Proceedings of the
Annual Stability Conference
Structural Stability Research Council
Pittsburgh, Pennsylvania, May 10-14, 2011

Parameters for the optimal section design of steel cold-formed channel in bending

Z.M. Chamberlain Pravia[1], M. Kripka[2], R. Bordignon[3]

Abstract

The present study aim to show a numerical study that concerns with the optimal design of cold-formed channel section subjected to bending, with and without stiffeners. The main goal is to offer parameters for the optimal design for that kind of cold-formed profiles, with the objective to reduce the cross section element. The methodology used is based on the effective section method (ESM), referenced by the revision of the Brazilian Standard for cold-formed Steel Structures ABNT NBR 14762, "Design of Cold-formed Steel Structures". Numerical results achieved in this job evidence economy in section design by the application of optimization techniques to the problem proposed..

1. Introduction

Cold-Formed steel sections has been used in large scale in building industry, mainly by the easy way to produce them and by the several alternatives to the section geometry dimensions and shape. The search by the maximum structural efficiency, associated to the low consume of material, is one of the big challenges of structural engineering, making possible several investments form the point of view of economy, safe and aesthetic. The proposal of this study aims to apply optimization techniques for the design of Cold-formed channel section of steel subjected to pure bending, with the objective to get several parameters for the minimum section of the profile, i.e., reduction of material consumption. The sections evaluated are channel with or without stiffeners, which are large used as purlins and other similar flexure elements. The resistance load used in the objective function, for the optimization process, is based on the effective section method (ESM) according the revision of the Brazilian Standard ABNT NBR 14762 (2009) From the formulation developed, optimal dimensions for the section were obtained for channel sections with and without stiffeners, subjected to increase loads.

Several references can be found focusing on the optimization of steel sections, with major or little simplification degree, as several sections, loads and optimization techniques. Therefore, the optimization of cold-formed profiles still is in incipient. Also, the authors does not have notices

---

[1] Graduate Research Profesor, Passo Fundo University, <zacarias@upf.br>

[2] Graduate Research Professor, Passo Funbdo University, <mkripka@upf.br>

[3] Graduate student, Passo Fundo Uniersity, school of Engineering and Architecture, <bordignon@upf.br>

for the application of the present approach (effective section method) based on Brazilian standard for cold-formed steel members ABNT NBR 14762 revision for the optimization objective function, mainly the methods used are effective width method (EWM) and direct strength method (DSM).

Seaburg e Salmon [1] develop studies on minimal weight for hat sections using direct and gradient optimization methods, showing only one example due to the complexity of the problem.

Dinovitzer [2] optimize the stiffener length of a cold-formed channel sections based on the Canadian Standard. The process used was based not in the section resistance, but in the ability of increase the resistance bending moment while the cross section was minimized.

Castelluci et al [3] shown a channel section with stiffeners in flange and two intermediates in web subjected to bending, Those authors confirm a squash load greater than 15% from the generic original section, with Just 5% of increase in section area. In her work authors does not mention which optimization technique was applied.

Adeli e Karim [4] develops a neural network for no-linear problems, and applied to simple beams with I and Z sections. They used the allowable Strength Design with effective widths acording to AISI.

Al-Mosawi e Saka [5] include in its procedure the warping stress and obtained optimal channel sections symmetric and non-symmetrical and Z sections subjected to uniform transverse loads. However, in the optimization process was only considered normal stress and displacements.

Tian [6] presented a theoretical and numerical study to get minimum weight of channel section subjected to compression prescribing a fixed length and the axial load. For the project load the British standard BS 5959 was used, and a non-linear method Square Quadratic Programation (SQP) of optimization. Also presented, a simplified method, in which the buckling stresses for different modes are matched. This author conclude that, in channel sections, exists a optimal parameter among web and flanges widths. The sections studied by Tian[6] provided increase of about 50% in section capacity with non increase of section size.

Kripka e Guerra [7] developed a formulation for determining the optimum configuration of the walls for steel rectangular silos, having as project variables the angle, the wave length and the width of the wall. The objective function was solved with the use of the Excel solver.

Pravia e Kripka [8] studied the optimization of compressed sections channel profiles with and without edge stiffeners, using the American Standard AISI(2001) with lengths and loads predefined. The optimization was developed trough the simulated annealing method (SA).

In the following section describes briefly the problem under study, including the procedures proposed by the revision of the Brazilian Standard ABNT NBR 14762[9] and also the optimization formulation. The effective section method, is based originally it the work developed by Batista[10].

In the third part of this work are presented the results of numerical simulations carried out to determine the minimum gross section area of section profiles with and without edge stiffeners (lips) subjected to simple bending. These results were obtained with the use of Microsoft Excel Solver. The work ends with some final considerations.

2 Problem description

2.1 Design of channel with and without stiffeners subjected to bending

The design load capacity of the profiles was based on the proposed revision of the Brazilian standard NBR: 14762 [9], described briefly below.

In Section 9.8 of the supra cited standard, the bending moment resistance design (Mrd) must be taken as the lowest calculated value that does not take place in the beginning of the effective yield section, the lateral Torsional buckling and distortional buckling, where applicable.

The initial yield of effective section, according to the proposed revision should be calculated according to the equations 1 to 4.

$$M_{Rd} = W_{ef} f_y / \gamma \tag{1}$$

where:

$$W_{ef} = W\left(1 - \frac{0,22}{\lambda_p}\right)\frac{1}{\lambda_p} \le W \tag{2}$$

$$\lambda_p = \left(\frac{W f_y}{M_\ell}\right)^{0,5} \tag{3}$$

$$M_\ell = k_\ell \frac{\pi^2 E}{12(1-\nu^2)(b_w/t)^2} W_c \tag{4}$$

The coefficient of local buckling for the section, kl, can be calculated by the expressions listed in Table 1 or obtained directly from Table 2. For beams with doubly symmetric or simple symmetric section, subject to bending around the axis of symmetry (x axis), can be obtained from the equations 5 to 8.

$$M_{Rd} = \chi_{FLT} W_{c,ef} f_y / \gamma \tag{5}$$

$$\gamma = 1,10$$

$$W_{c,ef} = W_c\left(1 - \frac{0,22}{\lambda_p}\right)\frac{1}{\lambda_p} \le W_c \tag{6}$$

$$\lambda_p = \left(\frac{\chi_{FLT} W_c f_y}{M_\ell}\right)^{0,5} \tag{7}$$

$$M_\ell = k_\ell \frac{\pi^2 E}{12(1-\nu^2)(b_w/t)^2} W_c \tag{8}$$

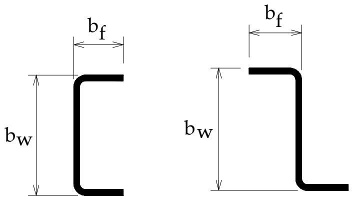
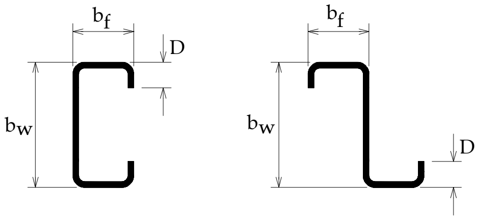
- for $\lambda_0 \le 0,6:$ $\chi_{FLT} = 1,0$

- for $0,6 < \lambda_0 \le 1,336:$ $\chi_{FLT} = 1,1,1(1 - 0,278\lambda_0^2)$

- for $\lambda_0 \ge 1,336:$ $\chi_{FLT} = 1/\lambda_0^2$ (9)

$$\lambda_0 = \left(\frac{W_c f_y}{M_e}\right)^{0,5} \tag{10}$$

Table 1 – Local buckling factor k_l for the complete section in bending in relation to the major inertia axis.

Case a	U and Z section without lips  $k_l = \eta^{-1,843}$ $(0,1 \le \eta \le 1,0)$
Case b	U and Z section with lips  The expressions are valids for $0,2 \le \eta \le 1,0$ and for the values of μ indicated $k_\ell = a - b(\mu - 0,2)$ $a = 81 - 730\eta + 4\,261\eta^2 - 12\,304\eta^3 + 17\,919\eta^4 - 12\,796\eta^5 + 3\,574\eta^6$ $b = 0$ para $0,1 \le \mu \le 0,2$ e $0,2 \le \eta \le 1,0$ $b = 0$ para $0,2 < \mu \le 0,3$ e $0,6 < \eta \le 1,0$ $b = 320 - 2\,788\eta + 13\,458\eta^2 - 27\,667\eta^3 + 19\,167\eta^4$ para $0,2 < \mu \le 0,3$ e $0,2 \le \eta \le 0,6$
NOTE 1 b_f, b_w and D are the nominal dimensions of the elements, according to the indicated in each associated figure. NOTE 2 $\eta = b_f / b_w$. NOTE 3 $\mu = D/b_w$.	

Source: Project Revision of Brazilian ABNT:NBR 14762

Table 2 – Local buckling factor k_l for the section subjected to bending in relation to major inertia axis.

$\eta = b_f / b_w$	**Case a**	**Case b**			**Case c**
	U and Z without lips	U and Z with lips			Hollow rectangular section (welded)
		$\mu \leq 0,2$	**$\mu = 0,25$**	**$\mu = 0,3$**	
0,2	18,4	32,0	25,8	21,2	31,0
0,3	9,6	29,3	23,8	19,7	28,9
0,4	5,6	24,8	20,7	18,2	25,6
0,5	3,6	18,7	17,6	16,0	19,5
0,6	2,6	13,6	13,3	13,0	14,2
0,7	1,9	10,2	10,1	10,1	10,6
0,8	1,5	7,9	7,9	7,9	8,2
0,9	1,2	6,2	6,3	6,3	6,6
1,0	1,0	5,1	5,1	5,1	5,3

NOTE 1 b_f, b_w and D are the nominal width of the flange, web and the stiffener, respectively.
NOTE 2 $\mu = D/b_w$.
NOTE 3 For intermediate values use linear interpolation.

Source: Project Revision of Brazilian ABNT:NBR 14762 (2009)

For bars with double symmetric section or mono-symmetric, subjected to bending over the axis of symmetry, (axis x):

$$M_e = C_b r_0 (N_{ey} N_{ez})^{0,5} \quad (11)$$

$$C_b = \frac{12,5 M_{\max}}{2,5 M_{\max} + 3M_A + 4M_B + 3M_C} \quad (12)$$

$$r_0 = \left[r_x^2 + r_y^2 + x_0^2 + y_0^2\right]^{0,5} \quad (13)$$

$$N_{ey} = \frac{\pi^2 E I_y}{(K_y L_y)^2} \quad (14)$$

$$N_{ez} = \frac{1}{r_0^2}\left[\frac{\pi^2 E C_w}{(K_z L_z)^2} + GJ\right] \quad (15)$$

For the bars subject to distortional buckling, the bending moment resistance design should be determined by the expressions of equations 16 to 18.

$$M_{Rd} = \chi_{dist} W_c f_y / \gamma \qquad \gamma = 1,10 \quad (16)$$

$$\chi_{dist} = 1 \quad \text{para} \quad \lambda_{dist} \leq 0,673$$

$$\chi_{dist} = \left(1 - \frac{0,22}{\lambda_{dist}}\right)\frac{1}{\lambda_{dist}} \quad \text{para} \quad \lambda_{dist} > 0,673 \quad (17)$$

$$\lambda_{dist} = \left(W_c f_y / M_{dist}\right)^{0,5} \tag{18}$$

Table 3 – Mininal values for the relation D/bw of U with lips section and Z section .

b_f/b_w	b_w/t				
	250	**200**	**125**	**100**	**50**
0,4	0,05	0,06	0,10	0,12	0,25
0,6	0,05	0,06	0,10	0,12	0,25
0,8	0,05	0,06	0,09	0,12	0,22
1,0	0,05	0,06	0,09	0,11	0,22
1,2	0,05	0,06	0,09	0,11	0,20
1,4	0,05	0,06	0,09	0,10	0,20
1,6	0,05	0,06	0,09	0,10	0,20
1,8	0,05	0,06	0,09	0,10	0,19
2,0	0,05	0,06	0,09	0,10	0,19
NOTE 1 b_f, b_w, and *D* are elements nominal dimensions, according with the indicated of Figures of Table 9. NOTE 2 For intermediary values use linear interpolation.					

Source: Revision Project of Brazilian ABNT:NBR 14762 (2009)

For stiffened channel and stiffened section Z beams, if the ratio D/bw is equal or greater than the values shown in Table 3, the verification of the distortional buckling may be waived.

2.2 Optimization process formulation

An optimization problem aims to gets the extremes of a particular function, i.e., determine the set of variables, of which this function is dependent, in order to find its maximum or minimum. The optimization problem can be stated according to the equations 19 to 23.

Minimize (or maximize):

$F(X)$ (Objective Function) (19)

Subject to:

$g_j(X) \leq 0$ $j = 1, m$ (inequalities restrictions) (20)

$h_k(X) = 0$ $k = 1, l$ (equalities restrictions) (21)

$X_i^l \leq X \leq X_i^u$ $i = 1, n$ (lateral restrictions) (22)

$$\text{where } \mathbf{X} = \begin{Bmatrix} X_1 \\ X_2 \\ X_3 \\ \vdots \\ X_n \end{Bmatrix} \quad \text{(Project variables)} \tag{23}$$

In equation 22, the letters 1 and u denotes lower and upper limits, respectively, and which values that can be assumed by the project variables.

For the present study, once known the solicitation Msd bending, the idea is to research the dimensions of the cross section area of the profile that resists the applied load with the lowest consumption of material (minimum section gross Ag). Thus, referring to the dimensions of A, B, C and t (as shown in Fig.1), the objective function to be minimized can be written according to equations 24 to 30.

$$A_g = f(A, B.C, t)) \qquad (24)$$

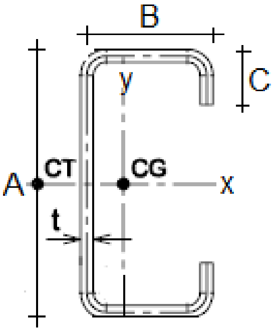


Figure 1 – U section

The Gross section area Ag can be rearranged has an explicit function of the Project variables:

$$A_g = t[a + 2b + 2u + \alpha(2c + 2u))] \qquad (25)$$

where:

$$a = A - (2r + t)) \qquad (26)$$

$$b = B - \left[r + \frac{t}{2} + \alpha\left(r + \frac{t}{2} \right) \right] \qquad (27)$$

$$c = \alpha\left[C - \left(r + \frac{t}{2} \right) \right] \qquad (28)$$

$$u = \frac{\pi r}{2} \qquad (29)$$

$$\alpha \left\{ \frac{1 \rightarrow C \neq 0}{0 \rightarrow C = 0} \right\} \qquad (30)$$

To simplify the process, the bending radius r is considered equal to the thickness t. Initially, all dimensions were considered as continuous variables. In a second analysis, the thicknesses were limited to those found commercially (1.0 mm, 1.2 mm, 1.5 mm, 2.0 mm and 2.25 mm).

The lower and upper limits for each dimension were defined in terms of manufacturing limitations and recommendations of the Brazilian Standard NBR 6355:2003, "Cold-Formed steel structural – Standards sections", and are given by intervals expressed in Equations 31 to 34.

$50 \text{ mm} < A < 300 \text{ mm}$ (31)

$$30 \text{ mm} < B < A/2 \text{ mm} \quad (32)$$

$$50 \text{ mm} < A < 300 \text{ mm} \quad (33)$$

$$1 \text{ mm} < t < 25 \text{ mm} \quad (34)$$

In addition to the dimensional restrictions, also the problem has a restriction on bending design capacity of the section, MRd, it has to be equal or greater than the bending applied Msd. (Equation 35).

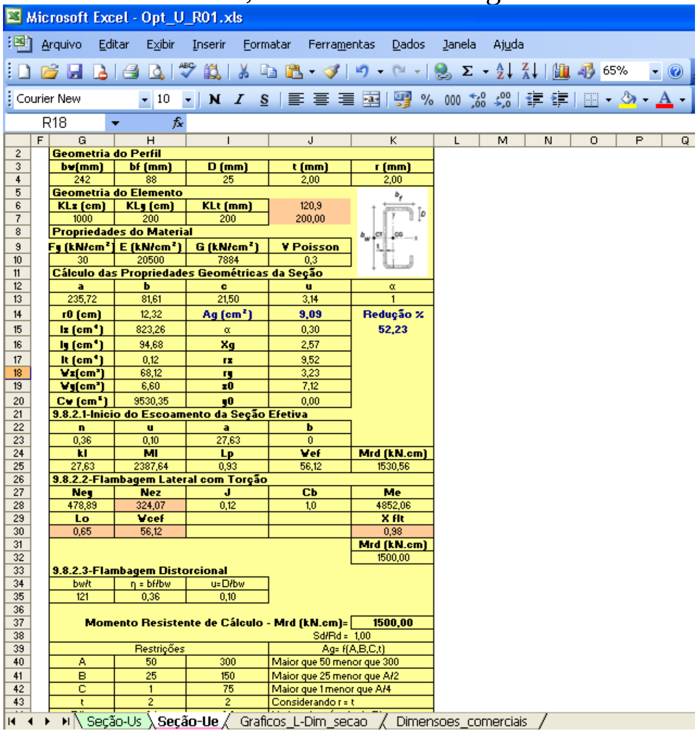
$$M_{Sd} \leq M_{Rd} \quad (35)$$

Thus, a profile with the dimensions of the section satisfying the limits proposed, as well as bending capacity than the applied may be considered as a feasible solution to the optimization problem. The goal, therefore, is to find, among all feasible solutions, which corresponds to the lower consumption of steel material.

Once formulated the problem, several processes are available to achieve the solution, and the choice depends basically on the environment in which the search takes, the goal to be achieved, the characteristics of variables and conditions that must be accepted by the solution. For the proposed formulation, an implementation was made in Microsoft Excel Solver, which is a tool provided with the spreadsheet in Microsoft Excel. Solver code incorporates the non-linear optimization method based on the Generalized Reduced Gradient (GRG2). The option for the use of this tool was based mainly on its wide availability and ease of use. Solver has been used successfully in other problems of structural optimization, as in the study by Kripka and Guerra [7] for structural optimization of trapezoidal and zigzag walls of silos.

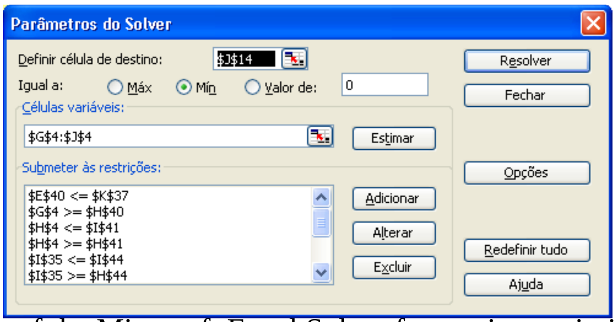
Figure 2 shows the spreadsheet developed for the optimization of profiles with lips.

In this worksheet, from the input data (geometry and material), are calculated the properties of the corresponding profile, and its bending capacity. These data, together with the restrictions of the problem, feed the Solver, which are defined as parameters for optimizing the objective, the variables and constraints, as illustrated in Figure 3.



	G	H	I	J	K
2	Geometria do Perfil				
3	bw(mm)	bf (mm)	D (mm)	t (mm)	r (mm)
4	242	88	25	2,00	2,00
5	Geometria do Elemento				
6	KLz (cm)	KLy (cm)	KLt (mm)	120,9	
7	1000	200	200	200,00	
8	Propriedades do Material				
9	Fy (kN/cm²)	E (kN/cm²)	G (kN/cm²)	V Poisson	
10	30	20500	7884	0,3	
11	Cálculo das Propriedades Geométricas da Seção				
12	a	b	c	u	α
13	235,72	81,61	21,50	3,14	1
14	r0 (cm)	12,32	Ag (cm²)	9,09	Redução %
15	Iz (cm⁴)	823,26	α	0,30	52,23
16	Iy (cm⁴)	94,68	Xg	2,57	
17	It (cm⁴)	0,12	rz	9,52	
18	Wz(cm³)	68,12	ry	3,23	
19	Wy(cm³)	6,60	z0	7,12	
20	Cw (cm⁶)	9530,35	y0	0,00	
21	9.8.2.1-Inicio do Escoamento da Seção Efetiva				
22	n	u	a	b	
23	0,36	0,10	27,63	0	
24	kl	Ml	Lp	Wef	Mrd (kN.cm)
25	27,63	2387,64	0,93	56,12	1530,56
26	9.8.2.2-Flambagem Lateral com Torção				
27	Ney	Nez	J	Cb	Me
28	478,89	324,07	0,12	1,0	4852,06
29	Lo	Wcef			X flt
30	0,65	56,12			0,98
31					Mrd (kN.cm)
32					1500,00
33	9.8.2.3-Flambagem Distorcional				
34	bw/t	η = bf/bw	u=D/bw		
35	121	0,36	0,10		
36					
37	Momento Resistente de Cálculo - Mrd (kN.cm)=				1500,00
38				Sd/Rd =	1,00
39	Restrições			Ag= f(A,B,C,t)	
40	A	50	300	Maior que 50 menor que 300	
41	B	25	150	Maior que 25 menor que A/2	
42	C	1	75	Maior que 1 menor que A/4	
43	t	2	2	Considerando r = t	

Figure 2 – Worksheet developed in Microsoft Excel (U sections with lips)


Parâmetros do Solver

Definir célula de destino: $J$14

Igual a: ○ Máx ● Mín ○ Valor de: 0

Células variáveis: $G$4:$J$4

Submeter às restrições:

$E$40 <= $K$37
$G$4 >= $H$40
$H$4 <= $I$41
$H$4 >= $H$41
$I$35 <= $I$44
$I$35 >= $H$44

Figure 3 – Parameters of the Microsoft Excel Solver for section optimization

3 Numerical results

The following are some of the results from the implementation of the formulation of the problem for minimizing the area of the profile section. As parameters of material in all cases studied, were used structural steel with E = 200 GPa, Poisson's ratio ν = 0.3 and yield stress fy = 250 MPa. Initially, we attempted to scale a profile of a simple channel simple supported beam subjected to a load uniformly distributed along the span. The value of the linear load calculation applied was 1.2 kN / m For this loading spans were considered from 4000 to 1000 mm, with multiples of 100 mm. For all the spans, a lateral bracing restriction was considered every 2000mm.

Starting from different initial solutions was searched optimal profiles with and without stiffeners. Table 4 presents the results of the minimum gross area Ag obtained for both profiles optimized without stiffeners (U) and for profiles with optimized stiffeners (Ue) for different spans and their maximum applied bending Msd. These data are presented graphically in Figure 4.

In lieu of results of Table 4 and Figure 4, a large reduction in the cross section with the use of lips (edge stiffeners) was observed. In the last line of Table 4 presents the data of percentage reduction in consumption of material between the profiles without lips (U) and with lips (Ue). The reduction varied between 13.2 and 19.8%, i.e., profiles with optimized stiffeners allowed to get an average savings of material more than 17% in section. Thus confirms the observation that edge stiffeners are fundamental in improving the performance of the profile also in bending. Similar results had been obtained for sections subjected to compression in previous studies from Chamberlain and Kripka [8].

Table 4 – Values of minimun Gross area Ag for the sections and bending moments.

Span (m)	4,00	5,00	6,00	7,00	8,00	9,00	10,00
Msd (kN.cm)	240	375	540	735	960	1215	1500
U (cm²)	3,76	4,93	5,95	7,38	8,47	9,59	10,47
Ue (cm²)	3,09	3,99	4,95	5,92	7,02	8,00	9,09
%Reduction Ue/U	17,8	19,1	16,8	19,8	17,1	16,6	13,2

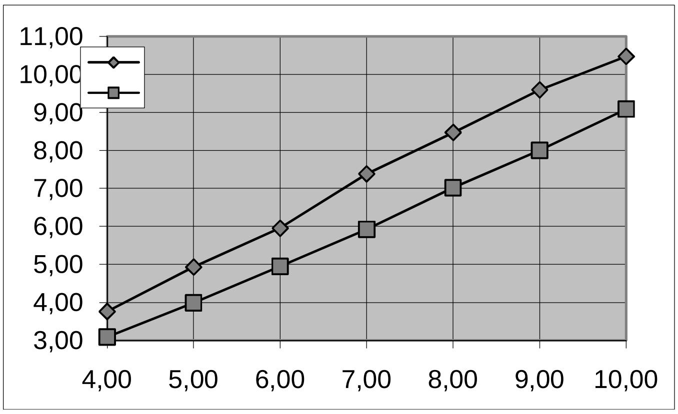


Figure 4 – Comparison of gross area section of channel optimized with lips (Ue) and without lips (U)

The results obtained from simulations carried out with consideration of continuous variables were further compared with the optimal values of limiting the thickness to those found commercially, namely, 1.0 mm, 1.2 mm, 1.5 mm, 2,0mm and 2.25 mm. It was observed that the results showed no significant change.

In order to provide subsidies for pre-sizing profiles subjected to bending, Figure 5 shows the relationship between the span length and the corresponding optimum height. For the channel profiles optimized without lips a relation of L / bw resulted in an average of 24. For the same profiles, but with lips, this relationship was an average of 36. As a reference, Bellei [11] gives this relationship as being equal to 40 for rolled channel profiles used as purlins. Additionally, the results indicate that the existences of stiffeners, and the reduction in the section of the profile, yet allow a significant reduction in the height of the section.

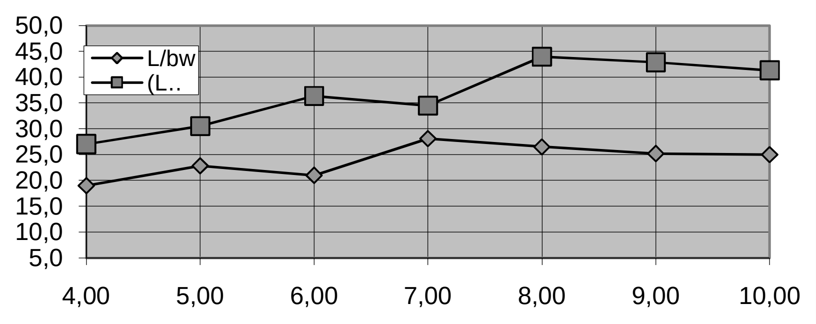


Figura 5 – Ratio of height of section to span length for the channel optimized profiles with lips and without Lips.

Figures 6 and 7 show the ratios obtained for the spans studied, the width of the flange bf divided by the height of the web bw for optimized profiles, respectively with and without stiffeners. It is observed that, for sections without stiffeners, the optimal relation relationship bf/bw ranged between 0.16 and 0.26, with a mean value of 0.22. And for the channels with lips this relation less variation, with values between 0.36 and 0.40 (average 0.36).

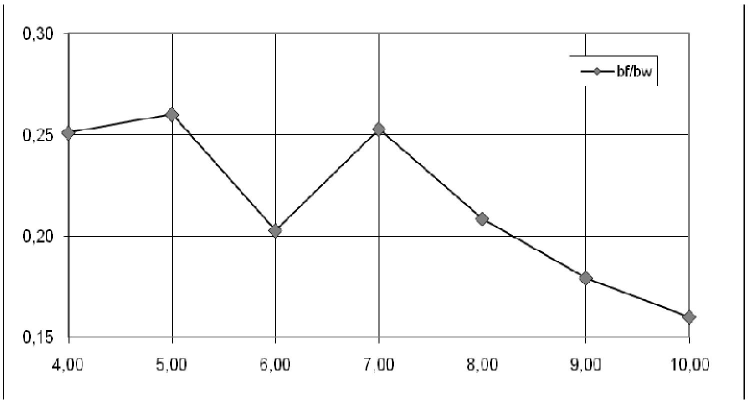


Figure 6 – Relation of flange width to the web width (sections without lips)

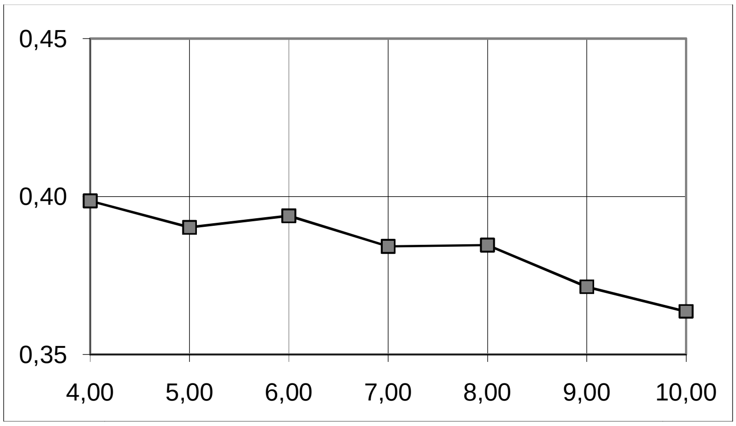


Figure 7 – Relation of flange width to the web width (sections with lips)

In all the cases studied, the relationships D/bw and bf/bw, was in the limits of the Brazilian Standard revision project ABNT NBR 14762, not needing to do a check for the occurrence of distortional buckling.

4 Final considerations

This study presented results of channels profiles with or without edge stiffeners subjected to bending, as analyzed using the design method of effective sections introduced in the draft project of Brazilian standard NBR 14762. The objective was to minimize the area of gross section, with the design variables height, width, thickness and length of the stiffener (when considered). Initially all variables were considered as continuous, and as a result, extended the study to the use of commercial thickness.

The results shows great advantages in the optimization it the sections examined. The profiles with edge stiffeners had about an economy, on average, just over 17% compared to the sections without stiffeners. Moreover, studying the relationship between span and optimum height of the section (bw) , it is feasible to recommend for pre-sizing channels without lips a relationships given by L/bw = 24, and L/bw = 36 for those with stiffeners. The method of effective sections is efficient and quite explicit in the calculation of the bending capacity of cold formed steel section, allowing the optimization process in an easy way to perform it.

5 References

[1] SEABURG, P.A. & SALMON,C.G., 1971. Minimum weight design of light gauge steel members. Journal of Structural Division ASCE, No. 97(1), pp. 203-222.

[2] DINOVITZER, A.S., 1992. Optimization of cold formed steel C-sections using Standard Can/CSA-S316-M89. Canadian Jornal of Civil Engineering, No. 19, pp. 39-50.

[3] CASTELUCCI, M.A., PILLINGER, I., HARTLEY, P., DEELEY, G.T., 1997. The optimization of cold rolled formed products, Thin-Walled Structures, Nr. 1-4, Vol. 29, 159-174

[4] ADELI, H. & KARIM, A., 1997. Neural network model for optimization of cold-formed steel sections. Journal of Structural Engineering ASCE, No. 123(11), pp. 1525-1543.

[5] AL-MOSAWI, S. & SAKA, M.P., 2000. Optimum shape design of cold-formed thin-walled steel sections, Advances in Engineering Software, Vol. 31, 851-862

[6] TIAN, Y.S., 2003. Optimal Design of Cold-formed Steel Sections and Panels. Ph.D. thesis, Cambridge University Engineering Department.

[7] KRIPKA, M. & GUERRA, P.A. Otimização estrutural das paredes enrijecidas de silos metálicos. In: KRIPKA, M., CHAMBERLAIN, Z.M. (org): *Novos estudos e pesquisas em construção metálica.* Passo Fundo: UPF Editora, 2008. p. 148-169.

[8] PRAVIA, Zacarias M. Chamberlain; KRIPKA, Moacir. Otimização númerica e experimental de perfis U formados a frio sujeitos à compressão. Rem: Rev. Esc. Minas, Ouro Preto, v. 61, n. 3, Set. 2008, doi: 10.1590/S0370-44672008000300016

[9] BATISTA, E.M. Local–global buckling interaction procedures for the design of cold-formed columns: Effective width and direct method integrated approach. Thin Walled Struct (2009), doi:10.1016/j.tws.2009.04.004

[10] ASSOCIACAO BRASILEIRA DE NORMAS TECNICAS. NBR 14762: Dimensionamento de estruturas de aço constituídas por perfis formados a frio - Procedimentos. (texto base de revisão), 2009.

[11] BELLEI, I.H., Edifícios Industriais em Aço. 5ª edição. São Paulo: Editora Pini, 2004.

[12] AMERICAN IRON AND STEEL INSTITUTE (AISI). Specification for the Design of Cold-Formed Steel Structural Members, Washington, D.C., USA, 2001

[13] _______. NBR 63552:2003: Perfis estruturais de aço formados a frio - Padronização. Rio de Janeiro, 2001.