. A new GEB section (cold-formed), patented two years ago may be used as a primary load-bearing member in fabricated steel frames. It is an open, trapezoidal cross-section, with a longitudinal assembly gap between the internal folded edges of the member (Fig.1a), where the system connector is located. This connector can be freely located along the length of the element. Additionally, the longitudinal assembly gap is useful to compensate fitting and dimensional deviations (Fig.1b).

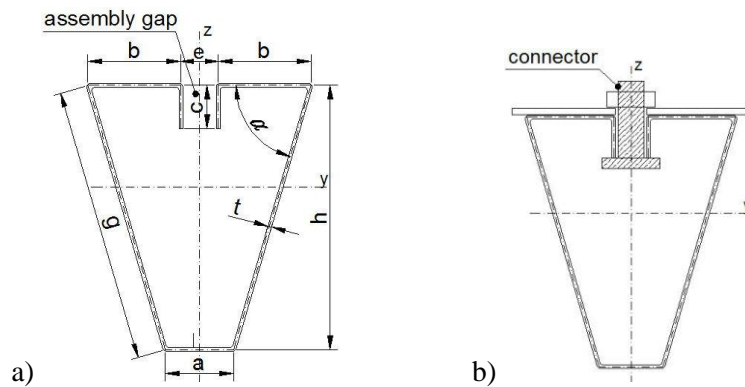


Fig. 1. GEB section: a) cross-section dimensions, b) a cross-section with connector in an assembly gap

The innovative shape and a free movement of connectors makes it possible to form structures without additional technological operations like cutting or welding. It can also simplify the assembly procedure and reduce the total construction costs [3]. Optimal dimensional parameters of this section restricted by the production capabilities are required to build a universal design format of a structural system.

According to the code [1] every new section shape should be tested to assign the cross section deformation and bearing capacity. Both numerical (MARC MANTAT) and experimental research of bearing capacity of cold formed GEB profiles were performed. The deformation shape and limit load were obtained from the bending test. The GEB cross section bearing capacity was also determined according to codes [1, 2].

2. GEB SECTION BENDING CAPACITY

The GEB cold-formed section is sensitive to distortional global buckling and local buckling of thin walls, therefore the GEB bending capacity calculations according to codes [1,2], experimental testing and FEM analysis were

performed for two following position variants (Fig. 2a): A - the loading force applied to the element centre to a wider base (the flange with the longitudinal assembly gap was under compression) and B - the loading force applied to the narrower section base (the flange with longitudinal assembly gap under tension). Furthermore, for the two variants the testing and calculations were performed on members of 2 mm thick walls made of DC04 steel grade and the 3 mm thick walls made of S235 steel grade. The dimensions of the GEB section were presented on (Fig. 2b).

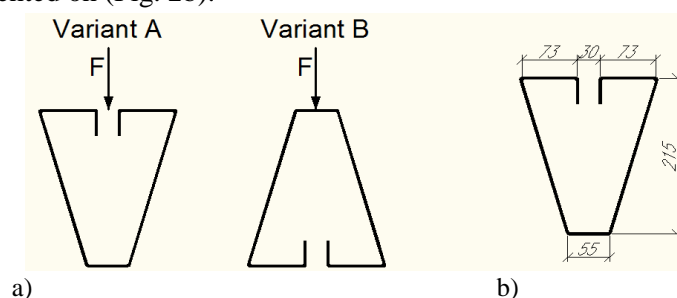


Fig. 2. a) variants position, b) cross-section dimensions.

The properties of steel were determined by means of experimental tensile tests conducted on a ZWICK-ROELL testing machine. The magnitudes of the f_u - maximum tensile strength, f_y - yield strength and E - Young's modulus, implemented in the numerical models, are presented in Table 1. Only four samples (for each steel grade) were used to determine the material characteristics. It is supposed to be the main reason for large discrepancies between the magnitudes of Young's modulus.

Table 1. Values of the steel material properties

Kind of samples	f_u [MPa]	f_y [MPa]	E [GPa]
Thickness - 2 mm DC04 grade of steel	292	205	178
Thickness - 3 mm S235 grade of steel	393	247	210

2.1. GEB cross section bearing capacity according to code [1, 2]

According to Winter's theory of super-critical bearing capacity, thin walls are analysed as plate panels with specific boundary conditions and effective width. The edge stiffeners of the panels act significantly on the deformation shape of the GEB cross section and the magnitude of buckling load. Local buckling may occur as a result of exceeding the critical stresses. The reduced cross-section area is therefore proposed (Figure 3).

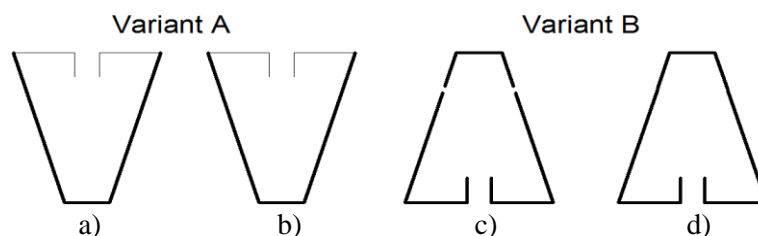


Fig. 3. Effective GEB cross-section area: a) 2 mm thick cross-section - variant A, b) 3 mm thick cross-section - variant A, c) 2 mm thick cross-section - variant B, d) 3 mm thick cross-section - variant B.

The GEB section is an open thin-walled, cold-formed cross-section, in class 4. It consists of 5 walls, including 3 internal plate elements (doubly supported) and 2 plate elements with edge stiffeners. The profile is sensitive to local and distortional buckling. The bending capacity can be obtained from code requirements PN-EN 1993-1-3. The cross-sectional characteristics of effective area according to [1], [2] are required. In order to achieve design resistance of the GEB profiles the deformation shape has to be taken into account. On the basis of Z or channel loaded profile behaviour (deformation shape) the effective cross-sectional areas (Fig. 3a,b,c,d) were adopted for the investigated members. One of the experimental test results (point 2.2) is the deformation form which was comparable to the Z or channel sections. According to the codes magnitudes of bending moment, shear force, local transverse forces for cross-sections with two unstiffened webs and interactive formula [1], [2] were determined (Table 2).

Table 2. The bearing capacity results for GEB section according to codes

Kind of samples	Bending moment [kNm]	Shear force [kN]	Local transverse forces for cross-section with two unstiffened webs [kN]	Combined shear force and bending moment [kN]
	Variant A	A	A	A
	Variant B	B	B	B
2 mm DC04	12,95	70	13,1	140
3 mm S235	23,6	189,8	33	378
	24,4	189,8	33	378

The maximum loading magnitudes are mostly the same for both variants except flexural resistance of the cross section. The reason may be different magnitude of effective area for variants A and B.

2.2. Experimental test results

The bearing capacity tests for bending of the GEB member were performed on a Zwick Roell Z400 testing machine. Experimental tests were carried out for four sample elements. In all cases the cross-sectional depth was 215 mm (Fig. 4a). Two of the tested members (with wall thickness 2 mm) were made of steel grade DC04 and the other two (with wall thickness 3 mm) of S235. The length of the members was 1,7 m and the distance between supports was 1m. The support for the tested GEB members was made of special steel framing fixed with the strength testing machine (Fig. 4b). The tested elements were located on the frame in two variants (Fig. 4c): position A - the load applied to the wider section part and position B - the load applied to a narrower part of the cross section. Experimental tests of the members were carried out for the constant displacement increase equal 3mm/min. The analysis was performed for the static model presented on Fig. 4c due to the experimental test set-up.

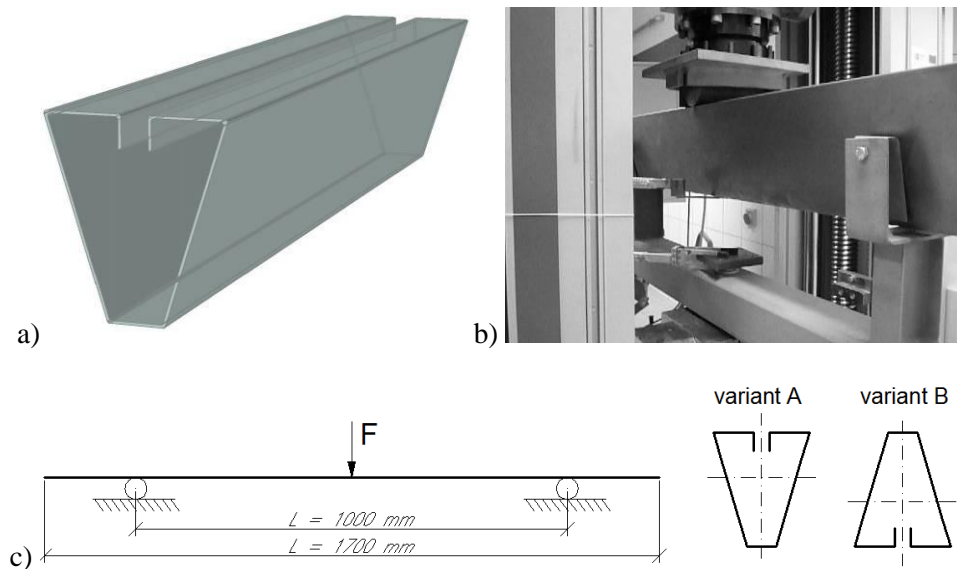
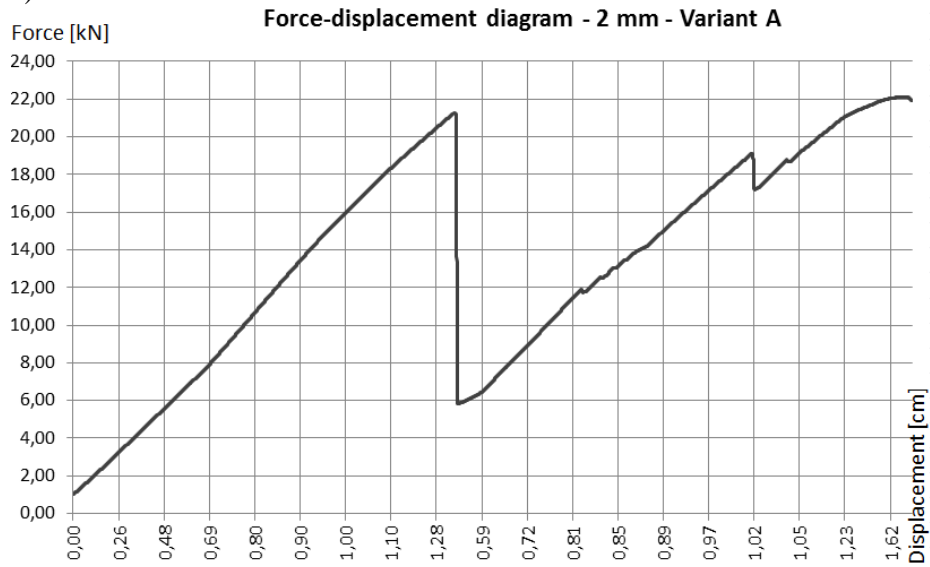


Fig. 4. Examined GEB profile: a) section view, b) view of the member during experimental testing, c) static schema.

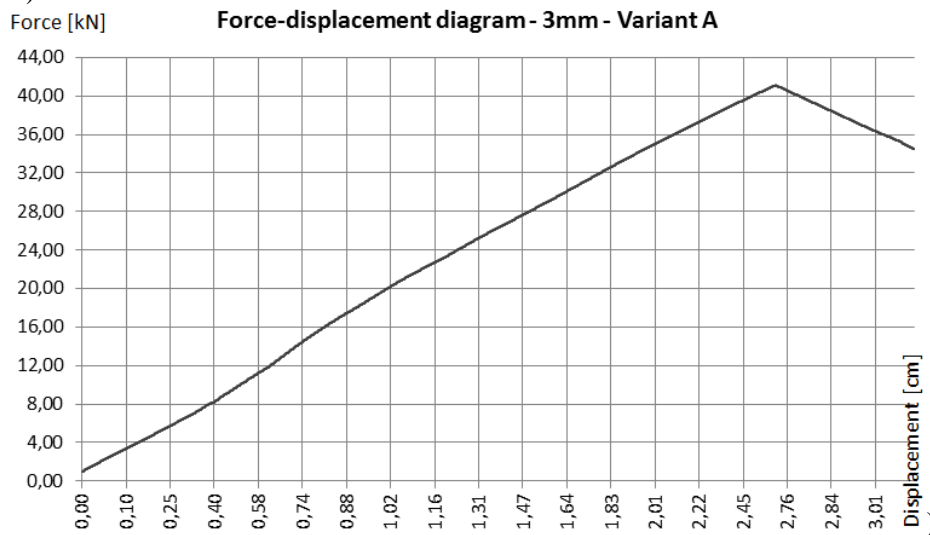
The deformation modes of particular walls were observed during the bending test. The magnitude of the maximum load for the member was determined on the base of the force-displacement diagrams (Fig. 5a,b,c,d). The deformation (vertical displacements) was measured in the middle of the span.



a)



b)



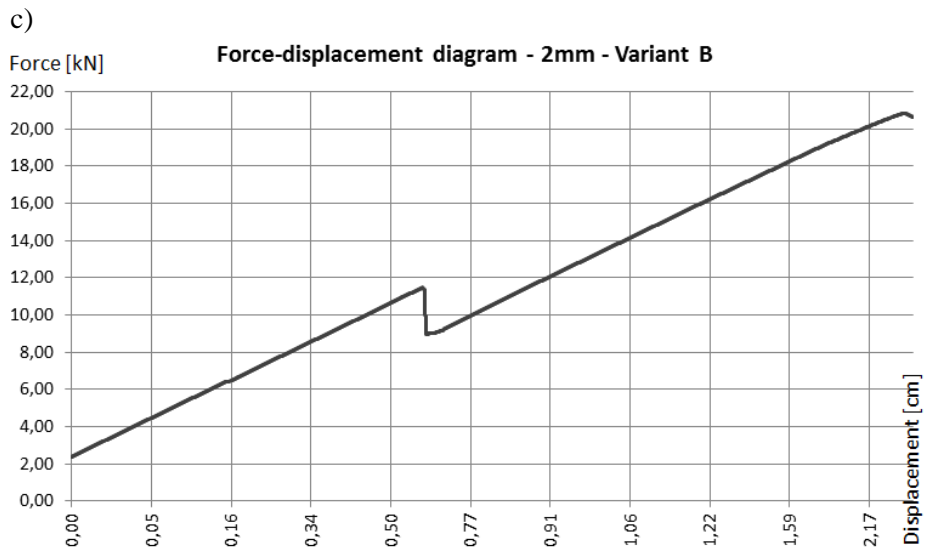


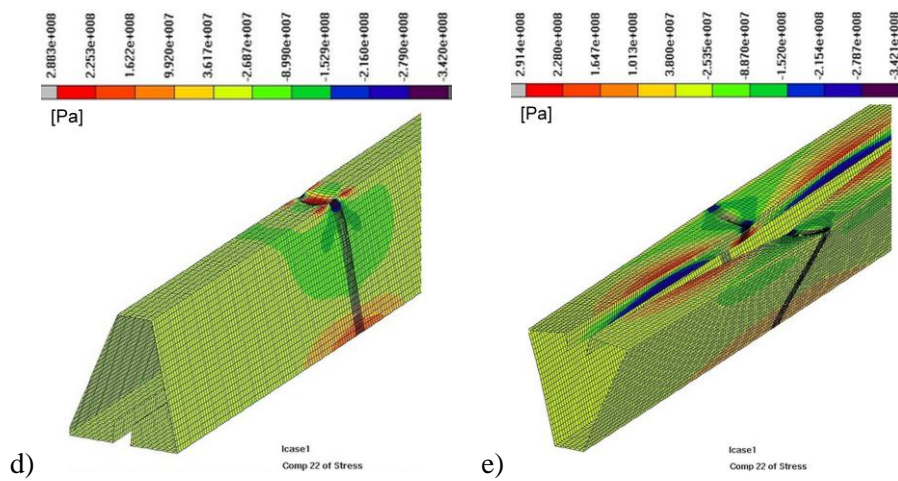
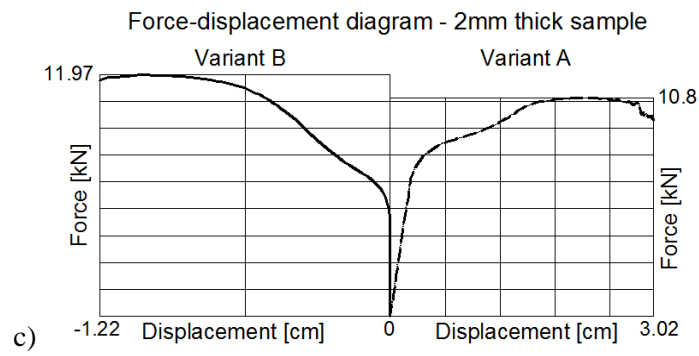
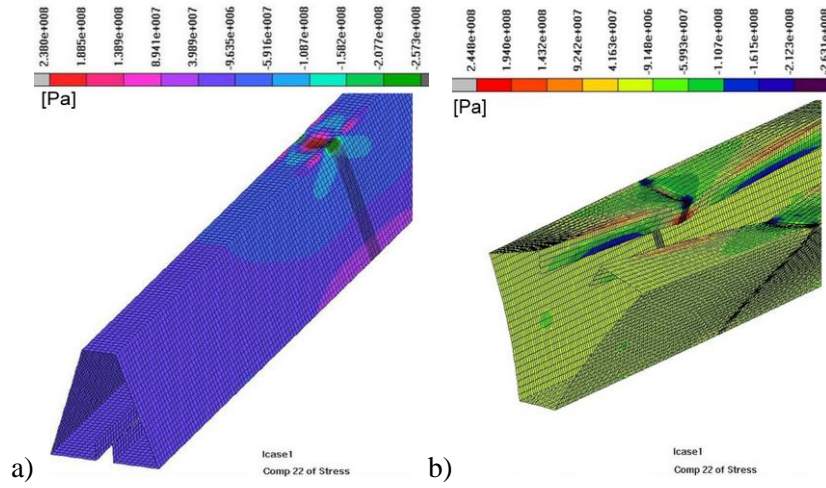
Fig. 5. Force-displacement diagram: a) 2 mm thick sample - Variant A, b) 3 mm thick sample -Variant A, c) 2 mm thick sample -Variant B, d) 3 mm thick sample -Variant B.

The characteristic drops of the force-displacement curves show local or distortional buckling of the GEB section. After the first decrease of the cross-section resistance shown as a drop of loading in the diagram, the section bending capacity grows up until it reaches the next maximum value. Primarily the magnitude of the first peak is smaller than the second one. Only one pick is observed for a 3 mm thick GEB member with the wider flange (with longitudinal assembly gap) under compression (Fig. 5b), while in the case of 2 mm thick GEB member at the same variant (Fig. 5a) a significant drop of loading occurs. In this case large loading decrease was produced by the local deformation of two compressed flanges with an edge stiffener observed during the experimental testing.

2.3. Numerical analysis results

Numerical analysis was performed by means of a MARC MENTAT FEM program. Sections were modelled by 4-nodes elements QUAD4 No. 139 [5]. The thickness of shell elements was equal to 2 or 3 mm, variable due to the analyzed section model. The assumed material constant parameters were: Poisson's ratio equal 0.3 and the density of steel equal 7850kg/m^3 . The Young's modulus and yield strength of the steel were determined experimentally (Table 1). A static analysis with geometric and material nonlinearity (elasto-ideal-plastic model of the material) were carried out for the structure without geometric imperfections (GMNA). It was assumed that each tested element was pinned at the supports. The distance between the supported nodes was 1,0 m. The loading was applied in the middle of the span as a set of nodal forces distributed on a surface corresponding to the roller diameter used in the experiment. The arc-length method was used for a load application. The final deformation of the loaded structure was presented in Figure 6 a), b), d) e). The analysis results in form of maps and force-displacement diagrams are presented in Figure 6 a÷f. A negative displacement value (Fig.6 c and 6 f) means the opposite direction of the loading force in variant B compared to A in the same coordinate system.





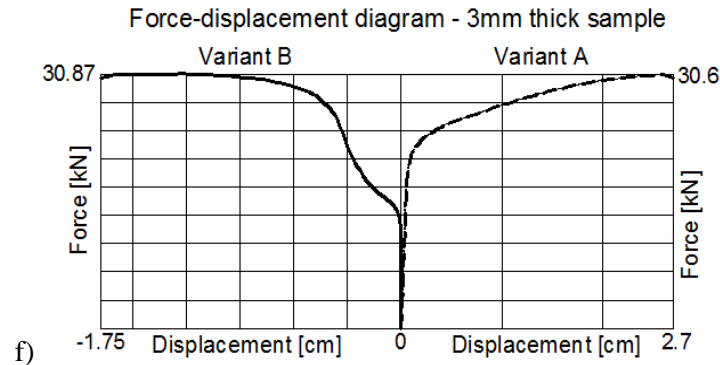


Fig. 6. Maps and diagrams of: a) normal stresses - 2 mm thick beam -variant B, b) normal stresses - 2 mm thick beam -variant A, c) force-displacement relation - 2 mm thick beam, d) normal stresses - 3 mm thick beam - variant B, e) normal stresses - 3 mm thick beam - variant A, f) force-displacement relation- 3 mm thick beam.

3. SUMMARY

The results of experimental tests and numerical analysis are presented below. The maximum magnitudes of loading determined by experimental tests before the first peak on a force-displacement curve were comparable with the FEM results in variant B only. The results are presented in Table 3. According to calculations based on code requirements the magnitude of transverse forces for a cross-section with two unstiffened webs acted on the load carrying capacity of the cross-section. Magnitudes of the loading force equal to 11,97 kN determined from FEM calculations and 11,5 kN reached at experimental test were found corresponding to the magnitude of the local transverse forces for the cross-section with two unstiffened webs equal to 13,1 kN.

Table 3. Experimental and numerical analysis results

Kind of samples	FEM calculations		Experimental testing first peak [kN]		Experimental testing second peak [kN]	
	Variant A [kN]	Variant B [kN]	Variant A [kN]	Variant B [kN]	Variant A [kN]	Variant B [kN]
2 mm DC04	10.8	11.97	21.4	11.5	22.2	20.8
3 mm S235	30.6	30.87	-	32.4	41	41.5

The possible explanation for discrepancies between loading magnitudes described above may be the initial shape of the tested elements. No geometric imperfections were implemented in the numerical analysis. It was also assumed that the elements were pinned at the supports and friction between the GEB members and the supporting frames was neglected. The main reason of differences between numerical and experimental test results in Variant A may be the length of the roller which was used to transfer loading to the examined GEB element. The length of the roller was exactly the same as the width of the wider base of GEB section what caused the local buckling of the element. During deformation the webs moved outside of the longitudinal assembly gap and the roller interacted only on flanges. The shapes of a deformed cross section obtained from experimental test and numerical analysis were similar (Fig. 7 a, b).

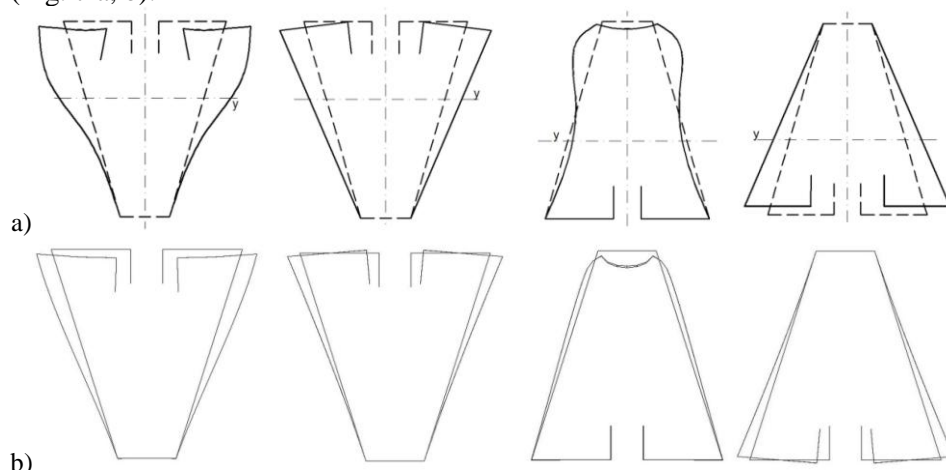


Fig. 7. Deformation modes: a) from experimental testing (midspan cross-section and free end cross-section) - variant A and B, b) from FEM calculations (midspan cross-section and free end cross-section) - variant A and B.

The relevant calculations according to codes [1,2], taking advantage of all relations within the experimental research deformation modes, are similar to the literature results for Z-sections and channel sections. Thus, the assumptions made for the calculation of the effective cross-section area assessment in analysed sections are also correct [4].

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Streszczenie

Jedną z najważniejszych zalet lekkich konstrukcji metalowych, wytwarzanych z kształtowników giętych na zimno, jest ich mała masa, dlatego też, producenci coraz częściej wykorzystują możliwości profili giętych do wytwarzania typowych konstrukcji halowych w budownictwie systemowym. Proces gięcia na zimno, pozwala na formowanie różnego rodzaju przekrojów poprzecznych, które mogą być wykorzystywane jako elementy konstrukcji. Typowe kształty elementów. tzn. Z, C oraz tzw. przekroje kapeluszowe, które zostały przebadane i opisane w literaturze, wykorzystuje się głównie jako płatwie lub części składowe wiązarów kratowych. Nowo opatentowany przekrój typu GEB ma być wykorzystany jako element nośny konstrukcji ramowych. W związku z tym innowacyjny kształt oraz parametry geometryczne przekroju takiego kształtownika, związane z możliwością jego wyprodukowania oraz z warunkami nośności, stateczności oraz sztywności, muszą być optymalne. Według normy PN-EN 1993-1-3, każdy nowo uformowany przekrój powinien być przebadany pod kątem nośności elementu i formy deformacji, dlatego też, ten innowacyjny kształtownik został poddany m.in. badaniom nośności na zginanie. Na ich podstawie została określona wartość nośności przekroju oraz forma jego deformacji. Jednocześnie dla analizowanego elementu zostały przeprowadzone obliczenia nośności przekroju, według normy PN-EN-1993-1-3 oraz numeryczne w programie MARC MENTAT.

Słowa kluczowe: przekroje gięte na zimno, konstrukcje stalowe, badania eksperymentalne, wytrzymałość na zginanie

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