PROPERTIES OF COLD-FORMED STEEL SECTIONS

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ABSTRACT

There is great flexibility in the design using cold-formed steel. The low cost, ease of manufacture and controlled quality can encourage the development of innovative uses. In spite of the advantages, the range of application is limited in Latvia, especially for load bearing structures. The resistance of thin-walled cold-formed steel sections should be determined according to EN 1993-1-3 (2006) and 1993-1-5 (2006) by the effective width method. As a first step, in this paper the resistance to local buckling of cold-formed sections in compression and bending is analysed taking into account geometrical proportions, influence of rounded corners and stiffeners. By numerical analysis there is given the estimation of effective U and C-section properties in the range of width-to-thickness (b/t) and width-to-height (b/h) in concordance with EN 1993-1-3, Section 5. In addition to the numerical analysis there are presented and assessed results of experimental research with natural beams in bending.

Key words: cold-formed steel; effective section properties; numerical analysis; experimental method; assessment of results

INTRODUCTION

Cold-formed steel offers many advantages, including: ease of prefabrication and mass production, increase of strength in fabrication process, uniformity of quality, low weight, economy of transportation and handling, and quick and simple erection or installation.

Thin-walled cold-formed steel sections (CFSS) are produced by bending and shaping flat sheets at room temperature. Material is easily workable and many possible shapes can be produced.

The structural behaviour of CFSS can be distinguished from typical hot rolled sections with the tendency to be more sensitive to buckling effects. The tendency to buckle increases as the width to thickness ratio of the plated elements increases. It is obvious, that design standards were needed to establishing requirements and laws to control the buckling and strength characteristics.

The use of CFSS members in building construction began more than 150 years ago in the United States and Great Britain. The first edition of specifications for design (in 1946) was followed by many revisions and developments finished in 2007. The European Union has adopted Eurocode EN 1993-1-3 in 2006 and it has been mandated that all member states adopt these codes in 2010. Further directions in reviewing of plate buckling rules are given in (Johansson and Veljkovic, 2009).

CFSS can be used widely in building applications (e.g., www.lysaght.com) and can be specially shaped to suit the particular application. The most common sections are the U, C and Z shapes. However, a whole range of variants of these basic shapes, including geometrical proportions, edge lips and internal stiffeners can be produced.

MATERIALS AND METHODS

Theoretical modelling

For practical design of CFSS designers normally refer to the manufacturers` data or use software in case of non-standard shapes. For this purpose there MathCad programme is used and numerical analysis performed to estimate the effective U and C-section properties in compression and bending in accordance with EN 1993-1-3, Section 5 by the effective width method. For comparison, for outstand compressed elements an alternative mixed method given in the Annex D is used. The resistance of compressed flanges with edge stiffeners was determined using iterations. Initially the data from the numerical tests were compared with those from the worked examples (ECCS TC7 TWG 7.5 (2008).

The summarized results, showing the influence of the geometric characteristics (in cm) on the properties of CFSS are given in some examples:

1) U-section formed from a steel sheet 300x4 mm in the available range of width-to-thickness (b/t) and width-to-height (b/h) ratios subjected to compression and bending. The results of the numerical analysis are shown as X-Y plots (Fig.1, Fig.2), where ratio$_i$ = b / h. The gross section and effective section modulus $W_{z``}$, $W_{efz``}$ were calculated according to the free edge (outstand compressed element). For comparison, the curve for the effective area of the compressed U-section (A_{efc}) is added (see Fig.1, a).

2) Double C-section arranged back-to-back, subjected to compression (Fig.3), made from steel sheets 300x1,5 mm with variable ratio (b/h) and edge stiffener width c = 0,4 b (Fig.4). For comparison, the curve for the effective area of the compressed double-C (A_{efc}) section is added (Fig.4).

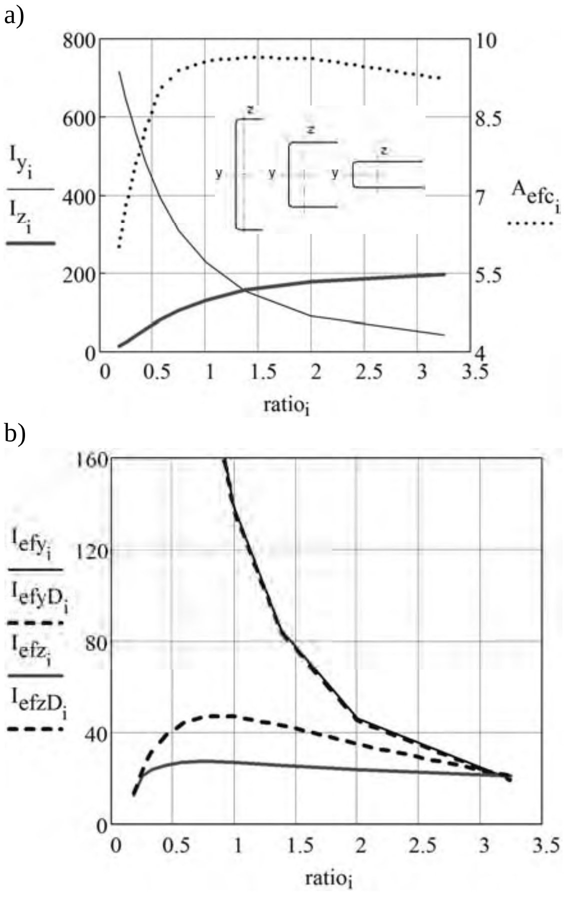

Figure 1. Properties of U-section in compression, where I_y, I_z and I_{efy}, I_{efz} – second moment of area for gross and effective section; I_{efD} – by mixed method.

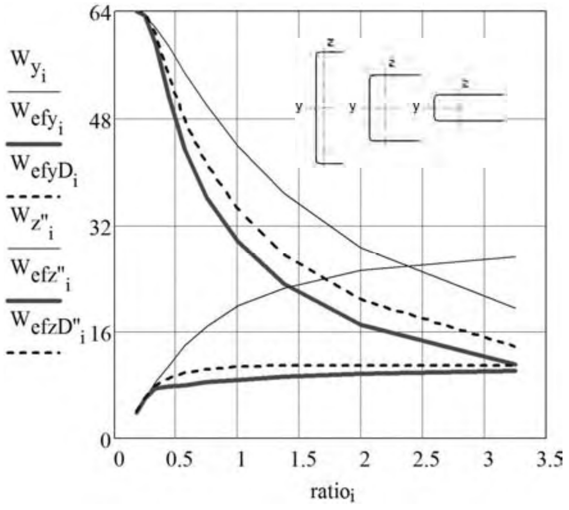

Figure 2. U-section in bending, where W_y, $W_{z''}$ and W_{efy}, $W_{efz''}$ – section modulus for gross and effective section; W_{efD} – by mixed method.

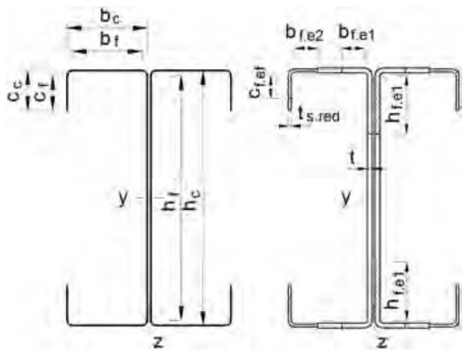

Figure 3. Double C-section.

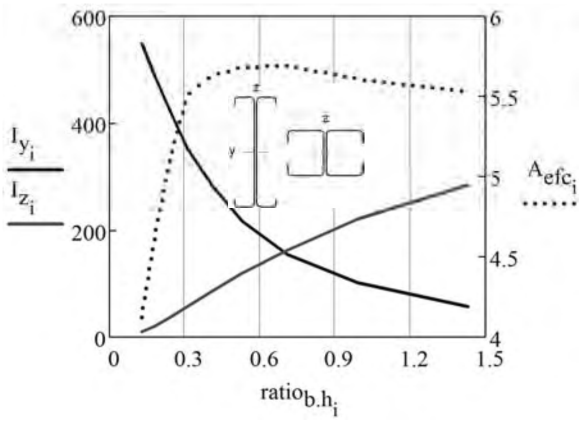

Figure 4. Properties of double C-section in compression

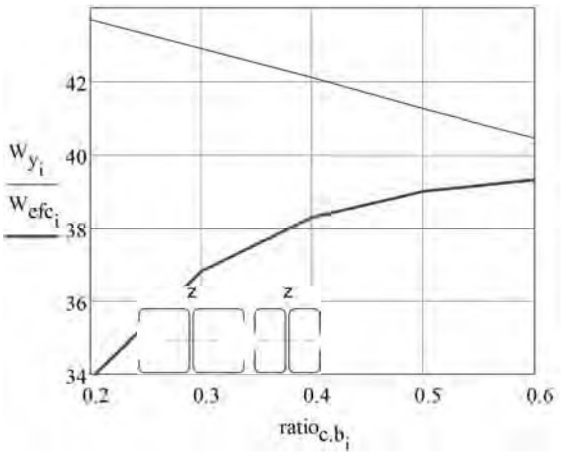

Figure 5. Double C-section in bending, where W_y and W_{efc} – section modulus for gross and effective section (for fibres in compression)

3) Double C-section arranged back-to-back, subjected to bending, made from steel sheets 300x1,5 mm with constant h = 150 mm and variable ratio (c/b), where edge stiffeners c = (0,2 ... 0,6) (Fig.5).

Experimental research

The test specimens (from RUUKKI standard sections) were taken as simply supported double-C beams (Fig.6), arranged back-to-back and loaded in bending at three points of the span (i.e., the four-point bending tests). Loads are applied only about y-y axis of the cross-section. Lateral restraints were added at the supports and load points to avoid torsional buckling. The tests were carried out by loading equipment Zwick-Roell using operating program TestXpertII:

a) “short beam” tests. Beams with span L = 1430 mm (it is less than 15 h) were tested for verification of the experimental method. One test with the beam from double-C 200 (t=2mm) and one test with double-C 150 (t=1mm) was performed and the moment resistance was determined;

b) “long beam” tests with beams according to EN 1993-1-3, Annex A:

- series of three specimens from double-C150 (t=1mm) with span L=15 h = 2250 mm;
- series of three specimens from double-C120 (t=1mm) with span L=15 h = 1800 mm.

The webs of beams are connected by pairs of bolts (see Fig.6 and Fig.7); as the webs can locally buckle independently of each other, the slenderness is considered equal to the width divided by the thickness.

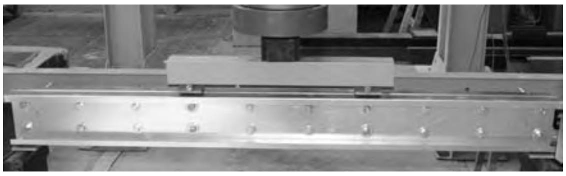

Figure 6. Experimental research of beams.

Figure 7. Supporting of beams and local buckling of compressed flange and web.

The experimental results are ilustrated in Fig.8, Fig.9 and Fig.10; deflections are shown relative to span of the beams (w / L). The tests for series of beams leads to practically equal graphs. All specimens were colapsed due to local buckling of compressed cross-section elements.

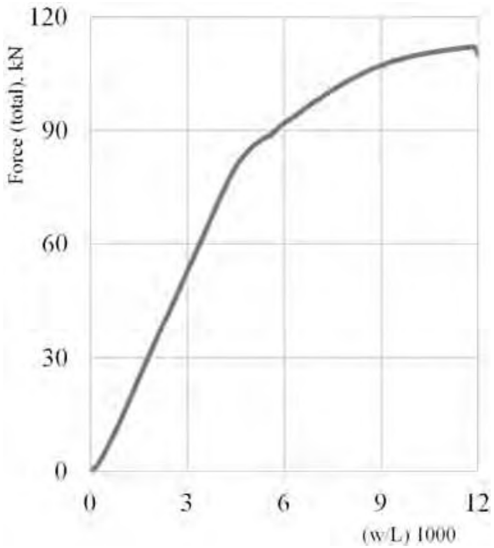

Figure 8. Double-C 200 “short beam” test.

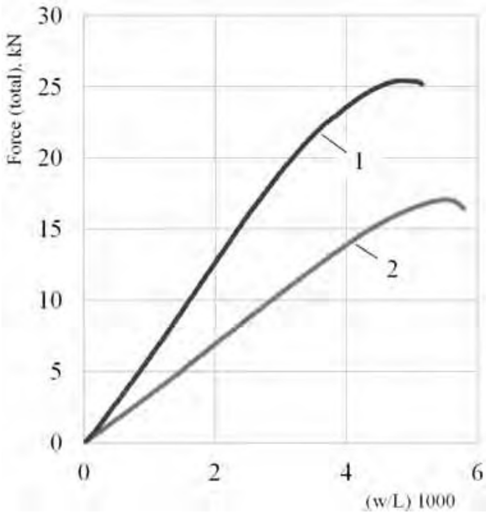

Figure 9. Double-C 150 beams tests, where 1 – “short beam”; 2 – series results.

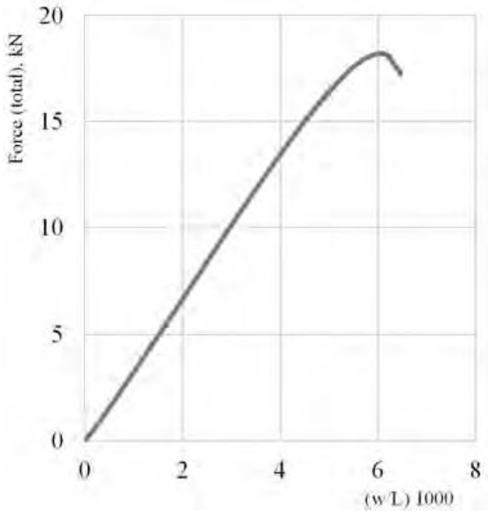

Figure 10. Double-C 120 beams tests.

The “short beam” tests validate the experimental method; in comparison with “long beam” tests the limit value of loading up to which direct proportionality exists is more explicit. The following nonlinear stage indicates that effective properties of cross-sections progressively become determinative and the effective section modulus W_{eff} is lesser than the gross elastic modulus W_{el}.

The relationship “force-deflection” for beam from the double-C200 section differs from other experimental curves due to greater thickness (t = 2 mm) and due to interaction with lateral restraints at the loading points prevented global torsional buckling. Prior to local buckling effects there was observed waving of the compressed flanges in the central part of the span.

RESULTS AND DISCUSSION

Evaluation of theoretical modelling

Estimation of correct CFSS properties is of essential importance. The presented examples illustrate the necessity of using the effective properties of CFSS and eliminate the possibilities of using the gross section properties. Modelling the different U-shapes by varying of the ratio=b/h leads to the conclusion, that determination of the section properties about z-z axis is of primary importance. Using for outstand elements (flanges) the mixed effective width/effective thickness method, given in the Annex D of EN 1993-1-3, shows evident differences (see Fig.2), thereby in some cases the mentioned mixed method must be used warily. Normally the influence of rounded corners on CFSS resistance may be neglected; the section modulus with increasing of the internal radius decreases under 3%. For determination of the stiffness properties the influence should always be taken into account. On the other hand, there is a well-known change in the mechanical properties of steel by virtue of cold forming. It is supposed, that the yield strength is increased in the bends of the section up to 15%.

Modelling the double C-sections in compression (see Fig.4) by varying of the ratio width-to-hight of the section elements shows up the rational proportions (where $I_y \approx I_z$ and the effectiveness of the compressed area) for the initial calculations. The curves for double C-section in bending (see Fig.5) reflect the meaning of the width of the edge stiffeners – the effective section modulus increases only with the width up to ~ 0,6 b.

Resistance of cross-sections

Generally design assisted by testing is recommended for determination of the resistance of CFSS at ultimate limit states. It is firmly applied for sections with relatively high b_p / t ratios.

In connection with the performed experimental research the properties of the used cross-sections are analysed in accordance with EN 1993-1-3, Sect.6.1, and summarized in Table1:

- bending resistance M_{cRd} is determined assuming yielding at the compressed flange and section modulus $W_{eff} < W_{el}$;
- shear lag shall be taken into account to 1993-1-5, Sect.3. As the ratio - compressed flange width-to-length between the points of zero moments for the beams (b_0/L_e) is relatively small, the effect of shear lag is considered having no influence on the bending resistance of the section;
- shear resistance V_{bRd} is determined depending on the shear buckling strength and web slenderness;
- local transverse resistance. As the local load (support reaction) is applied through a cleat (see Fig.7), distortion of the web is eliminated and the local resistance of the web to the transverse force needs not be considered (EN 1993-1-3, Sect.6.1.7.1);

Table 1

Evaluation of tests results

Cross section	Span, mm	W_{eff}, cm^3	M_{cRd}, kNm	V_{bRd}, kN	$\frac{V_{Ed}}{V_{bRd}}$	$\frac{M_{Ed}}{M_{cRd}}$
C150	1430	17,17	6,01	25,2	0,50	1,01
C200	1430	69,12	24,19	94,8	0,59	1,10
C120 (series)	1800	13,52	4,73	24,0	0,37	1,13
					0,38	1,16
					0,38	1,16
C150 (series)	2250	16,93	5,93	25,2	0,33	1,06
					0,34	1,09
					0,34	1,09

- combined shear and bending resistance. As for the beam from double-C200 the shear force V_{Ed} is larger than a half of the shear force resistance 0,5 V_{bRd} (web resistance), interaction between the shear force and bending moment have to be taken into account, because shear buckling may reduce the bending resistance of the cross-section.

The resistance needs not be reduced if the following equation should be satisfied (EN 1993-1-5, Sect.7.1):

$$\frac{M_{y,Ed}}{M_{y,Rd}} + \left(1-\frac{M_{f,Rd}}{M_{pl,Rd}}\right)\left(\frac{2V_{Ed}}{V_{pl,Rd}}-1\right)^2 \le 1{,}0\,,$$

In this case, the moment resistance of the cross-section consisting of the effective area of the flanges only - $M_{f,Rd} = f_y\, h\, A_f$ = 33,8 kNm is larger than the design plastic resistance of the cross-section consisting of the effective area of the flanges and the fully effective web - $M_{pl,Rd} = M_{cRd}$ (see Table1).

It is evident, that for this class of beams there is no interaction, because the flanges only can carry the bending moment and the web is resisting the shear. These results consistent with notations (Johansson and Veljkovic, 2009), accented the necessity to check the moment and shear resistances without interaction. By the numerical analysis it is clarified, that the provided height of the cross-section for the discussed beam should be above 300 mm, when reduction of the bending resistance starts.

CONCLUSIONS

The use of CFSS members in building can develop the diversity in steel design. The lack of discussion, explanation and worked examples delays to take advantages of CFSS in comparison with hot rolled sections in Latvia. It is caused also by slow implementation of the Eurocodes (including EC3).

The numerical analysis of the CFSS properties and plotted data for the sections subjected to compression and bending illustrates the influence of variable geometrical proportions. Knowing the preferable section properties, these data can help make a choice for the shape of the section or to improve the properties for non-standard sections. For example, for U-sections the ratio b/h = 0,75...1,5 is recommended in compression as well in bending. Without doubt, edge and intermediate stiffeners of flanges and webs increase the resistance to compression, but a highly stiffened section is less easy to manufacture and often less practicable from the point of connections. Thereby, a compromise between the section efficiency and practicability is often necessary and needs to be studied in further research.

The experimental research approved the method of testing and showed the stability of the acquired parameters, as well that keeping of precision in the tests with CFSS (e.g., symmetry of loading) is of great importance. Comparing with the numerical data shows good agreement.

ACKNOWLEDGEMENTS

The authors are much obliged to the company SIA Ruukki Latvija for providing the specimens for the tests.

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