International Specialty Conference on Cold-Formed Steel Structures

(2010) - 20th International Specialty Conference on Cold-Formed Steel Structures

Nov 3rd, 12:00 AM

Theoretical Analysis of Cold-formed Steel Battened Double Angle Members under Compression

W. F. Maia

J. Munaiar Neto

M. Malite

Recommended Citation

Maia, W. F.; Neto, J. Munaiar; and Malite, M., "Theoretical Analysis of Cold-formed Steel Battened Double Angle Members under Compression" (2010). *International Specialty Conference on Cold-Formed Steel Structures*. 3.
https://scholarsmine.mst.edu/isccss/20iccfss/20iccfss-session3/3

Twentieth International Specialty Conference on Cold-Formed Steel Structures
St. Louis, Missouri, U.S.A., November 3 & 4, 2010

THEORETICAL ANALYSIS OF COLD-FORMED STEEL BATTENED DOUBLE ANGLE MEMBERS UNDER COMPRESSION

W. F. Maia[1], J. Munaiar Neto[2], and M. Malite[2]

Abstract

In Brazil, battened double angle system is one of the systems most used in light truss, however, there are not any specific studies on its behavior, resulting in the fact that the standard procedures do not provide subsidies for the design of this section. Moreover, cold-formed steel simple angles under compression, mostly with slender legs, have an interesting structural behavior compared to other cold-formed steel shapes. Two critical modes are observed in the elastic stability analysis: (i) global flexural mode in the case of longer members and (ii) a coincident local-plate/global flexural-torsional mode, which is critical for shorter members. Studying the behavior of double angle members is interesting, because in this case, besides the critical modes of the single angle, they also show critical modes, due to the presence of the batten plates that sometimes interfere with the behavior of the system. In this work, a nonlinear numerical analysis on the behavior of double angle in battened system is presented. The number of batten plates was varied studying their effectiveness in the nominal axial strength. The sensitivity of the members to initial geometric imperfections was also analyzed. Except for the thin angle specimen (t = 1.5 mm) the results obtained from the nonlinear analysis showed that the presence of the batten plates significantly increased the nominal axial strength of the members. However for an increased number of batten plates the nominal axial strength of the members remained almost constant. It was observed that the members were more sensitive to initial geometric imperfections increasing that to the number of batten plates.

---

[1]Graduate Student, [2]Professor, Department of Structural Engineering – School of Engineering of Sao Carlos – University of Sao Paulo – Av. Trabalhador Sao-Carlense, 400 – CEP 13566-590 – Sao Carlos, SP, Brazil – Tel.: +55 16 3373 9468
e-mails: wfmaia@sc.usp.br; jmunaiar@sc.usp.br; mamalite@sc.usp.br

1. Introduction

Members made of double angles within a battened system, consist of two identical sections which are placed parallely. They are slightly separated and linked with each other just in some points by batten plates. The here shown system is often used, mainly in light trusses, however, it is difficult to find specific studies about their behavior. Consequently the existing standard procedures do not offer subsidies for the project of this structural component. Besides, simple angles which are exposed to compression show a particular behavior if compared to other sections. Analysing the elastic stability one can observe two critical modes, (i) the flexural mode in longer members and (ii) the coincident local-plate/global flexural-torsional mode (in the following called local/torsional mode), which is seen in shorter members (Maia et.al. (2008)). It is highly relevant to study the behavior of members made of double angles, as there can be seen buckling in the members, caused by the batten plates, which tend to modify the behavior of the system.

This paper deals with a numerical analysis about the behavior of members of double angles with batten plates, using either simple or lipped angles. The analyses were done using Ansys (1997). We varied the number of batten plates in order to study their efficiency in the nominal axial strength of the members. The results from this analysis show that it could be interesting to carry out deeper studies for a better understanding of member-associated phenomena, especially for eccentric compression.

In order to compare the results, two design procedures based on ANSI/AISI S100 (2007) were used, considering axial compression. First each angle was considered as a single member, independently from batten plates, considering local, flexural-torsional and flexural buckling. In the second procedure the double angle was analysed based only on local and flexural buckling in relation to the minor main axis (x-axis – see figure 1).

2. Numerical analysis

The numerical simulations were carried out with FEM, using the program Ansys v9.0. The element SHELL 181 was used to model the sections, batten plates and the application device of the load. The element is ideal for the non-linear analysis of thin shells exposed to large strains and rotations.

There are results for two sections of the simple double angle and one section of the lipped double angle with load applied to the legs. Initially simulations were carried out where centred load was applied. After that the applied load was moved to the legs, which actually happens in reality. The analyses did not indicate significant differences concerning the models where load was applied to the centre or to the legs that is why in this article the latter was chosen to represent the results.

In all simulations it was paid attention to the fact that the nodes of the batten plates coincided with the nodes of the sections, guaranteeing the compatibilization of their displacement. The same procedure was adopted at the extremities, i.e. the nodes of the channel section agreed with the nodes of the angles. All the elements were kind of square, with sides of approximately 1cm, except for the edges and the lips which each had been divided in two equal parts. All the sections were built with the dimensions of the midline and using round edges with a radius of 1.5 times thickness. The batten plates were adapted to the width and thickness of the angles, using the same material. The simulations were carried out with fixed extremities, only allowing the rotation in relation to the minor axis (x-axis). In order to apply load a line through the centroid was created in the double angle (x-axis). The longitudinal displacement of the nodes in that line was the same in all nodes.

In the present analyses we evaluated the sensibility of the members in relation to the initial geometric imperfections. Furthermore the number of batten plates was varied during the studies in order to reflect on their efficiency in the nominal axial strength towards the member compression. Regarding the initial geometric imperfections for the simple double angles we adopted imperfections type 2 associated to the coincident local/torsional mode, whereas for the lipped double angle imperfections type 1 associated to the local mode and type 2 associated to the flexural-torsional mode, according to Schafer & Peköz (1998). For the imperfection associated to the flexural mode one adopted $L_c/1500$. In the simulations where one did not use the imperfection associated to the coincident local/torsional, local and flexural-torsional mode, there was also not associated any flexural mode.

Figure 1 shows an overview of the system with batten plates and the position of the angles. In Table 1 the analysed angles and the geometric properties are presented.

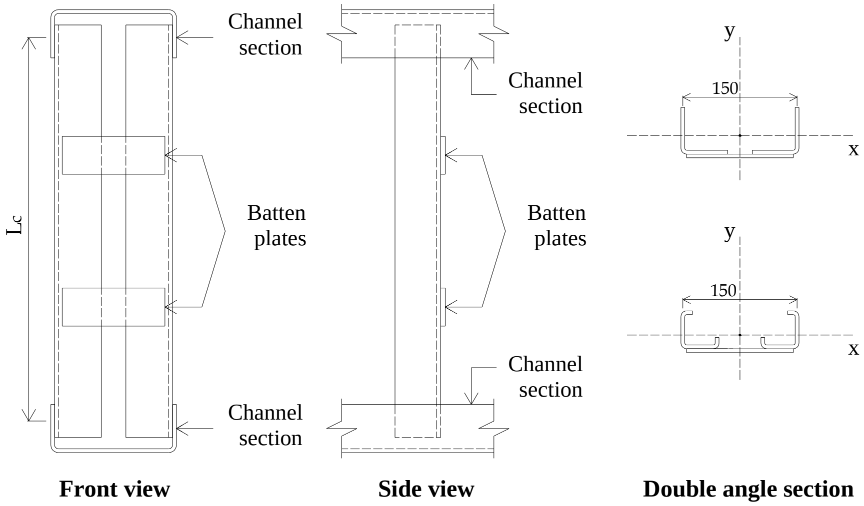


Figure 1 – Overview member in battened system

Table 1 – Sections and geometric properties

Section	**Leg (mm)**	**Lip (mm)**	**Thickness (mm)**	**Area (cm^2)**	**I_x (cm^4)**
2L 60x1.50	60	-	1.50	3.53	12.93
2L 60x3.00	60	-	3.00	6.90	24.75
2Le 50x15x1.50	50	15	1.50	3.68	12.02

3. Results

In the Tables 2 to 4 and the Figures 2 to 12 the results are shown, regarding the analyses of the sensibility towards the initial geometric imperfections compared to theoretical procedures.

Table 2 – Sensibility analysis of initial geometric imperfections: section 2L 60x1.50

L_c (mm)	Batten plates	Imperfections (local/torsional and flexural)	P_{FE} (kN)	Failure mode	P_{FE}/P_y
600 (λ_x=31)	0	0 and 0	41.7	LT+F*	0.43
		0.64t and L_c/1500	39.8	LT+F*	0.41
		1.55t and L_c/1500	34.5	LT+F*	0.36
	2	0 and 0	34.8	LT	0.36
		0.64t and L_c/1500	33.0	LT	0.34
		1.55t and L_c/1500	31.6	LT	0.33
	4	0 and 0	35.3	LT	0.37
		0.64t and L_c/1500	32.5	LT	0.34
		1.55t and L_c/1500	30.3	LT	0.31
1200 (λ_x=63)	0	0 and 0	29.4	LT+F*	0.30
		0.64t and L_c/1500	29.3	LT+F*	0.30
		1.55t and L_c/1500	NC	-	-
	2	0 and 0	30.2	LT+F	0.31
		0.64t and L_c/1500	27.9	LT+F	0.29
		1.55t and L_c/1500	26.9	LT+F	0.28
	5	0 and 0	30.0	LT+F	0.31
		0.64t and L_c/1500	26.8	LT+F	0.28
		1.55t and L_c/1500	24.4	LT+F	0.25
	7	0 and 0	31.1	LT+F	0.32
		0.64t and L_c/1500	25.4	LT+F	0.26
		1.55t and L_c/1500	22.3	LT+F	0.23
1800 (λ_x=94)	0	0 and 0	19.8	LT+F*	0.21
		0.64t and L_c/1500	NC	-	-
		1.55t and L_c/1500	NC	-	-
	1	0 and 0	23.9	LT+F	0.25
		0.64t and L_c/1500	23.2	LT+F	0.24
		1.55t and L_c/1500	22.6	LT+F	0.23
	2	0 and 0	25.0	LT+F	0.26
		0.64t and L_c/1500	22.7	LT+F	0.24
		1.55t and L_c/1500	21.9	LT+F	0.23
	6	0 and 0	26.0	LT+F	0.27
		0.64t and L_c/1500	22.4	LT+F	0.23
		1.55t and L_c/1500	20.0	LT+F	0.21
	11	0 and 0	27.1	LT+F	0.28
		0.64t and L_c/1500	20.5	LT+F	0.21
		1.55t and L_c/1500	16.9	LT+F	0.18

$P_y = A \cdot F_y$ = 96.4 kN – Squash load (F_y = 273 MPa)
P_{FE} = ultimate load from finite element analysis
L_c = member length ($\lambda_x = L_c/r_x$)
LT = coincident local/torsional mode (single angle), F* = flexural mode (single angle), F = flexural mode (double angle), NC = FE analysis did not converge

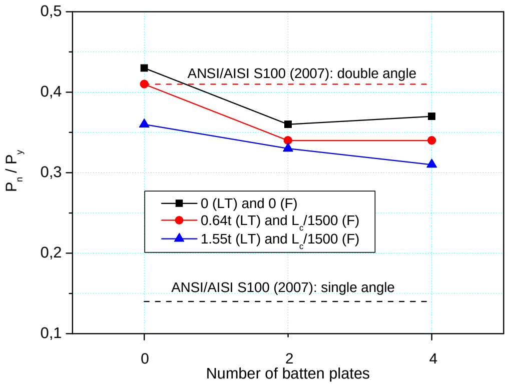


Figure 2 – Sensibility analysis of imperfections: section 2L 60x1.50 (L_c = 600 mm)

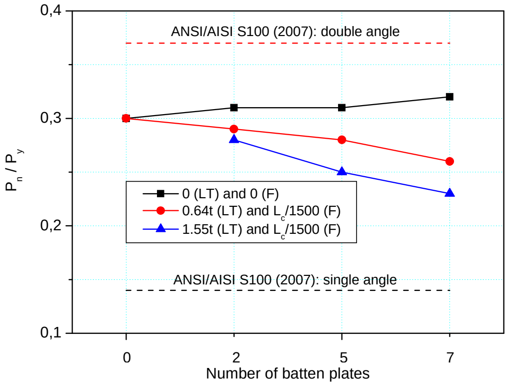


Figure 3 – Sensibility analysis of imperfections: section 2L 60x1.50 (L_c = 1200 mm)

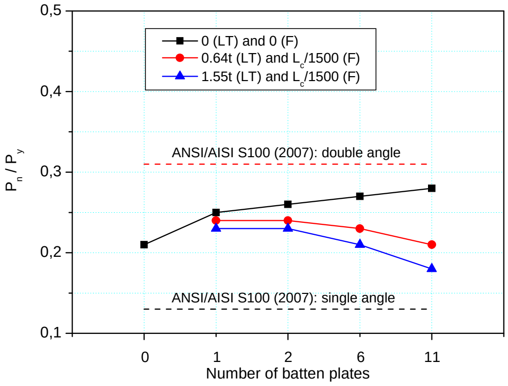


Figure 4 – Sensibility analysis of imperfections: section 2L 60x1.50 (L_c = 1800 mm)

Table 3 – Sensibility analysis of initial geometric imperfections: section 2L 60x3.00

L_c (mm)	Batten plates	Imperfections (local/torsional and flexural)	P_{FE} (kN)	Failure mode	P_{FE}/P_y
600 (λ_x=32)	0	0 and 0	94.6	LT+F*	0.50
		0.64t and L_c/1500	NC	-	-
		1.55t and L_c/1500	NC	-	-
	1	0 and 0	133.1	LT+F	0.71
		0.64t and L_c/1500	111.6	LT+F	0.59
		1.55t and L_c/1500	96.8	LT+F	0.51
	2	0 and 0	143.5	LT+F	0.76
		0.64t and L_c/1500	126.4	LT	0.67
		1.55t and L_c/1500	108.8	LT+F	0.58
	4	0 and 0	150.9	LT+F	0.80
		0.64t and L_c/1500	122.0	LT+F	0.65
		1.55t and L_c/1500	96.9	LT+F	0.51
1200 (λ_x=63)	0	0 and 0	67.8	LT+F*	0.36
		0.64t and L_c/1500	NC	-	-
		1.55t and L_c/1500	NC	-	-
	1	0 and 0	118.2	LT+F	0.63
		0.64t and L_c/1500	102.2	LT+F	0.54
		1.55t and L_c/1500	92.9	LT+F	0.49
	2	0 and 0	127.5	LT+F	0.68
		0.64t and L_c/1500	112.5	LT+F	0.60
		1.55t and L_c/1500	99.9	LT+F	0.53
	5	0 and 0	142.6	F	0.76
		0.64t and L_c/1500	103.5	LT+F	0.55
		1.55t and L_c/1500	81.4	LT+F	0.43
	7	0 and 0	145.4	F	0.77
		0.64t and L_c/1500	97.0	LT+F	0.51
		1.55t and L_c/1500	71.9	LT+F	0.38
1800 (λ_x=95)	0	0 and 0	47.1	LT+F*	0.25
		0.64t and L_c/1500	NC	-	-
		1.55t and L_c/1500	NC	-	-
	1	0 and 0	97.4	LT+F	0.52
		0.64t and L_c/1500	88.8	LT+F	0.47
		1.55t and L_c/1500	83.9	LT+F	0.45
	2	0 and 0	111.0	LT+F	0.59
		0.64t and L_c/1500	94.3	LT+F	0.50
		1.55t and L_c/1500	85.9	LT+F	0.46

See next page…

… continuing Table 3

L_c (mm)	**Batten plates**	**Imperfections (local/torsional and flexural)**	**P_{FE} (kN)**	**Failure mode**	**P_{FE}/P_y**
1800 (λ_x=95)	4	0 and 0	112.9	F	0.60
		0.64t and L_c/1500	91.7	LT+F	0.49
		1.55t and L_c/1500	81.8	LT+F	0.43
	6	0 and 0	108.8	F	0.58
		0.64t and L_c/1500	84.1	LT+F	0.45
		1.55t and L_c/1500	67.9	LT+F	0.36
	11	0 and 0	102.4	F	0.54
		0.64t and L_c/1500	74.4	LT+F	0.39
		1.55t and L_c/1500	53.0	LT+F	0.28
2400 (λ_x=127)	0	0 and 0	33.1	F*	0.18
		0.64t and L_c/1500	NC	-	-
		1.55t and L_c/1500	NC	-	-
	1	0 and 0	68.0	LT+F	0.36
		0.64t and L_c/1500	61.8	LT+F	0.33
		1.55t and L_c/1500	61.9	LT+F	0.33
	2	0 and 0	76.5	LT+F	0.41
		0.64t and L_c/1500	67.2	LT+F	0.36
		1.55t and L_c/1500	65.6	LT+F	0.35
	4	0 and 0	75.1	F	0.40
		0.64t and L_c/1500	63.8	LT+F	0.34
		1.55t and L_c/1500	57.3	LT+F	0.30
	8	0 and 0	72.9	F	0.39
		0.64t and L_c/1500	60.7	LT+F	0.32
		1.55t and L_c/1500	50.8	LT+F	0.27

$P_y = A \cdot F_y$ = 188.4 kN – Squash load (F_y = 273 MPa)
P_{FE} = ultimate load from finite element analysis
L_c = member length ($\lambda_x = L_c/r_x$)
LT = coincident local/torsional mode (single angle)
F* = flexural mode (single angle)
F = flexural mode (double angle)
NC = FE analysis did not converge

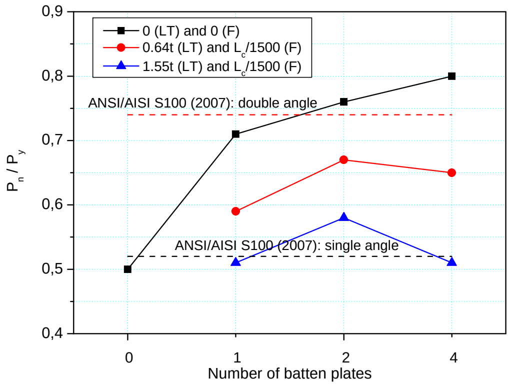


Figure 5 – Sensibility analysis of imperfections: section 2L 60x3.00 (L_c = 600 mm)

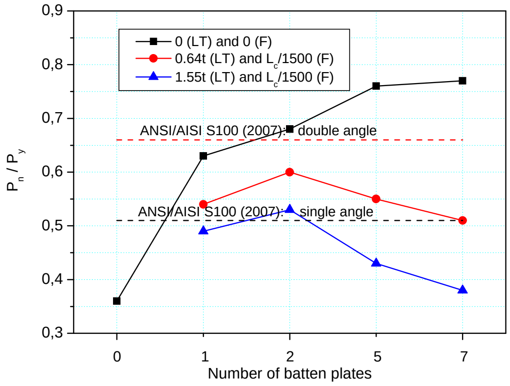


Figure 6 – Sensibility analysis of imperfections: section 2L 60x3.00 (L_c = 1200 mm)

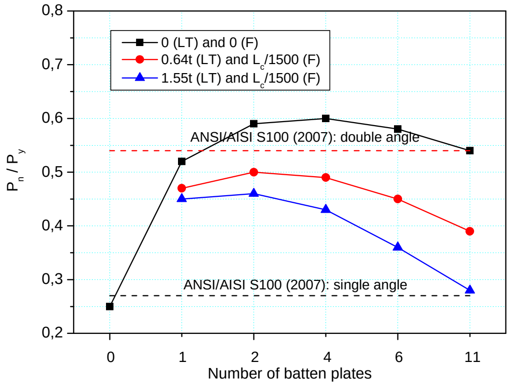


Figure 7 – Sensibility analysis of imperfections: section 2L 60x3.00 (L_c = 1800 mm)

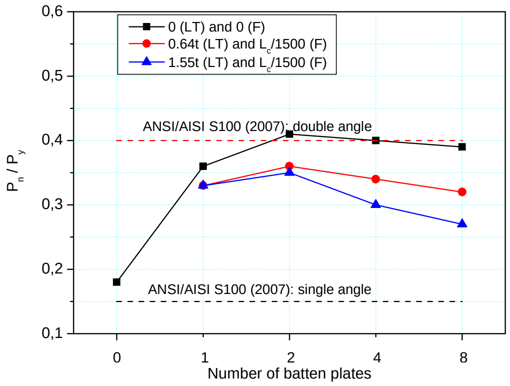


Figure 8 – Sensibility analysis of imperfections: section 2L 60x3.00 (L_c = 2400 mm)

Table 4 – Sensibility analysis of initial geometric imperfections: section 2Le 50x15x1.50

L_c (mm)	Batten plates	Imperfections (local; flexural-torsional and flexural)	P_{FE} (kN)	Failure mode	P_{FE}/P_y
600 (λ_x=33)	0	0; 0 and 0	47.7	FT+F*	0.47
		0.14t; 0.64t and L_c/1500	NC	-	-
	1	0; 0 and 0	62.0	FT+F	0.62
		0.14t; 0.64t and L_c/1500	58.5	FT+F	0.58
	2	0; 0 and 0	64.0	FT+F	0.64
		0.14t; 0.64t and L_c/1500	61.1	FT+F	0.61
	4	0; 0 and 0	65.3	FT+F	0.65
		0.14t; 0.64t and L_c/1500	62.4	FT+F	0.62
1200 (λ_x=66)	0	0; 0 and 0	34.3	FT+F*	0.34
		0.14t; 0.64t and L_c/1500	NC	-	-
	1	0; 0 and 0	46.5	FT+F	0.46
		0.14t; 0.64t and L_c/1500	44.5	FT+F	0.44
	2	0; 0 and 0	54.7	FT+F	0.54
		0.14t; 0.64t and L_c/1500	48.4	FT+F	0.48
	4	0; 0 and 0	62.6	FT+F	0.62
		0.14t; 0.64t and L_c/1500	59.7	FT+F	0.59
	6	0; 0 and 0	64.0	FT+F	0.64
		0.14t; 0.64t and L_c/1500	62.4	FT+F	0.62
1800 (λ_x=100)	0	0; 0 and 0	23.8	FT+F*	0.24
		0.14t; 0.64t and L_c/1500	NC	-	-
	1	0; 0 and 0	38.2	FT+F	0.38
		0.14t; 0.64t and L_c/1500	30.1	FT+F	0.30
	2	0; 0 and 0	45.3	FT+F	0.45
		0.14t; 0.64t and L_c/1500	36.3	FT+F	0.36

See next page…

… continuing Table 4

L_c (mm)	Batten plates	Imperfections (local; flexural-torsional and flexural)	P_{FE} (kN)	Failure mode	P_{FE}/P_y
1800 (λ_x=100)	4	0; 0 and 0	56.4	FT+F	0.56
		0.14t; 0.64t and L_c/1500	47.6	FT+F	0.47
	6	0; 0 and 0	54.5	F	0.54
		0.14t; 0.64t and L_c/1500	47.1	F	0.47
	8	0; 0 and 0	53.4	F	0.53
		0.14t; 0.64t and L_c/1500	46.7	F	0.46
2400 (λ_x=133)	0	0; 0 and 0	16.6	FT+F*	0.17
		0.14t; 0.64t and L_c/1500	NC	-	-
	1	0; 0 and 0	29.4	FT+F	0.29
		0.14t; 0.64t and L_c/1500	26.7	FT+F	0.27
	2	0; 0 and 0	32.8	FT+F	0.33
		0.14t; 0.64t and L_c/1500	29.7	FT+F	0.30
	4	0; 0 and 0	36.1	F	0.36
		0.14t; 0.64t and L_c/1500	31.0	F	0.31
	6	0; 0 and 0	36.0	F	0.36
		0.14t; 0.64t and L_c/1500	32.7	F	0.33
	8	0; 0 and 0	35.8	F	0.36
		0.14t; 0.64t and L_c/1500	32.7	F	0.33

$P_y = A \cdot F_y$ = 100.5 kN – Squash load (F_y = 273 MPa)
P_{FE} = ultimate load from finite element analysis
L_c = member length ($\lambda_x = L_c/r_x$)
FT = flexural-torsional mode (single angle)
F* = flexural mode (single angle)
F = flexural mode (double angle)
NC = FE analysis did not converge

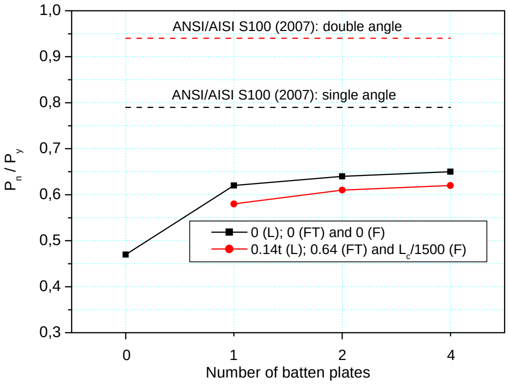


Figure 9 – Sensibility analysis of imperfections: section 2Le 50x15x1.50 (L_c = 600 mm)

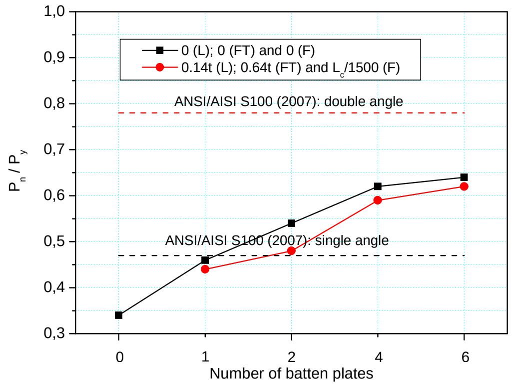


Figure 10 – Sensibility analysis of imperfections: section 2Le 50x15x1.50 (L_c = 1200 mm)

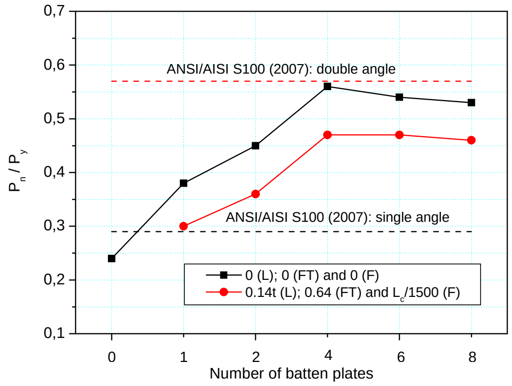


Figure 11 – Sensibility analysis of imperfections: section 2Le 50x15x1.50 (L_c = 1800 mm)

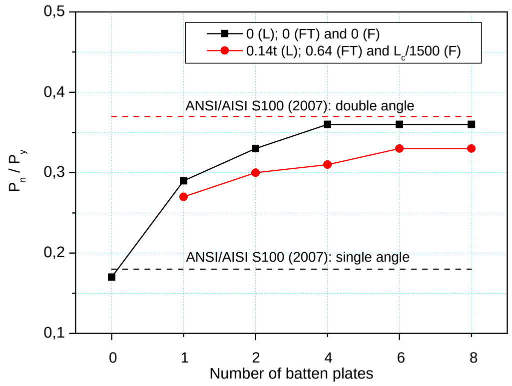
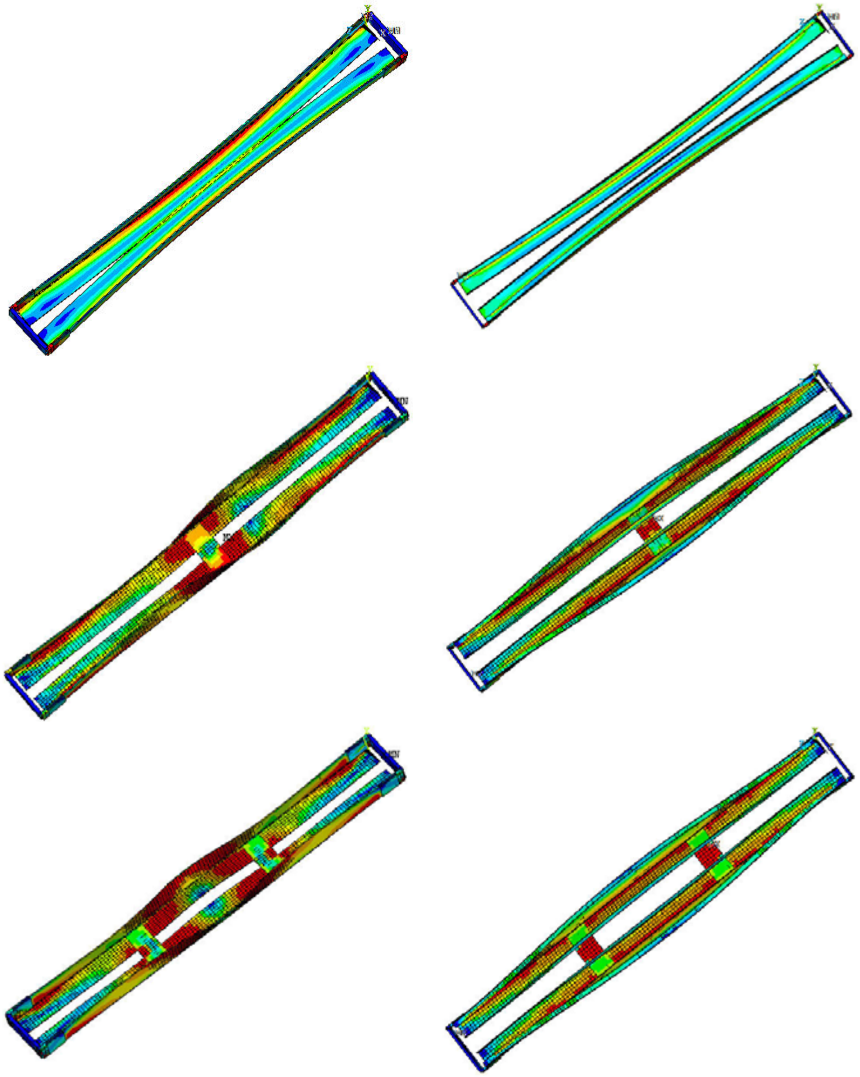


Figure 12 – Sensibility analysis of imperfections: section 2Le 50x15x1.50 (L_c = 2400 mm)

Figure 13 shows buckling modes obseved in the analyses of the simple or the lipped double angles for different numbers of batten plates.



(a) **(b)**

Figure 13 – Buckling modes observed in the numerical analysis
(a) simple double angle (b) lipped double angle

The results of the analysis of the members in simple double angles (2L 60x1.50) shows that the insertion of batten plates did generally not improve the behavior of the members. On the contrary, in some cases it even worsened it, mainly in members with high imperfections of the local/torsional type (LT). This behavior can be explained by the fact that here we deal with a section of an elevated width-thickness ratio. The most dominant mode of buckling was the local/torsional one, and because of this the increase of the local/torsional imperfection can have induced the early buckling. Moreover, with the increasing number of batten plates there was a greater shift of the effective centroid of the section, a fact that was not taken into consideration in the analysis, and created a number of effects, i.e. the initial geometric imperfection and the shift of the centroid of the section. During the analyses the most critical combination was considered.

For the 2L 60x3.00 section the insertion of batten plates raised the nominal axial strength significantly, however, from a certain number on one could observe that the nominal axial strength stayed practically the same for the members with a low rate of imperfections. In the case of members with a high rate of imperfections one observed a tendency of reduction in the nominal axial strength. It is of importance that this fact occurs mostly in short members, i.e. where there is seen some predominance of local/torsional buckling.

For the lipped double angle (2Le 50x15x1.50) one can observe that the insertion of the batten plates also increased significantly the nominal axial strength, however, like in the case of the simple double angles, there was a certain number of plates from which on the nominal axial strength almost remained the same. It is important to observe that in this case the members do not tend to reduce their nominal axial strength.

4. Conclusions

The numeric analysis generally shows intermediate results among the ones obtained by the theoretical procedures. It was observed that for the members with a predominance of flexural buckling the results tended to look like the ones for the double angle, however, in the case of the members with a predominance of local/torsional (in simple double angles) or flexural-torsional (in lipped double angles) buckling the results showed the need for a procedure that evaluates more adequately the influence of the local and flexural-torsional modes.

The influence of the number of batten plates deserves a closer and more detailed investigation, considering that from a certain number on the nominal axial strength of the member remains practically constant for a low rate of imperfections and tends to decrease for the ones with a high rate of imperfections. Thus, one can deduct that it is necessary to deepen the knowledge of a numeric analysis as well as a realization of an experimental program which allows the evaluation and gives some consistency to the here obtained results.

Acknowledgments

Research conducted in this paper was supported by CNPq.

References

ANSI/AISI S100. North American Specification for the Design of Cold-Formed Steel Structural Members. American Iron and Steel Institute, Washington, DC, 2007.

Ansys. Structural nonlinearities: user's guide for revision 5.5, Houston. v.1, 1997.

Maia, W. F.; Munaiar Neto, J.; Malite, M. Stability of cold-formed steel simple and lipped angles under compression. In: LaBoube, R.A.; Yu, W.W. (Ed). Recent research and developments in cold-formed steel design and construction (19th International Specialty Conference on Cold-Formed Steel Structures, St. Louis, USA, Oct. 14 & 15, 2008). Missouri University of Science & Technology, Rolla, Missouri, USA, 2008.

Schafer, B.W.; Peköz, T. Computational modeling of cold-formed steel: characterizing geometric imperfections and residual stresses. Journal of Constructional Steel Research, v.47, 193-210, 1998.