International Specialty Conference on Cold-Formed Steel Structures

(2004) - 17th International Specialty Conference on Cold-Formed Steel Structures

Oct 26th, 12:00 AM

Distortional Buckling of Cold-formed Steel Members

Maximiliano Malite

Roberto Martins Goncalves

Jorge Munaiar Neto

Gustavo M. B. Chodraui

Seventeenth International Specialty Conference on Cold-Formed Steel Structures
Orlando, Florida, U.S.A, November 4-5, 2004

DISTORTIONAL BUCKLING OF COLD-FORMED STEEL MEMBERS

Gustavo M.B. Chodraui[1]; Maximiliano Malite[2];
Roberto Martins Gonçalves[2]; Jorge Munaiar Neto[2]

School of Engineering of São Carlos – University of São Paulo
Department of Structural Engineering
Av. Trabalhador São-Carlense, 400 - CEP 13566-590
São Carlos, SP - Brazil
e.mail: mamalite@sc.usp.br

ABSTRACT

Cold-formed steel members are widely employed in steel construction because their structural components are lighter and more economical than traditional hot-rolled ones. Nowadays, the easy availability and accessible cost of high-strength low-alloy steels, weathering steels and zinc-coated steels have led to members with high width/thickness ratios, rendering them even more susceptible to local buckling, which is characterized by a plate buckling and which can also lead to another buckling mode called distortional buckling, affecting mainly members with edge stiffeners (lipped channels and Z-sections, hat, rack, etc.). Hence, current versions of technical codes for cold-formed steel design have warned about the importance of this phenomenon and has outlined procedures to evaluate bar strength based on distortional buckling, e.g., the simplified model of the Australian/New Zealand Standard AS/NZS 4600 proposed by Hancock & Lau (1987), which was also adopted by the new Brazilian Standard NBR 14762:2001. In this study, an analysis is made about lipped channels under compression and bending, comparing the results obtained through the Brazilian Standard simplified model against those of the elastic

[1] *Civil Engineer, Doctoral Student – University of São Paulo, Brazil*
[2] *Doctor Professor – University of São Paulo, Brazil*

analysis via the finite strip method, evaluating the conformity and the range of validity of the simplified model application.

1. INTRODUCTION

Beyond global buckling and local buckling, another buckling mode may occur, related to cross section's distortion (Figure 1), which is characteristic of members with edge stiffeners, such as lipped channels and Z-sections, hat and rack. Some examples of the deformed section's configuration caused by distortional buckling are shown in Figure 1.

Most of times distortional mode isn't critical in members without edge stiffeners – local buckling predominates due to the fact that the element has only one supported edge.

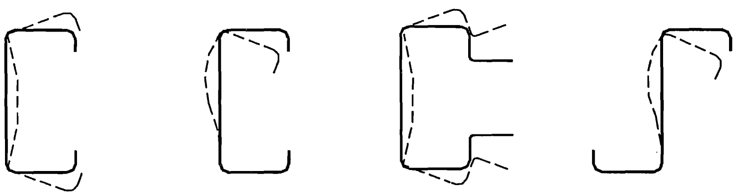


Figure 1 – Examples of distortional buckling

Distortional buckling is characterized by the rotation and possible translation of the compressed flange and edge stiffener set, which alters the initial shape of the section (Figure 1), as opposed to local buckling which, by definition, admits the conservation of the original position of the angles (corners) formed by the joining of two plate elements.

The new Brazilian Standard NBR 14762:2001 adopts the "Australian model", kind of "closed-form" solutions, proposed by Hancock & Lau (1987) and also incorporated into the Australian/New Zealand Standard AS/NZS 4600, which analyzes the stability of compressed flange and edge stiffener sets elastically connected to the other part of the cross section (Figure 2), dispensing the use of computational tools to evaluate the critical distortional buckling stress. It should be noticed that Hancock and Lau's formulae has the inability to handle situations in which the web flexural instability induces distortional buckling phenomena.

Beyond closed-form solutions, there are also numerical procedures, such as the Finite Element Method (FEM), the Finite Strip Method (FSM) and the Generalized Beam Theory (GBT) – see Silvestre & Camotim (2004).

Direct Strength Method (DSM) has actually been an interesting alternative to estimate the load-carrying capacity of members – including all buckling modes – but demanding previous usage of one of the procedures aforementioned to evaluate buckling stresses.

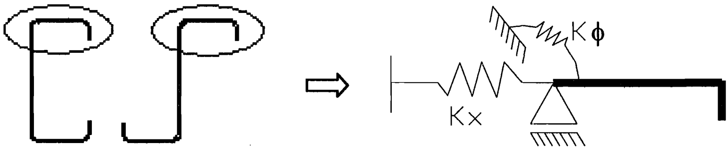


Figure 2 – Simplified model proposed by Hancock & Lau

According to Batista et al. (2000), geometric ratios of the cross section indicated in Table 1 strongly influence the critical buckling mode, and the distortional mode is critical in members with wide flanges and small edge stiffeners (lips).

Table 1: Influence of geometric ratios of lipped channel and rack section on the critical buckling mode

Lesser	**Geometric ratio**	**Greater**
Local mode	b_f / b_w	Distortional mode
Distortional mode	D / b_w	Local mode
Distortional mode	b_w / t	Local mode
b_f ; b_w ; D and t - see Figure 4		

3. BRAZILIAN STANDARD PROCEDURE

The Brazilian Standard analyzes local buckling by the effective width method (Winter's equation) analogously to the AISI Specification. Distortional buckling should subsequently also be checked based on the curves proposed by the AS/NZS 4600 (Figure 3), whose equations are given below:

Compression members:

$N_{c,Rd} = N_{dist} / \gamma \qquad (\gamma = 1.1)$ (1)

N_{dist} : elastic distortional buckling axial force, determined as follows:

$N_{dist} = Af_y (1 - 0.25\lambda_{dist}^2)$ for $\lambda_{dist} < 1.414$ (2)

$N_{dist} = Af_y \{0.055[\lambda_{dist} - 3.6]^2 + 0.237\}$ for $1.414 \leq \lambda_{dist} \leq 3.6$ (3)

Flexural members:

$M_{Rd} = M_{dist} / \gamma \qquad (\gamma = 1.1)$ (4)

M_{dist} : elastic distortional buckling moment, determined as follows:

$M_{dist} = W_c f_y (1 - 0.25\lambda_{dist}^2)$ for $\lambda_{dist} < 1.414$ (5)

$M_{dist} = W_c f_y / \lambda_{dist}^2$ for $\lambda_{dist} \geq 1.414$ (6)

Where:

γ : resistance factor

A: full unreduced cross-sectional area

W_c : elastic section modulus of full unreduced section relative to extreme compression fiber

$N_y = Af_y$

$M_y = W_c f_y$

f_y : yield stress

$\lambda_{dist} = (f_y/\sigma_{dist})^{0.5}$ - slenderness factor

σ_{dist} : distortional elastic buckling stress, which can be calculated by the theory of elastic stability, by numerical analysis, or according to the simplified model proposed by Hancock & Lau.

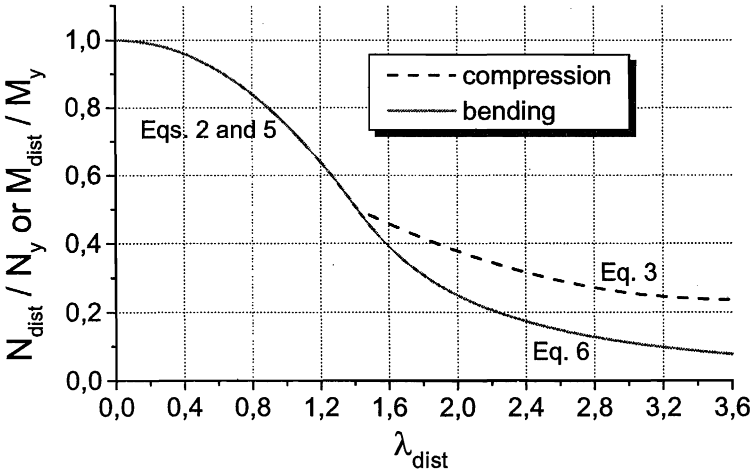


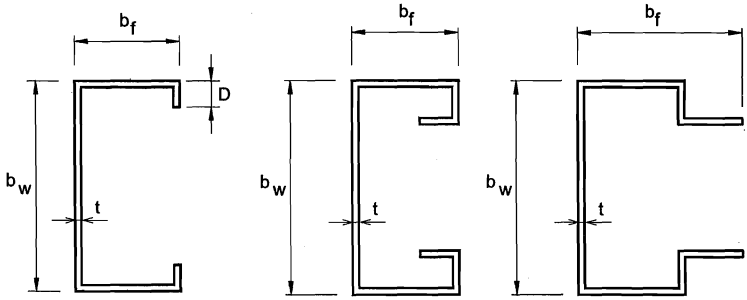
Figure 3 – Distortional buckling curves: AS/NZS 4600 and NBR 14762

Although AS/NZS 4600 does not establish limits for the use of the simplified model, Batista et al. (2000) stated, based on comparisons with results due to numerical analyses using the finite strip method, that this procedure can be applied with good precision provided geometric ratios given below are followed (see Figure 4):

$0.4 \leq b_f / b_w \leq 2.0$ (lipped channel)
$0.6 \leq b_f / b_w \leq 1.3$ (rack section)

Based on the aforementioned limitations, the Brazilian Standard has restricted the use of the simplified model. Moreover, it presents limit values of the D/b_w ratio of simple lipped channels and Z-sections subjected to compression or bending, in order to identify, initially, whether the distortional mode may be critical (Tables 2 and 3). These values were obtained by a parametric analysis of sections via finite strip method, comparing the elastic values of the distortional critical stress against the local critical stress.

It is important to say that as distortional mode has lower post-buckling capacity than local mode, thus even if $(\sigma_{cr})_{local} < (\sigma_{cr})_{distortional}$, distortional mode may still control the strength. Therefore, one should know that Tables 2 and 3 are useful but not completely correct.



a) Simple lipped channel b) General lipped channel c) rack section

Figure 4 – Lipped channel and rack section

4. ANALYSIS VIA THE FINITE STRIP METHOD

The finite strip method is an interesting alternative for thin-walled members' elastic stability analysis, since it allows one to identify the buckling modes and critical stresses associated with members subjected to axial compression and bending.

Table 2 – Minimum values of the D/b_w ratio of simple lipped channels subjected to compression, in order to dispense checking for distortional buckling

b_f/b_w	b_w/t				
	250	200	125	100	50
0.4	0.02	0.03	0.04	0.04	0.08
0.6	0.03	0.04	0.06	0.06	0.15
0.8	0.05	0.06	0.08	0.10	0.22
1.0	0.06	0.07	0.10	0.12	0.27
1.2	0.06	0.07	0.12	0.15	0.27
1.4	0.06	0.08	0.12	0.15	0.27
1.6	0.07	0.08	0.12	0.15	0.27
1.8	0.07	0.08	0.12	0.15	0.27
2.0	0.07	0.08	0.12	0.15	0.27
Note: linear interpolation for intermediate values					

Table 3 – Minimum values of the D/b_w ratio of simple lipped channels and Z-sections subjected to bending, in order to dispense checking for distortional buckling

	b_w/t				
b_f/b_w	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: linear interpolation for intermediate values					

The software via finite strip method CUFSM (Cornell University – Finite Strip Method) developed by Schafer (2001), used here, makes a general analysis of the elastic stability of open section thin-walled members subjected to the distribution of any axial stresses at the ends, allowing for the restriction of the node's degree of freedom. Critical stress and corresponding deformed configuration, indicating the buckling mode, are filed for a variety of analyzed member lengths, resulting in a general elastic buckling curve (Figure 5). This curve correlates the load factor (the ratio between critical stress and a reference stress, for which the yield stress f_y is usually adopted) and the half-wavelength, evidencing local and distortional modes.

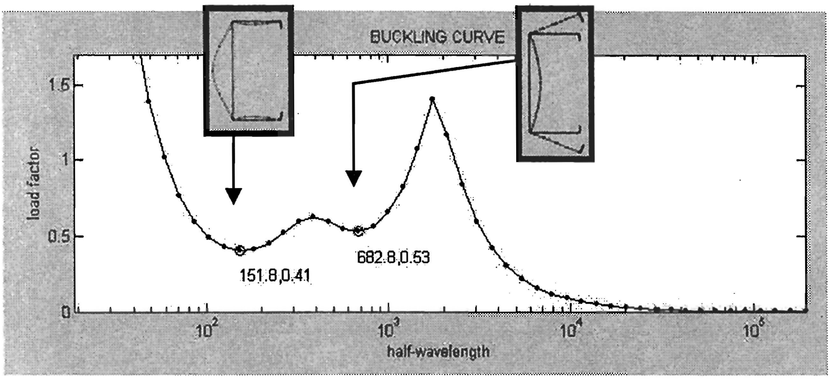


Figure 5 – Analysis of elastic stability via CUFSM

The software uses a finite strip with 4 nodes, each having 4 degrees of freedom, of which 3 are translations and 1 rotation. The discretization was performed so that flat parts of each of the section's elements were divided as follows: 4 strips (flanges, web and lips) and 17 strips (corners).

As a complement of the work developed by Batista et al., a parametric study of simple lipped channels subjected to compression and bending was conducted with the purpose of making a more in-depth analysis about the conformity and the range of validity of the Brazilian Standard simplified model. Table 4 lists sections analyzed in the work of Chodraui (2003):

Table 4: Simple lipped channels analyzed by Chodraui (2003)

Channel	b_w x b_f x D x t (mm) (see Figure 4a)	b_f / b_w	D / b_w	b_w / t
C1[+]	200x50x10x1	0.25	0.05	200
C2	200x50x10x2	0.25	0.05	100
C3	200x50x10x4	0.25	0.05	50
C4[+]	200x50x20x1	0.25	0.10	200
C5[+]	200x50x20x2	0.25	0.10	100
C6	200x50x20x4	0.25	0.10	50
C7	200x50x30x1	0.25	0.15	200
C8	200x50x30x2	0.25	0.15	100
C9	200x50x30x4	0.25	0.15	50
C10	200x100x10x1	0.5	0.05	200
C11	200x100x10x2	0.5	0.05	100
C12	200x100x10x4	0.5	0.05	50
C13	200x100x20x1	0.5	0.10	200
C14	200x100x20x2	0.5	0.10	100
C15	200x100x20x4	0.5	0.10	50
C16	200x100x30x1	0.5	0.15	200
C17	200x100x30x2	0.5	0.15	100
C18	200x100x30x4	0.5	0.15	50
C19	200x200x10x1	0.5	0.05	200
C20	200x200x10x2	1	0.05	100
C21	200x200x10x4	1	0.05	50
C22	200x200x20x1	1	0.10	200
C23	200x200x20x2	1	0.10	100
C24	200x200x20x4	1	0.10	50
C25	200x200x30x1	1	0.15	200
C26	200x200x30x2	1	0.15	100
C27	200x200x30x4	1	0.15	50

Notes:
NBR 14762 limits not satisfied to Channels C1 to C9
[+] Distortional mode in compression non evident by CUFSM

Figures 6 and 7 compare the simplified procedure of the Brazilian Standard NBR 14762:2001 and the finite strip method (CUFSM software), clearly showing that channels C1 to C9 that do not meet the limits established by NBR 14762 show more divergent results than the others, in compression. This tendency was not observed in bending, in which the greatest differences were found for members that meet the limits of NBR 14762 (e.g., channels C20 and C21).

A good congruence was generally found between the values obtained through the simplified method and the finite strip method, particularly in compression (ratios of 0.92 to 1.18). Ratios of 0.9 to 1.38 were obtained in bending, indicating that the model requires revision and adjustments.

To exemplify the above, Figures 8 to 10 show distortional elastic stress values as a function of the parameters t, D and b_f, confirming the tendency indicated in Table 1.

The results obtained also indicate that the D/b_w limits shown in Tables 2 and 3 are satisfactory for a preliminary evaluation of the need to verify distortional buckling, since it covered the great majority of members analyzed, in both compression and bending. Only channel C11, in compression, presented the distortional mode as critical, contrary to Table 2.

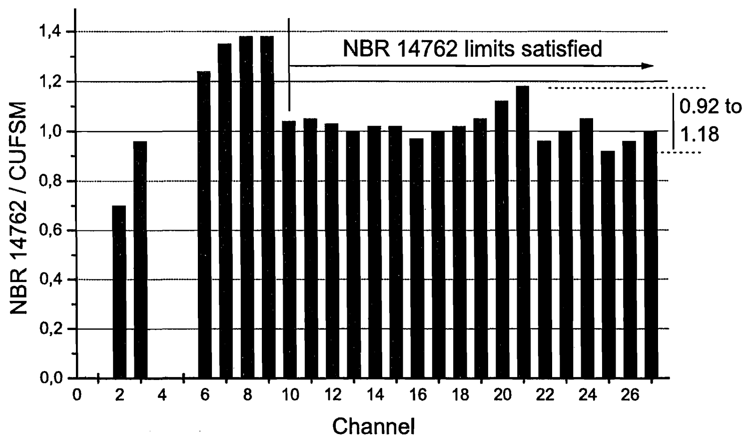


Figure 6 – Comparative analysis of σ_{dist} for axial compression NBR 14762 *versus* CUFSM

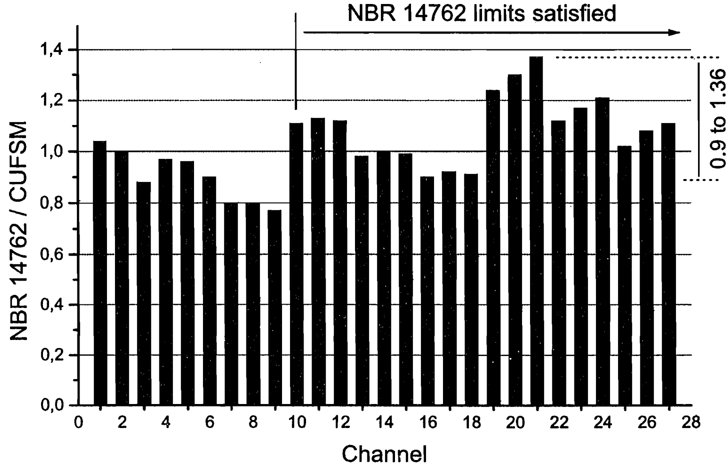


Figure 7 – Comparative analysis of σ_{dist} for bending
NBR 14762 *versus* CUFSM

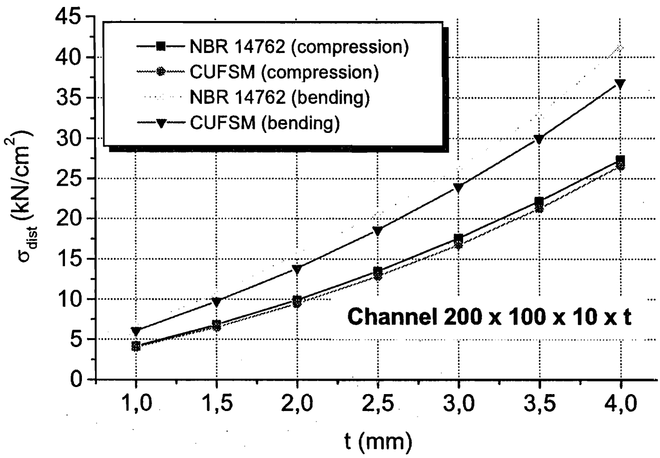


Figure 8 - σ_{dist} *versus* t: channel 200 x 100 x 10 x (t)

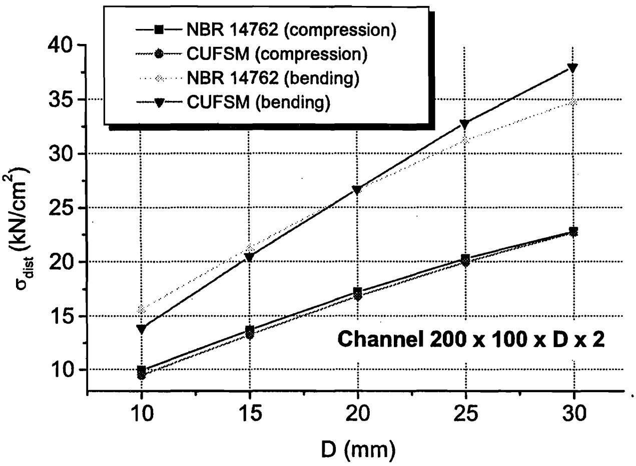


Figure 9 - σ_{dist} *versus* D: channel 200 x 100 x (D) x 2

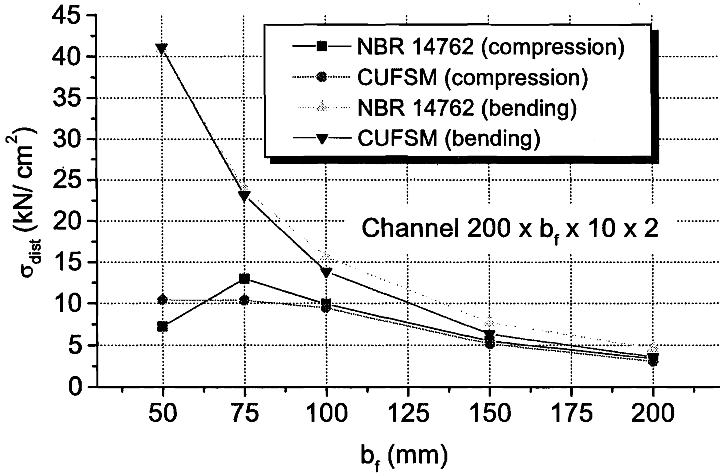


Figure 10 - σ_{dist} *versus* b_f: channel 200 x (b_f) x 10 x 2

5. CONCLUSIONS

The distortional instability mode is part of the most recent codes, including the new Brazilian Standard NBR 14762:2001, and can constitute the critical mode in open section thin-walled members, being most sensitive to distortion members with wide flanges and edge stiffeners, such as lipped channels and Z-sections, hat and rack sections.

The analysis of elastic buckling via finite strip method has been widely employed to evaluate the parameters of interest in distortional buckling, allowing one to easily determine the elastic buckling stress for various half-wavelengths and thus build the buckling curves corresponding to the local, distortional and global mode (Figure 5). The results have indicated a good agreement with those obtained by the finite element method.

NBR 14762:2001 procedure is based on the Australian/New Zealand Standard AS/NZS 4600 and corresponds to the simplified model proposed by Hancock & Lau. When compared with the results obtained via the finite strip method, this procedure has led to satisfactory results for compression, provided the limits established by the code are respected (Figure 6). In the case of bending, differences obtained were greater, including those for members contained within the range of application indicated by the Brazilian Standard NBR 14762:2001 (Figure 7), indicating that the model requires revision and adjustments.

The D/b_w limits listed in NBR 14762 (Tables 3 and 4) are satisfactory for a preliminary evaluation of the need to check for distortional buckling, since they cover the great majority of members analyzed, both in compression and in bending.

7. ACKNOWLEDGEMENTS

To FAPESP (São Paulo State Research Support Foundation – Brazil)

8. REFERENCES

American Iron and Steel Institute (2001). North American Specification for the Design of Cold-Formed Steel Structural Members. Washington: AISI

Ansys (1995). Structural nonlinearities: user's guide for revision 5.1. Houston. v.1.

Brazilian Association of Technical Specifications (2003). *NBR 6355*: Cold-Formed Steel Structural Members - standardization. Rio de Janeiro: ABNT (in Portuguese).

Brazilian Association of Technical Specifications (2001) Design of Cold-Formed Steel Structural Members. NBR 14762. ABNT, Rio de Janeiro (in Portuguese).

Australian/New Zealand Standard (1996). Cold-formed steel structures. AS/NZS 4600:1996.

Silvestre N.; Camotim D. - "Towards an Efficient Design Against Distortional Buckling: Formulae for C and Z-Section Cold-Formed Steel Members", Proceedings of Structural Stability Research Council (SSRC) 2004. Annual Stability Conference, Long Beach, pp. 239-263, March 24-27, 2004.

Batista, E.M. et al (2000). Studies of the local and distortional buckling modes of cold-formed steel members (in Portuguese). In: SOUTH AMERICAN CONGRESS OF STRUCTURAL ENGINEERING, 29. Punta del Este, Uruguay, 14p.

Chodraui, G.M.B. (2003). Distortional buckling of cold-formed steel members under compression and bending. São Carlos. 173p. MSc Thesis (in Portuguese) – School of Engineering of São Carlos, University of São Paulo, Brazil.

Hancock, G.J.; LAU, S.C.W. (1987). Distortional buckling formulas for channel columns. Journal of Structural Engineering, ASCE, v.125, n.2, February, p.118-127.

Schafer, B.W. (2001). Finite strip analysis of thin-walled members. In: CUFSM: Cornell University – Finite Strip Method.