Web and/or Flange-Stiffened Lipped Channel Columns

Buckling Behaviour

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Abstract

This work present and discuss a group of results concerning the stability behavior of simply supported-endend and fixed-ended cold-formed steel web and/or flange-stiffened lipped channels columns. The members exibit V-shape in the web and/or flanges. The study identify a significant number of geometries members, by dimensions of the cross section and length, affected by interaction phenomena between local and distortional buckling modes. Through a stability analysis we could identify columns geometries affected by local/distortional interaction phenomena. All stability analyzes were performed with GBTUL1.0β software by using Generalized Beam Theory (GBT). After indicating the essential characteristics and potential of GBTUL1.0β program we presents the methodology adopted in the geometry columns selection, with particular attention to the criteria considered in identifying the dimensions of the members.

Keywords: Cold-formed steel columns, Local and distortional buckling, Mode interaction, web and/or flange-stiffened lipped channel columns,

1 Introduction

Most thin-walled cold-formed steel columns are susceptible to occurrence a interaction phenomena between (i) local and (ii) distortional buckling. The local mode is characterized by flexion of the internal walls without displacement of the longitudinal edges while the distortional buckling mode is characterized by significant displacements of the walls with one or more inner longitudinal edges. For the identification of the interactions is necessary to perform an stability analysis. This analysis allows:(i) obtaining curves relating the critical load parameter of structural elements to length and (ii) identifying lengths values which allow to observe equal or very close bifurcation stress associated to local and distortional buckling modes. The paper discusses two types of support conditions (i) simply supported end section and (ii) fixed end section. The simply supported condition is characterized by the following displacements/rotations are prevented: (i) transversal translator displacements and torsional rotation (global), and (ii) transversal membrane and flexural displacements (local). The fixed end section is characterized by all the global and local displacements/rotations are prevented. This is the condition implemented in the overwhelming majority of columns experimental tests, obviously, the loaded end section axial translation must be free.

2 Stability of Columns

The web and flange-stiffened in the shape of "V" located at intermediate points of the walls in the section will increase the resistance of local buckling. The web and flange-stiffened reduce local thinness of the walls of the profile by wall segments subdivision increasing the critical stress by simulating a “type” of elastic supports. It is necessary to take into account that (i) local buckling mode is strongly influenced by the most slender element usually the web and (ii) distortional buckling mode involves the rotation of the lips-flange around the connection flange – web.

The Figure 2.1 shows the stability curves of channel sections with equal transverse dimensions including width of web, flange, lips and thickness. The green line represents a stability curve of a channel section which is observed the sturdy little capacity in which the flange act like a cantilever. The red line represents the stability curve of a lipped-channel section and is characterized by the occurrence of distortional buckling mode consequence of the lip. The blue line represents the stability curve of web and flange-stiffened lipped channel section that increase capacity in local buckling mode

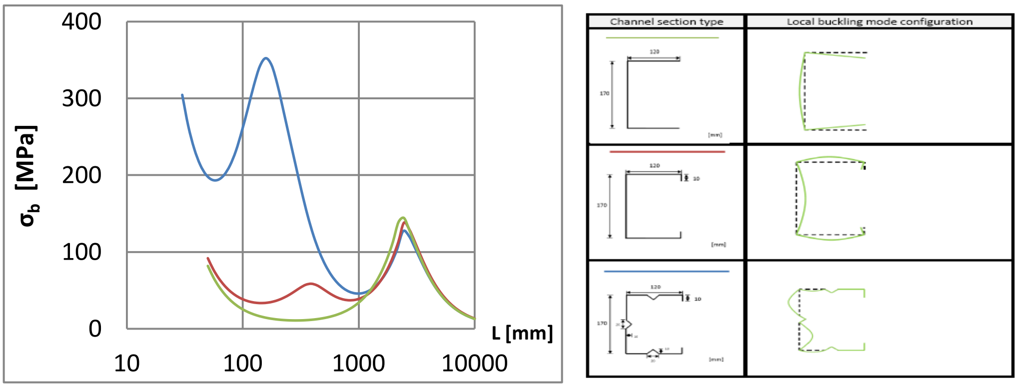


Figure 2.1 – Stability curves of profiles with channel section.

Is defined as the longitudinal dimension value the length (L) of the bar. The transverse dimensions are defined by (i) web (b_w), (ii) flange (b_f), (iii) lips (b_s), iv) thickness (t), v) width of strengthening the soul (S_{1w}) vi) height of strengthening the soul (S_{2w}), vii) strengthening the flange width (S_{1f}) and viii) strengthening the height of flange (S_{2f}).

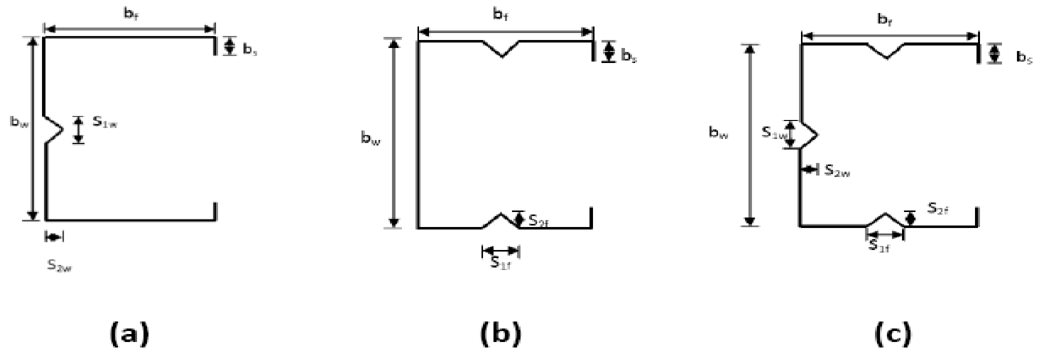


Figure 2.2 – Channel sections (a) web-stiffened, (b) flange-stiffened and (c) web and flange-stiffened.

2.1 Examples

2.2.1 Columns simply supported

Through the stability analysis were determined $\sigma_{cr}\ vs\ L$ curves. For examples of simply supported appealed to the analytical solution with a half-wave (n_w = 1). The minimum points of each curve are respectively associated local and distortional buckling modes. The minimum point of the curve contain information relating to (i) critical tensions (σ_L ; σ_D) and (ii) critical length (L_L ; L_D) respectively associated local and distortional buckling modes.

The case studies may have different distortional critical stress below the local critical stress ratio. The $\frac{\sigma_D}{\sigma_L}$ relationship has the following range $0 < \frac{\sigma_D}{\sigma_L} \ll 1$ in the situations with of local / distortional interaction phenomena lie in the range $0{,}9 \ll \frac{\sigma_D}{\sigma_L} \ll 1$. To be able to compare with the yield strength of the material the distorcional and local tensions are shown in MPa.

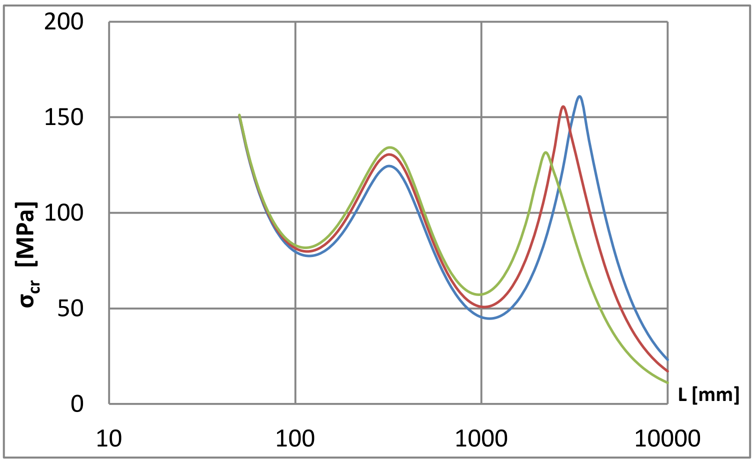
A Web-stiffened lipped channel columns

The initial geometric configuration called "A0" is as follows {(b_w=190; b_f=130; b_s=13; t=1.2; S_{1w}=25; S_{2w}=12.5) mm} which corresponds to the red curve stability the following graphs of figures 2.3. By variation the width of the web in the "A0" section resulted in different stability curves shown in Figure 2.3 with the following observations:

(i) The variation of the width of the web has the effect of changing the value of local and distortional critical stress. The distortional buckling mode occured by rotation of the flange-lip around the connection flange-web with the web act as spring relative to the flange. By reducing the web width increases the stiffness of the spring and therefore increases the value of the critical stress - when b_w=190 mm passes to b_w=140 mm the σ_L=80 MPa increases to σ_L=82 MPa and σ_D=51 MPa increases to σ_D=57 MPa.

(ii) The σ_D/σ_L ratio increases with decreasing web width as it is observable in the table in Figure 2.3 (where b_w=190 mm passes to b_w=140 mm and the σ_D/σ_L ratio increase from 64% to 70%).

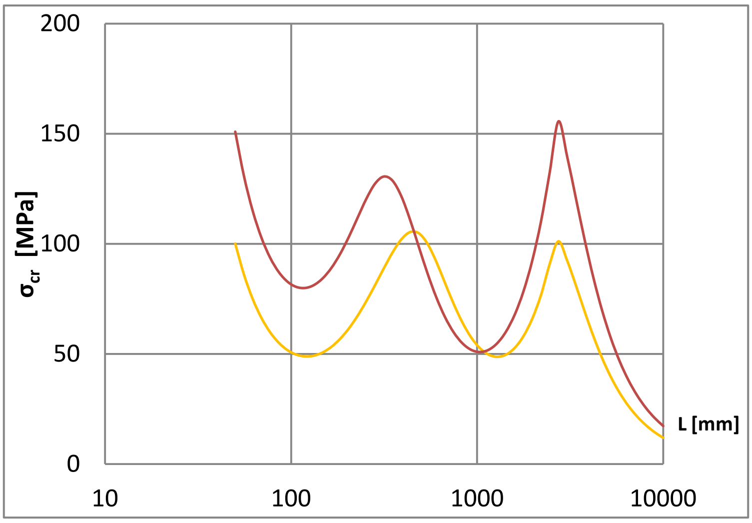
(iii) The values of global tensions vary with the change of web width. This effect is due to the fact that the instability of the long bars (L> 2200 mm) can be linked to the flexural-torsional mode and flexural mode. The flexural mode is influenced by the higher inertia of the section. The higher inertia of the section is more controlled by varying the web width than the variation of the remaining transversal dimensions.



b_f = 130 ; b_s = 13; t = 1,2 ; S_{1w} = 25 ; S_{2w} = 12,5 [mm]			
b_w [mm]	140	190	240
L_L [mm]	119	119	119
σ_L [MPa]	82	80	77
L_D [mm]	927	1032	1150
σ_D [MPa]	57	51	45
σ_D/σ_L [%]	70%	64%	58%

Figure 2.3 – Stability curves σ_{cr} vs L (n_w=1) of columns by variation the web width (b_w).

After studying the various cases where only changed one transverse dimension, in order to understand the importance in the change of σ_D/σ_L ratio, we arrive at a geometric configuration that presents the local / distortional interaction phenomenon. This configuration is called "AB" and has the following geometry {(b_w=150; b_f=140; b_s=16; t=1; S_{1w}=25; S_{2w}=12.5) mm} which corresponds to the orange curve stability in chart of Figure 2.4.



Specimen	A0	AB
L_L [mm]	119	119
σ_L [MPa]	80	49
L_D [mm]	1032	1282
σ_D [MPa]	51	49
σ_D/σ_L [%]	64%	100%

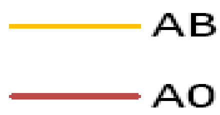


Figure 2.4 – Stability curves σ_{cr} vs L (n_w=1) of columns on section “A0” and section “AB”.

2.2.2 Columns fixed

The stability analysis to determine the curves $\sigma_{cr}\ vs\ L$ into fixed end columns using the numerical solution. The analysis involves the numerical solution of the discretization length in finite bar elements. The choice of the number of finite elements depends on the number of half-waves used for obtaining the solution, making it less precise with the increase of the number of half-waves.

Figures 2.5 show examples of geometry in fixed end sections with web/flange-stiffened lipped channel columns. Distinguished cases interact with those who show a difference in the local and distortional strain in the order of $0 \leq \Delta\sigma \leq 6$ MPa. The $\Delta\sigma$ is understood as the difference between local and distortional critical stress in absolute value in MPa. In σ_D/σ_L ratio define the cases where local / distortional interaction phenomena occurred when critical tensions are in range of $0{,}9 \ll \frac{\sigma_D}{\sigma_L} \ll 1$.

B Web and flange-stiffened lipped channel columns

The observation of the table 2.1 and graph 2.5 enables the understanding of the changing geometry of a web/flange-stiffened lipped channel columns, in order to reach a stability curve presenting the local / distortional interaction phenomenon process. During the process were made the following comments:

(i) Initially, the process entails the conversion of the initial geometry "FV" to a final geometry "FZ", passing through an intermediate geometry "FX". The transformation of "FV" to "FX" occurs at the level of the flange width (b_f=150 mm passes to b_f=100 mm); thickness (t= 1.2mm becomes t=1.4 mm). For changes "FX " to " FZ " are the web width (b_w=210 mm shall b_w=290 mm); the flange width (bf=150 mm shall bf = 100 mm); thickness (t=1.2 mm becomes t=1 mm); the dimensions of web/flange-stiffen (S_{1w}=20 mm passes to S_{1w}=30 mm ; S_{2w}=10 mm passes to S_{2w}=15 mm; S_{1f}=20 mm passes S_{1f}=30 mm; S_{2f}=10 mm passes S_{2f}=15 mm).

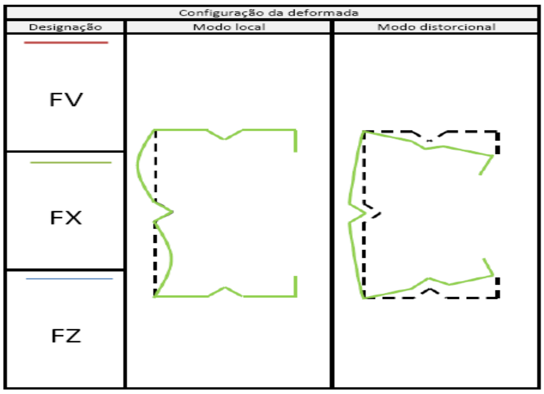
(ii) The red stability curve "FV" presents local and distortional stress far apart. Observe the poor linearity of the curve and presentation of a kind of "gap" between the values of the local and distortional stress.

(iii) The green stability curve "FX" section gives local and distortional stress. It is apparent discontinuity values between local and distortional stress very similar to the red curve stability.

(iv) The blue stability curve "FZ " section reflects the local/distortional interaction phenomenon. It is possible to note the linearity of the curve stability and find a great number of local and distortional tensions very similar There is a low local and distortional stress compared to the red and green curves, and should this effect to the thick reduction.

Specimen	b_w [mm]	b_f [mm]	b_s [mm]	t [mm]	S_{1w} [mm]	S_{2w} [mm]	S_{1f} [mm]	S_{2f} [mm]
FV	210	150	20	1,2	20	10	20	10
FX	210	100	20	1,4	20	10	20	10
FZ	290	100	20	1	30	15	30	15

Table 2.1 – Geometries of web and flange-stiffened lipped channel columns.



Specimen	FV	FX	FZ
L_L [mm]	670	832	1428
σ_L [MPa]	174	242	68
L_D [mm]	10000	7230	10000
σ_D [MPa]	60	117	62
$\Delta\sigma$ [Mpa]	114	126	6
σ_D/σ_L [%]	34	48	91

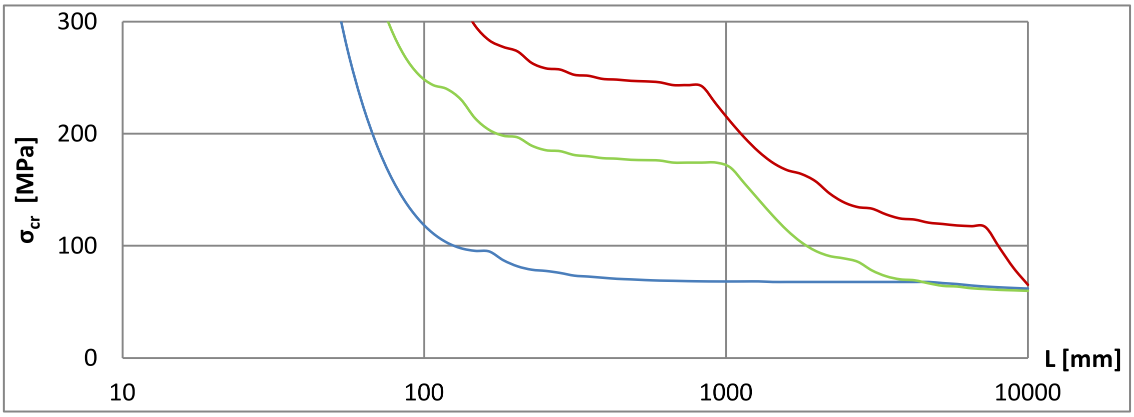


Figure 2.5 – Stability curve for the case of web and flange-stiffened lipped channel columns and the respective table columns transverse dimensions.

3 Geometry Selection of columns

3.1 Criteria for geometry selection

The tax base in obtaining dimensions of criteria profiles, which are critical loads associated to local, distortional and global buckling modes are:

i) $0,9 \leq \sigma_D/\sigma_L \leq 1$

ii) $1 \leq \sigma_D/\sigma_L \leq 1,1$

iii) $\sigma_D \approx \sigma_L << \sigma_G$

In supported conditions:

i) simply supported end section

ii) fixed end section

By web/flange-stiffened lipped channel sections and it was suggested that the results respected a set of geometric and physical criteria:

L [mm]	b_w [mm]	b_f [mm]	b_s [mm]	t [mm]	S_{1w} [mm]	S_{2w} [mm]	S_{1f} [mm]	S_{2f} [mm]	σ_D [MPa]	σ_G [MPa]
> 300	> b_f	< b_w	> 0,1b_f	$1 \leq t \leq 2$	20	10	20	10	≤ 350	≥ 3σ_D
$(L/b_w)>3,5$	< 240	$1 \leq (b_w/b_f) \leq 1,5$	> S_{2w}		25	12,5	25	12,5		
			> S_{2f}		30	15	30	15		
			$10 \leq b_s \leq 20$							

Table 3.1 – Criteria for columns selection.

3.2 Results

A Simply supported columns (preview Table 3.2)

(i) The profile group of (C-28 to C-39) has the same thickness value (t=1 mm). The determination process for this kind of geometry has particular difficulties in raising the thickness value (t>1 mm). The progressive increase of the web and flange width led to use the maximum lip width (bs=20 mm) and the progressive use web/flange-stiffen. Is noticeable the progressive increase of the critical length induced by the progressive increase of the transverse dimensions.

(ii) The range of lengths values L ϵ {530;860} mm . The transverse dimensions have the following ranges of values $b_w \in \{150;240\}$; $b_f \in \{100;170\}$; $b_s \in \{20\}$ and $t \in \{1\}$ in mm.

(iii) The values of the local maximum local/distortional stress varies in the range $Max\{\sigma_{L;}\sigma_D\} \in \{97;253\}$ and the global tensions in the range $\sigma_G \in \{3159;3734\}$ in MPa.

(iv) Analyzing the results of the global average voltage is 24 times the maximum local /distortional strain. The σ_D/σ_L voltage ratio in percentage is on average equal to 93 indicating a good quality of results.

B Fixed Columns (preview Table 3.3)

(i) The profile group of (F-67 to F-78) has the same thickness value (t = 1 mm). As in the previous examples the progressive increase of the web and flange width led to use the maximum lip width (bs=20 mm) and the progressive use web/flange-stiffen. Where the progressive increase of the critical length is induced again by the progressive increase of the transverse dimensions.

(ii) The profile group (F-79 to F-87) is characterized by the use of thicknesses (t =1.2, t=1.4, t=1.6, t=1.8 mm). Using this range of thickness takes to apply the maximum dimension of intermediate reinforcement (S_{1w}=30; S_{2w}=15; S_{1f}=30; S_{2f}=15 in mm).Thus it is possible to achieve results with the occurrence of the local/distortional interaction phenomenon. Another noticeable fact is significant reduction of the critical length in relation to increasing thickness.

(iii) The range of lengths values $L \in \{760,1680\}$ mm . The transverse dimensions have the following ranges of values: $b_w \in \{150;240\}$; $b_f \in \{100;170\}$; $b_s \in \{20\}$ and $t \in \{1;1.8\}$ mm .

(iv) The values of the local maximum / distortional stress varies in the range $Max\{\sigma_L;\sigma_D\} \in \{109,788\}$ and the global tensions in the range $\sigma_G \in \{3241;25193\}$ in MPa.

(v) Analyzing the results of the global average voltage is 26 times the maximum local / distortional strain. The σ_D/σ_L voltage ratio in percentage is on average equal to 98 classifying the quality of results as good.

3.2.1 Simply supported columns

3.2.1.1 Web and flange-stiffened lipped channel sections

Specimen	L [mm]	b_w [mm]	b_f [mm]	b_s [mm]	t [mm]	S_{1w} [mm]	S_{2w} [mm]	S_{1f} [mm]	S_{2f} [mm]	Max $\{\sigma_D;\sigma_L\}$ [MPa]	σ_G [MPa]	σ_G/Max $\{\sigma_D;\sigma_L\}$	σ_D/σ_L [%]
C-28	530	150	100	20	1	20	10	20	10	253	3530	14	84
C-29	560	160	110	20	1	20	10	20	10	218	3582	16	83
C-30	600	170	120	20	1	25	12,5	25	12,5	202	3450	17	92
C-31	630	180	120	20	1	25	12,5	25	12,5	178	3417	19	95
C-32	670	190	130	20	1	25	12,5	25	12,5	157	3369	21	93
C-33	700	200	140	20	1	25	12,5	25	12,5	148	3734	25	93
C-34	740	210	150	20	1	25	12,5	25	12,5	132	3244	25	92
C-35	770	220	160	20	1	25	12,5	25	12,5	112	3422	30	89
C-36	760	210	150	20	1	30	15	30	15	132	3159	24	97
C-37	780	220	160	20	1	30	15	30	15	118	3294	28	99
C-38	820	230	160	20	1	30	15	30	15	107	3201	30	99
C-39	860	240	170	20	1	30	15	30	15	97	3177	33	97
Min	530	150	100	20	1	20	10	20	10	97	3159	14	83
Max	860	240	170	20	1	30	15	30	15	253	3734	33	99

Table 3.2 – Geometry of web and flange-stiffened lipped channel columns in simply supported conditions

3.2.2 Fixed Columns

3.2.1.2 Web and flange-stiffened lipped channel sections

Specimen	L [mm]	b_w [mm]	b_f [mm]	b_s [mm]	t [mm]	S_{1w} [mm]	S_{2w} [mm]	S_{1f} [mm]	S_{2f} [mm]	Max {σ_D;σ_L} [MPa]	σ_G [MPa]	σ_G/Max {σ_D;σ_L}	σ_D/σ_L [%]
F-67	970	150	100	20	1	20	10	20	10	284	4216	15	96
F-68	990	160	110	20	1	20	10	20	10	244	4578	19	99
F-69	1140	170	120	20	1	25	12,5	25	12,5	226	3824	17	100
F-70	1260	180	120	20	1	25	12,5	25	12,5	199	3418	17	97
F-71	1280	190	130	20	1	25	12,5	25	12,5	176	3693	21	100
F-72	1330	200	140	20	1	25	12,5	25	12,5	157	3791	24	100
F-73	1380	210	150	20	1	25	12,5	25	12,5	140	3883	28	100
F-74	1430	220	160	20	1	25	12,5	25	12,5	126	3969	31	100
F-75	1200	210	150	20	1	30	15	30	15	145	4866	34	99
F-76	1560	220	160	20	1	30	15	30	15	132	3295	25	98
F-77	1630	230	160	20	1	30	15	30	15	120	3241	27	10
F-78	1680	240	170	20	1	30	15	30	15	109	3330	31	99
F-79	1280	220	160	20	1,2	30	15	30	15	187	4895	26	97
F-80	1370	230	160	20	1,2	30	15	30	15	171	4589	27	95
F-81	1150	230	160	20	1,4	30	15	30	15	227	6512	29	97
F-82	1020	240	170	20	1,4	30	15	30	15	661	22901	35	99
F-83	760	210	150	20	1,6	30	15	30	15	711	25193	35	98
F-84	980	220	160	20	1,6	30	15	30	15	657	17144	26	92
F-85	1000	230	160	20	1,6	30	15	30	15	591	17602	30	97
F-86	830	220	160	20	1,8	30	15	30	15	788	23473	30	99
F-87	910	230	160	20	1,8	30	15	30	15	697	20210	29	93
Min	760	150	100	20	1	20	10	20	10	109	3241	15	92
Max	1680	240	170	20	1,8	30	15	30	15	788	25193	35	100

Table 3.3 - Geometry of web and flange-stiffened lipped channel columns in fixed conditions

4 Concluding Remarks

Through the stability analysis we could identify geometries of web/flange-stiffened lipped channel columns affected by local/distortional interaction phenomena. The study of such profiles developed to improve the methodology that allows to reach geometries sections affected by local/distortional interaction phenomena in simply supported and fixed.

After an exhaustive study of the methodology described above were identified and selected a set of columns with the occurrence local/distortional interaction phenomena in simply supported and fixed. The selection of these profiles was based on the discovery of a set of geometric criteria tensions and allowing its application in the commercial context.

The occurrence of the interaction phenomena results in reduced load capacity of the profiles. The study of a methodology to understand how these phenomena occurred is very beneficial. By analyzing the results of the selected profiles was possible to identify a number of conditions for which the occurrence the local/distortional interaction phenomena is reduced. Indicate the conditions identified below :

A. Simply supported columns

(i) In columns with web and flange-stiffened lipped channel sections the occurrence of local/distortional interaction phenomena is reduced when they occurred simultaneously the following conditions:

(i_1) The thickness between 1.6 mm to 2.2 mm

(i_2) For web/flange-stiffen the width less than 25 mm and height less than 12.5 mm.

(i_3) The width lip less than 20 mm.

B. Fixed Columns

(ii) In columns with web and flange-stiffened lipped channel sections the occurrence of local/distortional interaction phenomena is reduced when they occurred simultaneously the following conditions:

(ii_1) The thickness between 1,8 mm to 2,2 mm

(ii_2) For web/flange-stiffen the width less than 25 mm and height less than 12.5 mm.

(ii_3) The width lip less than 12 mm.

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