Analysis of the distortional buckling curves of cold-formed steel beams through GBTUL and DSM

L. Cruvinel[1], G. Vieira[1], E. Silva[1]

[1] *Universidade Federal de Uberlândia*
Av. João Naves de Ávila, 212 - Santa Mônica, Uberlândia - 38408-100, Minas Gerais, Brazil
lucasrabelo.c@gmail.com, gregorio.vieira@ufu.br, Emersonrodrigues.72@gmail.com

Abstract. Due to the wide variety of cross-section as well as their good mass/strength ratio, cold-formed steel (CFS) components are gaining prominence among metal structures. However, this material is more susceptible to local, distortional, and global buckling. The Direct Strength Method (DSM) requires obtaining the buckling critical loads and applying these data in conjunction with a series of resistance curves to determine the final cross-section strength. This study aims to investigate the behavior of distortional buckling mode for a CFS simply supported beam, and to compare the results obtained through DSM and GBTUL (software responsible for numerical computational analysis). To obtain the data, the GBTUL was used, which, in turn, uses the geometries and flow stresses. For this analysis, a cold-formed, non-drilled, multi-dimension section was chosen. From the analyses presented in this paper, it was noticed that the distortional curves available in the Brazilian standard do not overestimate the final strength of the CFS beams simply supported when subjected to uniform bending.

Keywords: Buckling; Cold-formed steel; Direct Strength Method; Distortional curves; GBTUL.

1 Introduction

In the last decades, there has been a great evolution in the civil construction industry, boosting the development of new technologies, which are searching for low cost, versatile, and high-quality materials. Cold-formed steel profiles (CFS) are an attractive product within civil construction because they present high ratio resistance/weight, better use of space on the construction site, and great ease of obtaining open sections due to their malleability, giving you great employability in works that need greater architectural freedom. Between the most common sections in the CFS models, there are, for example, the U and the Rack type section (Figure 1).

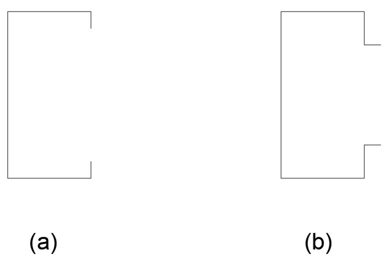

Figure 1. (a) U stiffened e (b) Rack

As they are profiles developed from the folding of thin plates, they are more susceptible to local, global, and distortion buckling. As it affects the bearing capacity of the CFS, it is essential to know the buckling mode and its respective critical strength.

For the determination of such efforts, computer programs or normative procedures can be used, such as those described in the Brazilian standard ABNT NBR 14762: 2010 [1], which define the necessary calculations for the design of CFS. Computer programs are based on numerical methods while a large part of the design standards for CFS is based on the Effective Width Method (EWM). The Effective Section Method (ESM), developed by Batista [2], has been incorporated into the Brazilian standard in its current version. In addition to these, the Direct Resistance Method (DSM), developed by Schafer [3], is also presented in ABNT NBR 14762: 2010 [1], and in the American standard AISI S100-16 [4].

The DSM was initially formulated for columns subjected to compression. This method has shown simple and accurate by, through direct calculations, design beams subjected to centered compression and simple bending. The calculation of critical stresses by DSM uses the dimensions of the cross-section and performs an interaction between the elements that compose it, maintaining its conditions of equilibrium and compatibility.

In their numerical and experimental investigation, Yu and Schafer [5] obtained results that were used to calibrate the DSM distortional curve. Through elastic analysis, the method obtained the critical values for the bend moments of distortion buckling that are fundamental for the design through the normative curve of the DSM. The curve shown is present in the American standard AISI (American Iron and Steel Institute). In the United States, this curve is used for beams subjected to simple bending, symmetrical about the bending axis, and with the initial yield point in the most compressed fibers.

In another way, the General Beam Theory (GBT), was originally developed by Schardt [6], being greatly responsible for improving the understanding of the distortion buckling mode. According to Silvestre and Camotim [7], GBT has proven to be a very efficient and elegant tool for investigating the CFS buckling behavior. Based on the GBT, Bebiano et. al. [8] developed the GBTUL software, to determine the buckling modes and critical tensions, with the possibility of modal decomposition as a differential. According to Faria [9] the tool allows the evaluation of the buckling modes and the critical forces of the section for different beam lengths.

2 Objectives

To analyze, if the current distortion curve used by the DSM of ABNT NBR 14762: 2010 [1] overestimates the CFS bars simply supported, a comparison was made between the buckling curves obtained with the use of DSM and GBTUL. Thus, it intends to expand the knowledge about the distortional buckling mode in rack sections under simple bending, in addition to understanding the relationship between the variations of the cross-section dimensions and the critical load of distortional buckling, as well as the factors that influence the differences in critical load from one beam model to another.

3 Methods

The results presented in this work were collected from analyzes carried out in the GBTUL software and by DSM, found in ABNT NBR 14762: 2010 [1].

To reach the proposed objectives, proceed initially with the selection of cross-sections in which the distortional buckling was predominant. In this way, 8 CFS beams rack type were selected (Table 1 and Figure 2), ASTM A36 steel, with yield stress of 250 MPa, elasticity modulus (E) of 210 GPa , Poisson's ratio of 0.3 and a specific mass of 7850 kg/m^3.

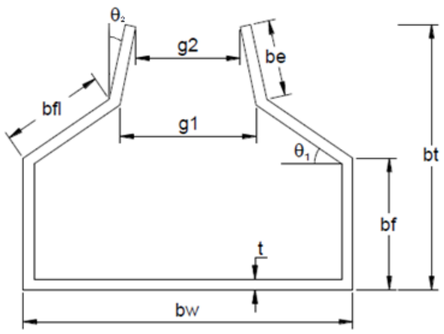

Figure 2. Variables of cross-section rack type

After defining the cross-sections configurations, these models were launched at GBTUL. With the processing done by the software, it was possible to obtain the buckling curve, as well as M_{dist} for each model length. To

Table 1. Studied beams cross-sections

Models	bw(mm)	bf(mm)	bfl(mm)	be(mm)	$\theta(°)$	$\theta 2(°)$	t(mm)
1	80	70	15	10	32	0	2,0
2	80	70	15	10	32	0	1,5
3	75	65	10	5	32	0	2,0
4	75	65	10	5	32	0	1,5

determine for which lengths the distortion buckling is the predominant mode, the participation of each mode was analyzed, being selected the lengths with distortional modal participation above 85%. For the present work, it was determined that the beams were simply supported and subjected to a bending moment of 1000 Nm, at both ends of the beam, configuring a situation of simple bending.

With the lengths defined and using M_{dist} for each length, the values of M_{Rdist} (DSM) were calculated for each model. They were also used to do this calculation, the values of the area, the moment of inertia (I), the module of elastic resistance of the cross-section (W), the yield stress of steel (f_y) and the product between W and f_y (Table 2).

Table 2. Selected models properties

Modelos	Área$(10^2 \cdot mm^2)$	$I(10^4 \cdot mm^4)$	$W(10^3 \cdot mm^3)$	$Fy(MPa)$	$WFy(Nm)$
1	5.40	65.27	16.32	250	4079.4
2	4.05	48.95	12.24	250	3059.4
3	4.70	50.55	13.48	250	3370.0
4	3.52	37.91	10.11	250	2527.3

4 Results and Discussions

4.1 GBTUL Analysis

The results obtained by the analysis in GBTUL were reached while the material was still in the elastic regime. They are presented in Tables 3 and 4, in which the P4 mode refers to the beam torsion and the P5 and P6 modes are distortional buckling modes (Figure 3).

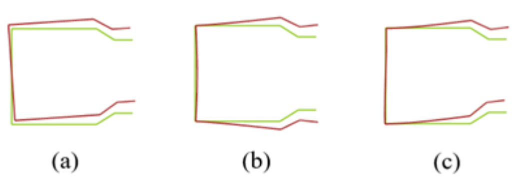

Figure 3. (a) P4, (b) P5 e (c) P6

From the values found for M_{dist}, it can be seen that there is no significant variation at the moment for the length of the beams. In all of them, the analyzes were performed varying only the cross-sections of the pieces, keeping the values of the applied bending moment constant, as well as the area of the cross-sections and the moments of inertia are not constant. As expected, models with a larger area and moment of inertia have higher values of M_{dist}. The increase in thickness (t) of the profiles, significantly increases the values of M_{dist}. This

Table 3. Distortional buckling moments e modal participation of the models 1 e 2

Model 1						Model 2					
L	M_{dist}	Modal participation(%)				L	M_{dist}	Modal participation(%)			
(mm)	(Nm)	P5	P6	P4	others	(mm)	(Nm)	P5	P6	P4	others
2000	4201.3	48.62	43.60	3.29	4.49	2000	2240.8	47.99	41.83	3.51	6.67
2100	4215.4	48.65	43.26	3.71	4.38	2100	2231.4	48.12	43.61	2.76	5.51
2200	4234.0	49.06	44.91	2.56	3.47	2200	2220.5	48.40	43.77	2.98	4.85
2300	4209.2	49.21	44.93	2.73	3.12	2300	2220.5	48.54	43.68	3.27	4.50
2400	4202.2	49.31	44.81	2.95	2.93	2400	2229.6	48.59	43.43	3.62	4.36
2500	4209.5	49.36	44.62	3.18	2.83	2500	2244.7	48.53	43.08	3.99	4.40
2600	4208.5	48.19	43.67	4.29	3.85	2600	2234.2	49.13	45.10	2.61	3.16

Table 4. Distortional buckling moments e modal participation of the models 3 e 4

Model 3						Model 4					
L	M_{dist}	Modal participation(%)				L	M_{dist}	Modal participation(%)			
(mm)	(Nm)	P5	P6	P4	others	(mm)	(Nm)	P5	P6	P4	others
1600	3512.9	47.66	43.15	2.57	6.62	1600	1795.7	46.91	42.98	2.26	7.85
1700	3489.1	48.31	44.81	1.82	5.06	1700	1795.5	47.36	43.28	2.16	7.20
1800	3483.3	48.52	44.84	2.01	4.63	1800	1807.2	47.52	43.21	2.44	6.83
1900	3495.2	48.60	44.74	2.19	4.47	1900	1806.6	48.15	44.77	1.72	5.36
2000	3473.8	48.32	44.92	2.38	4.38	2000	1801.9	48.42	44.98	1.86	4.74
2100	3466.5	48.30	44.75	2.73	4.22	2100	1806.2	48.57	44.98	2.03	4.43
2200	3469.8	47.99	44.19	3.38	4.44	2200	1810.3	48.28	45.09	2.12	4.50

fact can be observed when comparing models 1 and 2, in which the only difference in the section is the thickness. Whereas for the length of 2000 mm, model 1 has a M_{dist} of 4201.3 Nm, model 2 has a M_{dist} of 2240.8 Nm. This means an increase of 87.5% from M_{dist} from model 2 to model 1, for the same beam length.

4.2 The Direct Strength Method (DSM)

It is possible to observe that the slenderness of models is different for the same length values. This is due to the variation of the cross-section existing between the models. From the values presented in table 2 and the values of M_{dist} obtained by GBTUL it was possible to obtain the values of the estimated slenderness ratio (Tables 5). After calculating the slenderness, it was possible to calculate the values of M_{Rdist} for each model. (Table 6).

It is possible to observe a similar behavior of the values obtained by the GBTUL since the values of M_{Rdist} do not present significant variations with the increase in the lengths of the models. The values of M_{Rdist} also decrease with the thickness decrease of the profiles, because there is a reduction in the area and moment of inertia of the sections.

4.3 Results Comparison

Through the distortional buckling moments values presented above, was made a comparison of results between the two methods (Tables 7 and 8).

Table 5. Distortional buckling slenderness ratio (λ_{dist}) of the models 1 to 4

L (mm)	Model 1	Model 2	L (mm)	Model 3	Model 4
2000	0.9854	1.1685	1600	0.9794	1.1864
2100	0.9837	1.1709	1700	0.9828	1.1864
2200	0.9816	1.1738	1800	0.9836	1.1826
2300	0.9845	1.1738	1900	0.9819	1.1828
2400	0.9853	1.1714	2000	0.9849	1.1843
2500	0.9844	1.1674	2100	0.9860	1.1829
2600	0.9845	1.1702	2200	0.9855	1.1816

Table 6. Distortional buckling bend moment (M_{Rdist}) of the models 1 to 4 (Nm)

L (mm)	Model 1	Model 2	L (mm)	Model 3	Model 4
2000	3215.6	2125.3	1600	2667.9	1735.3
2100	3219.4	2121.9	1700	2661.4	1735.2
2200	3224.5	2117.9	1800	2659.9	1739.6
2300	3217.8	2117.9	1900	2663.1	1739.3
2400	3215.8	2121.2	2000	2657.3	1737.6
2500	3217.8	2126.7	2100	2655.3	1739.2
2600	3217.6	2122.9	2200	2656.2	1740.7

Table 7. Distortional buckling moments comparison between GBTUL and DSM (Modelos 1 e 2)

Model 1			Model 2		
L (mm)	$M_{dist}(Nm)$	$M_{Rdist}(Nm)$	L (mm)	$M_{dist}(Nm)$	$M_{Rdist}(Nm)$
2000	4201.3	3215.6	2000	2240.8	2125.3
2100	4215.4	3219.4	2100	2231.4	2121.9
2200	4234.0	3224.5	2200	2220.5	2117.9
2300	4209.2	3217.8	2300	2220.5	2117.9
2400	4202.2	3215.8	2400	2229.6	2121.2
2500	4209.5	3217.8	2500	2244.7	2126.7
2600	4208.5	3217.6	2600	2234.2	2122.9

From the results found, can be observed that the values of M_{Rdist} obtained by DSM were smaller than M_{dist} found by GBTUL. For models with a thickness of 2 mm, the percentage difference between the two methods was greater than models with a thickness of 1.5 mm. The percentage difference for models of 2 mm exceeds 20%, while the difference for models of 1.5 mm does not exceed values of 7%. (Table 9).

Table 8. Distortional buckling moments comparison between GBTUL and DSM (Modelos 3 e 4)

Model 3			Model 4		
L (mm)	$M_{dist}(Nm)$	$M_{Rdist}(Nm)$	L (mm)	$M_{dist}(Nm)$	$M_{Rdist}(Nm)$
1600	3512.9	2667.9	1600	1795.7	1735.3
1700	3489.1	2661.4	1700	1795.5	1735.2
1800	3483.3	2659.9	1800	1807.2	1739.6
1900	3495.2	2663.1	1900	1806.6	1739.3
2000	3473.8	2657.3	2000	1801.9	1737.6
2100	3466.5	2655.3	2100	1806.2	1739.2
2200	3469.8	2656.2	2200	1810.3	1740.7

Table 9. Moment percentage difference between GBTUL and DSM

Models					
L (mm)	1	2	L (mm)	3	4
2000	23.46	5.15	1600	24.06	3.36
2100	23.63	4.91	1700	23.72	3.36
2200	23.84	4.62	1800	23.64	3.74
2300	23.55	4.62	1900	23.81	3.72
2400	23.47	4.86	2000	23.51	3.57
2500	23.56	5.26	2100	23.40	3.71
2600	23.55	4.98	2200	23.45	3.84

5 Conclusion

From the results obtained by the two methods, it can be concluded that for both MRD and GBTUL results the distortional buckling moment for the different lengths behaved similarly in all tested models, suffering little variation in the length range where the distortional mode is the predominant mode.

Analyzing all beam models, the values of the distortional moments were variable from model to model. Observing these variations, it can be concluded that the increase in the dimensions or thickness of the cross-section and, consequently, the increase in the area and the moment of inertia, cause an increase in the distortional moment, in both calculation methods.

The values of the local and distortional buckling moment obtained in this investigation varied according to the cross-section of each of the studied beam models. It was found that, for CFS beams with a thickness of 2 mm, the DSM presented values that were more distant from the values found by the GBTUL computational method, when compared to the 1.5 mm beams.

Finally, it was observed that when using the GBTUL software, the distortional buckling moment values obtained were higher than the values calculated via DSM. Therefore, for the models presented in this work, the current DSM distortional curve proposed in ABNT NBR 14762: 2010 [1] does not overestimate the buckling resistance of CFS beams simply supported when subjected to uniform bending.

The comparison work between the results obtained by the EWM, ESM, and DSM methods presented at ABNT NBR 14762: 2010 [1] is under construction.

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