Acta Technica Napocensis: Civil Engineering & Architecture Vol. 55, No. 3 (2012)
Journal homepage: **http://constructii.utcluj.ro/ActaCivilEng**

Optimized sections for cold formed steel channel profiles under compression and bending according to EN1993-1-3

Paul M. Pernes[1], Zsolt Nagy[2], Cristina Campian[3], Maria Pop[4]

[1, 2, 3, 4] *Technical University of Cluj-Napoca, Faculty of Civil Engineering. 25 G.Barițiu Str., 400027, Cluj-Napoca, Romania*

Received 15 September 2012; Accepted 5 November 2012

Abstract

The paper summarizes the obtained results of a theoretical optimization study of the geometry cold –formed steel open-Channel sections at the Technical University of Cluj-Napoca. The C-sections with lips are analyzed under axial compressive load and pure bending. The evaluation factor of the sections performance is considered to be the carrying capacity calculated according to the EN 1993-1-3 specifications. Based on the obtained results of the parametric studies and also implementing optimized technological principles a list of new C-sections with lips was designed in order to be manufactured. The result shows that C-channel sections with the optimal geometry are performing much better than the existing ones in the Romanian market.

Rezumat

Lucrarea sintetizează rezultatele obținute în urma studiului teoretic de optimizare a geometriei secțiunilor C formate la rece realizat în cadrul Universității Tehnice din Cluj-Napoca. Secțiunile au fost analizate pentru cazul de solicitare la compresiune centrică și respectiv încovoiere pură. Factorul de evaluare a performanței secțiunilor s-a considerat capacitatea portantă a acestora care s-a calculat conform normativului european EN 1993-1-3. În baza rezultatelor obținute prin studiul parametric realizat și prin implementarea principiilor tehnologice de optimizare s-a obținut în final un set nou de secțiuni C dimensionate în vederea producției. Rezultatele indică faptul că secțiunile obținute sunt mai performante decât cele existente în prezent pe piața de profil din România.

Keywords: sections optimization, cold-formed steel channel sections, channel section performance

1. Introduction

Steel construction made by cold form profiles represents one of the most new branches of construction industry been in constant development and expansion.

The research developed in the last decade has led to the elaboration of technical regulation, relationship expressed by engineering calculation have been standardized. The current regulation A.I.S.I, A.S/N.Z.S, Eurocode 3 refers to thin-walled elements calculation by using a method for

---

[*] Corresponding author: Tel./ Fax.: +40-744580145 E-mail address: paul.pernes@ dst.utcluj.ro
[*] Corresponding author: Tel./ Fax.: +40-264-401540 E-mail address: zsolt.nagy@gordias.ro
[*] Corresponding author: Tel./ Fax.: +40-264-401540 E-mail address: cristina.campian@dst.utcluj.ro
[*] Corresponding author: Tel./ Fax.:+40-745262072 E-mail address: maria.pop@dst.utcluj.ro

effective widths of strenght of element stability. This calculation method gradually evolved based on laboratory tests, numerical analytical application (see [1-8] etc).

In parallel with the development of calculation methodologies, the numbers of producers of cold formed sections continues is increasing, competition is pushed to streamline.

In this context the geometry optimization section problem is a topic of great interest to obtain a consumer report-resistance of highest steel consumption. Various assessment methods are used for different scientific works. Studies conducted by Y. S. Tian and T. J. Lu [9], Z. M. Chamberlain Pravia and M. Kripka [10] section C are treated with and without stiffeners subjected to pure compression analytically and experimental. Z section were studied through failure off minimized aria by Anđelić, N., Mitić, V.M., Maneski, T [11] using the method based on multiplier Lagrange. In order to obtain new sectional types, studies have been conducted such as those presented by Lewiński, J., Magnucki, K [12] , Magnucki, K., Paczos, P [13] and R. Kasperska, Magnucki, K., Ostwald, M [14] where are treated sectional variations different typologies that are based on classic sections C or Z.

Currently, thin-walled sections that occur, most common type of structural role in producing buildings stands out are C, Z and Ω. In this paper is presented an optimization study of C section realized to obtain a competitive product. To determine optimal geometric parameters for sections subjected to pure tension and compression a standardized calculation method was used based on effective width included in the European Standard EN 1993-1-3.

2. Sectional effective characteristics for centric bending and compression calculation method

The undertaken study based on the variation analysis of various parameters used to calculate the sectional characteristics. Eurocode 3 offers a calculation method according to an automatic evaluation procedure of the mechanical characteristics of the elements.

According to Annex C and SR EN 03.01.1993 a calculation routine is implemented by the program which describes analytically computing relations for the determination of mechanical characteristics of thin sections of any form. Automatic calculation procedure was composed from the following calculation steps (Figure): (1) Gross characteristics of the section, (2) determining effective width of the flange by stability calculation according to SR EN 1993-1-5:2007 p.4, (3) distorting calculation of the stiffned wall according to SR EN 1993-1-3:2007 : p.5.5.3 which was obtained the reduce thickness wall, (4) For the reduce section with effective flange was calculated the tensile of the extremities of he web for the centric compression case, pure bending for compressed large flange and bending for compressed small flange, (5) determining the effective width of the web from the stability characteristics of the inner wall, (6) for the final stage were obtained entirely effective section, supressed segments were modeled with zero tickness (Figure 1).

Parametric studies were allowed by using automatic calculation of the effective sections in the optimization process. The studied sections were within the norms limits.

3. Optimization process of channel sections

Generally, the optimization process has a multi criteria character. The presented paper aimed to obtain a parametric study of the C section typology with stiffness flanges in order to obtain geometrical efficient conformation. An effective section is characterized on the one hand by a relation raised resistance/weight and on the other hand is adapted to the technological process characterized by minimum losses of material and reduced production time.

The first stage of the study was to fractionate the geometry to a set of typo dimensions. Generally, the range of sections is represented by varying the height (h), currently on the market exist a range of heights of sections well defined. Conservatively we adopted a set of dimensions for web with five different sizes existing established values in the catalogs (h=150 mm, 200 mm, 250 mm, 300 mm, 350 mm).

Starting from these values, providing a sufficient variety of sections, a parametric study was made for the thickness element that is easy to use on the one hand and on the other hand the widths of the flanges and the stiffeners.

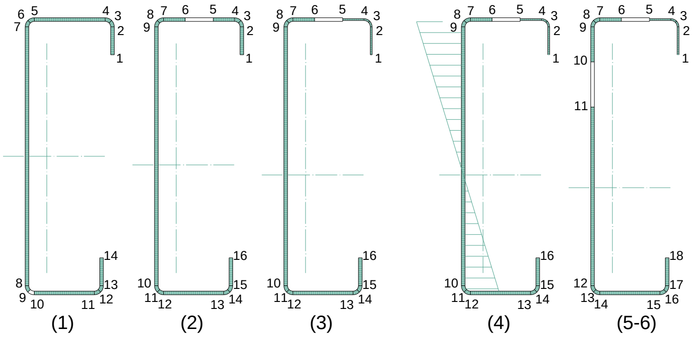


Figure 1. Procedure stages for determining sectional characteristics

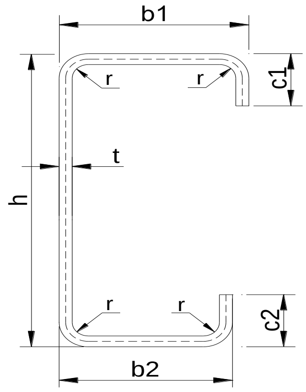


Figure 2. Cross section notations

3.1 Choosing plate thickness

Sectional geometrical parameters, inclusive the plate thickness, will be elected by the technological limits of the tape rolling. The maximum thickness admitted is of 4 mm, which requires an inner radius of connection between wall sections of 4 mm that will keep a constant value for all the used thicknesses.

Parameter of determination the plate thickness, for the entire range of sections, a ratio was chosen $A_{i.eff}$ /$A_{i.brut}$ representing the the index of use for the web wall used for the centric commpresion stress.

The parametric curves obtained through the plate thickness variation are presented in Figure 1. Representing for each version an independent height.

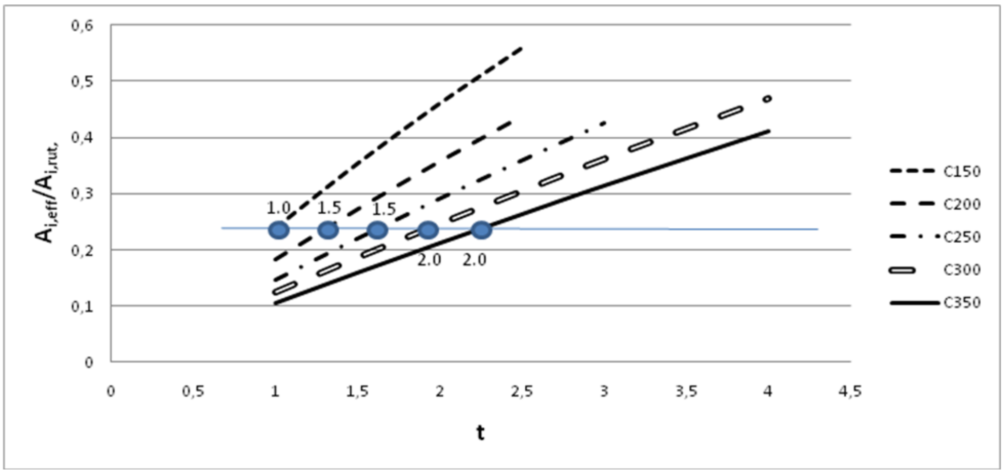


Figure 1. Minimum plate thickness of determination for the range of heights

For a lower limit value by index of Use of 0,25 minimum thickness were determined for each height version (Table 1.) For these values the slenderness web wall fits in the limit t/h ≤ 500 imposed by EC3.1-3.

Table 1.Minimum thickness results according to standard sizes

Section	C150	C200	C250	C300	C350
t_{min}	1.0	1.5	1.5	2.0	2.0

3.2 Determination of the optimal value for the width flange and stiffeners

Flanges dimensions and the marginal stiffness are marked by structural and technological limitation

Technological method of production and equipment characteristics often required through fact sheets of use of the superior limit and that lower wall dimensions. In the conducted study required dimensions limitations included : h = (100-400mm) ; b = (40-100 mm) ; c = (13-30 mm) ; t = (1.5-4 mm).

Sectional profiles C, Z and Ω usually occur with unequal flanges. This results mainly from transport considerations are necessary to stack in a compact manner as the elements. It also notes the need for overlapping elements assembly considerations.

Another aspect targeting dimensional characteristics of the flanges is to reduce the production time. Cold form lamination is a technological process used for large quantities of finite elements, the necessary time production of one unit of product is very small in the calibration band of a certain size section.

The recalibration process for a different heights section is a time-consuming, leading to a substantial increase of the average production per unit. To reduce this time-consuming of calibration is adopted for different heights sections for the same flange width.

A final criterion for choosing width flange is based on the reduction consideration of the material losses. In this sense the flange sizes are chosen so that tola can be partitioned an integer number of strips, in this way technological material losses are greatly diminished. Regarding the stiffneres, this will choose different for each height version of the section and for each version of plate tickness. This results from optimization considerations of the steel consumption. To reduce the losses is preferable that the strips plate for all tickness versions to be equal. Therefore to keep the outer constant dimensions for different plate thicknesses, the width of the gross strips would result with significantly different widths. These small fluctuations of sizes will be corrected by adopting different width of stiffeners.

From the technological point of view some limits are imposed because of the wall dimensions of the composed section, with the value of 30mm by data sheet of the lamination process. The influence of stiffness dimensions are studied for pure bending stress of C section with large flange compressed and dimensions from Fig.4. The ratio variation W_{eff} /A_{brut} were monitored along with increasing the dimensions of the bulges ”c”, this fitting in the european norms specifications ($0.2 \leq c/b \leq 0.6$, şi $c/t \leq 50$). In the chart of the Fig. 5 an optimal ratio can be oberved c/b=0,52, this ratio extends its validity and for plate tickness of 1.5 si 2.5 mm.

Although the share of bulges dimension, is represented as a fraction from the width flanges, in the evaluation of W_{eff} is only 7%, this will be chosen with values as close as possible of the maximum represented in Fig.5. In order to comply the maximum technological admited dimension of the lamination strip (30 mm), the ratio c/b was finally chosen with an avarage value of 0.43.

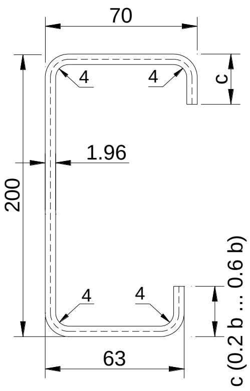


Figure 4. Section dimensions

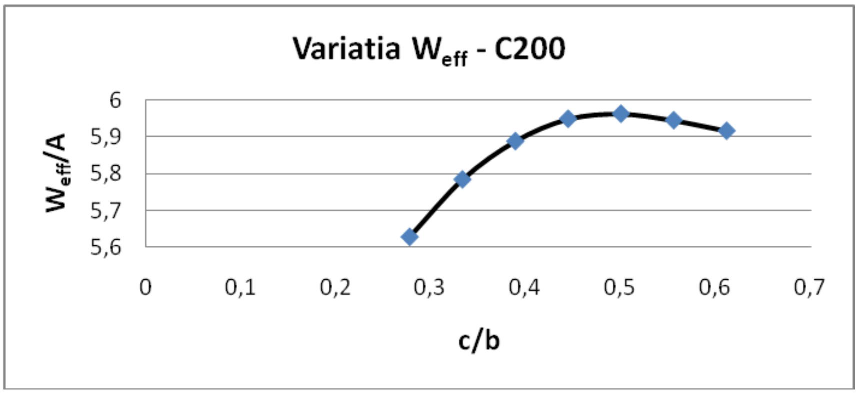
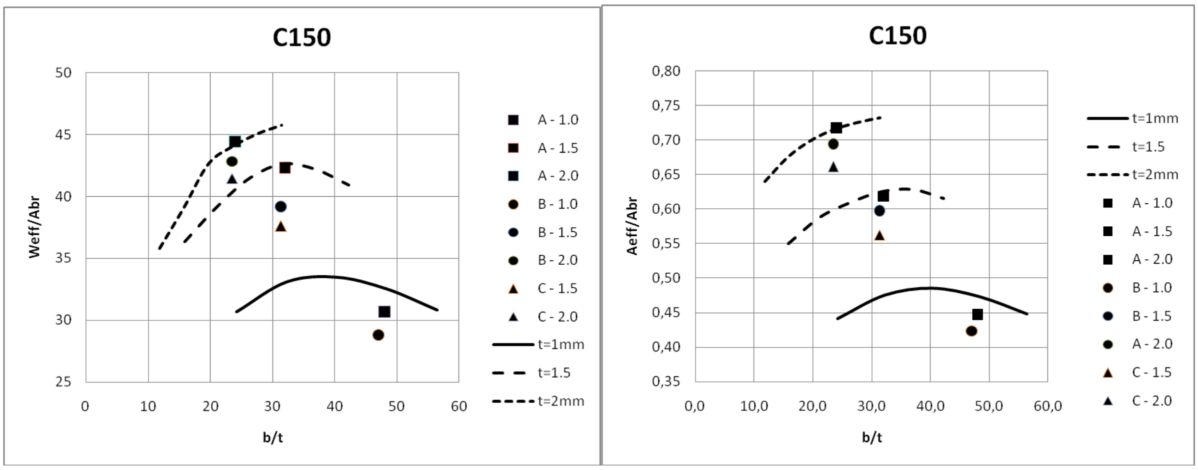
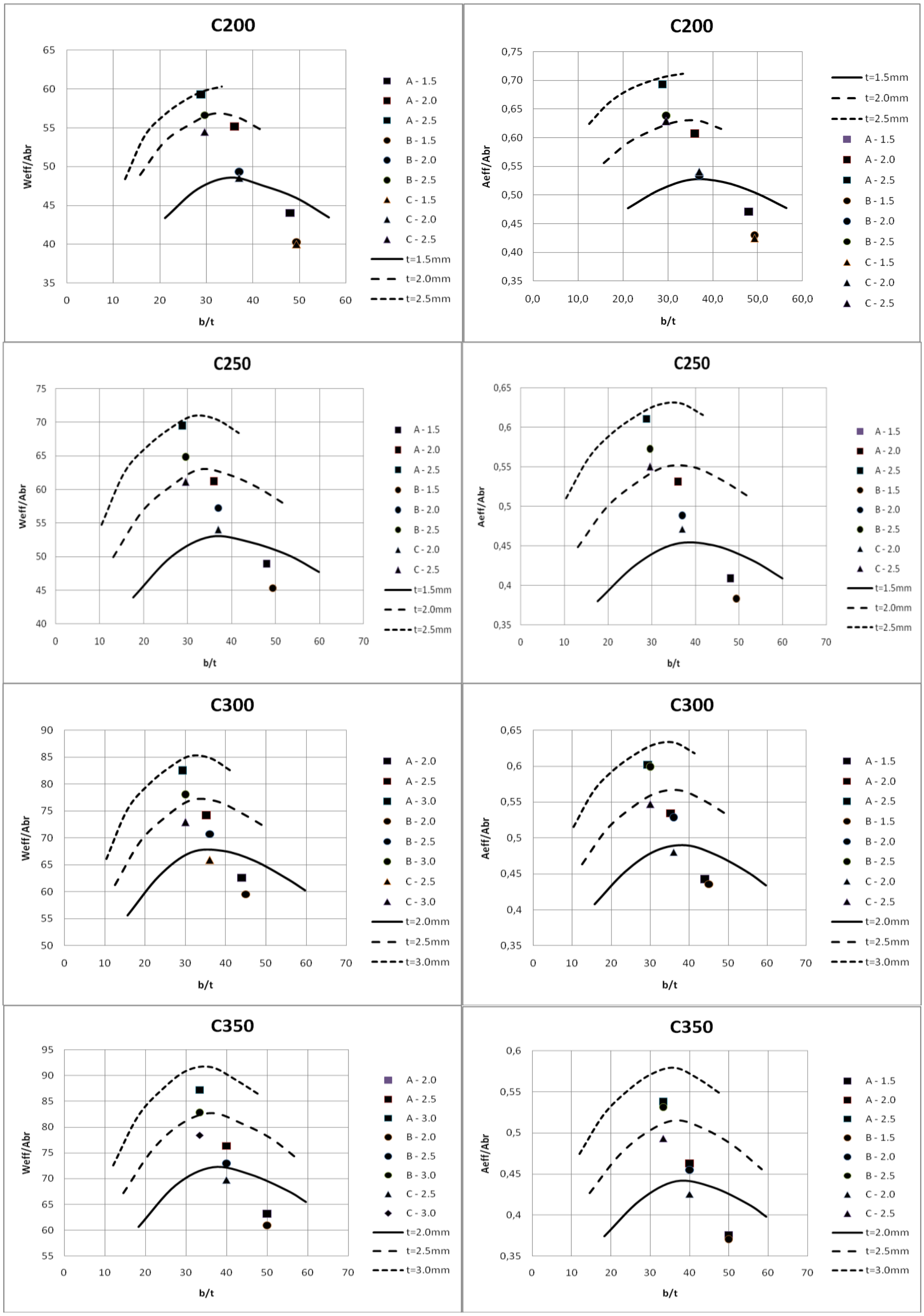


Figure 5.The influence of the stiffness dimension on the resistance of the section

Optimal width of the flange is determinated by studying efficiency index represented through the ratio: A_{eff}/A_{brut} and W_{eff}/A_{brut}. This indices quantifies the yielding section for the centric compression stress and that pure bending (with the large flange compressed) for all height ranges and all the variations of corresponding tickness where the parameter that ranged was the large flange width as a ratio(b_1/t) şi ($b_2=b_1$-7mm).
The obtained graphs for the ranges of heights can be seen in Figure 6.





- A- calibrated sections in this study
- B-produced sections by the company I
- C- produced sections by the company II

Figure 6.Optimization curves

It is noted that optimal width of the large flanges of the C profile represented in the ratio form (b_1/t)

focused around the value b/t=35 for all height ranges and tickness for both indices efficiency tracked. Although for each determined value offers a maximum efficiency of profiles, due to limitations previously presented this cannot be achieved but it is a good landmark.

Therefore for each height was chosen a fixed width calculated so that the ratio b/t=35 to be achieved average thickness used for that height. The calibrated sections by optimization process were found in the graph from the Fig. 6 and marked with (A). These were compared with the existing ones on the profile market emitted by other companies marked on the chart with B and C. The comparison was made by studying efficiency indices A_{eff}/A_{brut} şi $W_{eff}/A_{brut.}$

It can be seen that the company sections (B) is very close to the top indicated by analitical calculation, but fot the ones from the (C) company have characteristics well below (B) company. The resistance variation is still called into question because sectional characteristics of the elements produce by the two companies (B and C) are almost identical. Recommendations that we enounced set follow to a ratio b/t that are closer to the maximum, the obtained results in the A_{eff} calculation and that W_{eff} stood better on the optimization curves than the analyzed companies.

For the compression stress in case of the heights sections (C300 , C350) the obtained results by the optimization process and the two products of the B company are very similar, it can be observed a resistance variation for bending stress.

4. Conclusions

An optimization process is presented focused on the C sections with stiffened flanges. Through this optimization process has wanted to obtain a ratio (resistance/ steel consumption) as high, reduce production time and lower material losses.
The first step of the study is to determine structural and tehnological limitations that marks the elements production, transport, montage process. This stage is particularly important therefore was treated in detail.

In the second stage of the study was conducted an optimisation process based on indices maximization of efficiency. These indices were represented as a ratio between the effective sizes of the sections and the gross section and calculated for compression stress and respectively pure bending.

Effective sizes were calculated for a large number of geometrical conformation represented by variations of wall dimensions. For this purpose was developed a calculation procedure which included analytical relations given by the european noms including informative character of the Annex C of SR EN 1993-1-3, which allowed dividing section into strips to calculation of all sectional characteristics. For this study were used the effective sizes of the walls respectively $A_{eff\ and}$ $W_{eff.}$

The range of represented sectors by their height was chosen based on the headings existing on the profile market. The remaining geometry determined the thickness, widths of the flanges and the bulges were optimized through a parametric study. The obtained results have close values from those represented by maximal curves but do not fall entirely perfectly due to structural limitations. This compromising strength is accepted to obtain minimum technological losses (time, material).
In comparison with other sections with the same typology produced by the existing companyes now on the profile market, was noted that the proposed sections resistance is greater with 5% toward company B sections and respectively 11% to the C company. In case of (C) company were noticed mistaken tables, which causes a loss of 6% engineering calculations.

In conclusion the study obtained an optimized sectional geometries with C tipology and stiffened flanges. The obtained data have a great ratio resistance/ weight compared to many of the existing market profile and the lamination process was streamlined by reducing material losses and reducing the duration of production.

5. References

[1] Lau, S.C.W. and Hancock, G.J. (1987), "Distortional Buckling Formulas for Channel Columns", Journal of Structural Engineering, ASCE, Vol. 113, No.5, pp 1063-1078

[2] L K Seah and J Rhodes, " Behaviour of channel beams with unbraced compression flanges", Tenth International Specialty Conference on Cold-formed Steel Structures, St. Louis, Missouri, U.S.A., October 23--24, 1990, pp 335-361

[3] Y.B. Kwon G.J. Hancock (1992), "Design of channels against distortional buckling" Eleventh International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri, U.S.A., October 20-21,1992, pp 323-350

[4] Maria E. Moreyra and Teoman Peköz , " Finite element studies on lipped channel flexural members", Twelfth International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri, U.S.A., October 18-19, 1994, pp57-74;

[5] Maria E. Moreyra and Teoman Peköz , " A design procedure for lipped channel flexural members", Twelfth International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri, U.S.A., October 18-19, 1994, pp75-90;

[6] Ben Young & Kim J. R. Rasmussen, " Sidft of the effective centroid of channel columns" , Fourteenth International Specialty Conference on Cold-Fonned Steel Structures, St. Louis, Missouri U.S.A., October 15-16, 1998, pp265-287;

[7] Ben Young & Jintang Yan, " Finite element analysis of cold-formed channel columns", Fifteenth International Specialty Conference on Cold-Fonned Steel Structures, St. Louis, Missouri U.S.A., October 19-20,2000, pp281-305;

[8] Fang Yiu, Teoman Peköz, " Design of Cold-Formed Steel Plain Channels", Fifteenth International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri U.S.A., October 19-20,2000, pp13-22;

[9] Y. S. Tian and T. J. Lu : "Minimum weight of cold-formed steel sections under compression", Thin-Walled Structures, Volume 42, Issue 4, April 2004, Pages 515-532

[10] Z. M. Chamberlain Pravia and M. Kripka: "Numerical and experimental optimization of cold formed steel c-sections under compression" REM: R. Esc. Minas, Ouro Preto, jul. set. 2008-61(3): 371-377,

[11] Andelić, N., Mitić, V.M., Maneski, T.: "An approach to the optimization of a thin-walled Z-beam" Strojniski Vestnik/Journal of Mechanical Engineering, 2009, pp. 742-748

[12] Lewiński, J., Magnucki, K.: "Optimization of anti-symmetrical open cross-sections of cold-formed thin-walled beams", Journal of Theoretical and Applied Mechanics, 2009, 47 (3), pp. 553-571

[13] Magnucki, K., Paczos, P.: "Theoretical shape optimization of cold-formed thin-walled channel beams with drop flanges in pure bending", Journal of Constructional Steel Research 2009, 65 (8-9), pp. 1731-1737

[14] R. Kasperska, Magnucki, K., Ostwald, M.,.: "Bicriteria Optimization of Cold-Formed Thin-Walled Beams with Open Cross Sections" , 6Th World Congresses of Structural and Multidisciplinary Optimization , Rio de Janeiro, 30 May - 03 June 2005, Brazil

[15] Lee, J., Kim, S.-M, Seon Park, H.: "Optimum design of cold-formed steel columns by using micro genetic algorithms", Thin-Walled Structures 2006, 44 (9), pp. 952-960

[16] ENV 1993-1-3 EUROCODE 3 „Design of Steel Structures, Part 1 - 3: General Rules,Supplementary Rules for Cold-Formed Thin-Gauge Members and Sheeting", CEN/TC 250/SC3 –European Committee for Standardisation, Brussels, 1996.

[17] ENV 1993-1-5 EUROCODE 3 - „Design of steel structures, Part 1 - 5: - Plated structural elements",European Committee for Standardisation, Brussels, 2005.

[18] A.I.S.I. – American Iron and Steel Institute - „Cold-Formed Steel Design Manual", Washington,D.C., 1996.

[19] A.S./N.Z.S. 4600 – Australian Standards/New Zealand Standards „Cold-formed Steel Structures",Sydney, Australia,1996.