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NUMERICAL STUDY OF STABILITY OF COLD FORMED BUILT-UP COLUMNS

BY

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By means of numerical simulations using ANSYS program, the stability behaviour of built-up columns made of back-to-back cold-formed C sections, bolted together by C stitches, is analysed. Comparison of the numerical analysis with the results obtained using two different design methods and experimental results is provided.

1. Introduction

Battened columns composed of hot-rolled profiles are a common solution for heavily loaded compressed elements. Built-up columns made of back-to-back cold-formed C sections, bolted together by C stitches became also more frequently used in cold-formed steel framing. Such elements can be used in framed stuctures or as chords for trusses [1], as shown in Fig. 1.

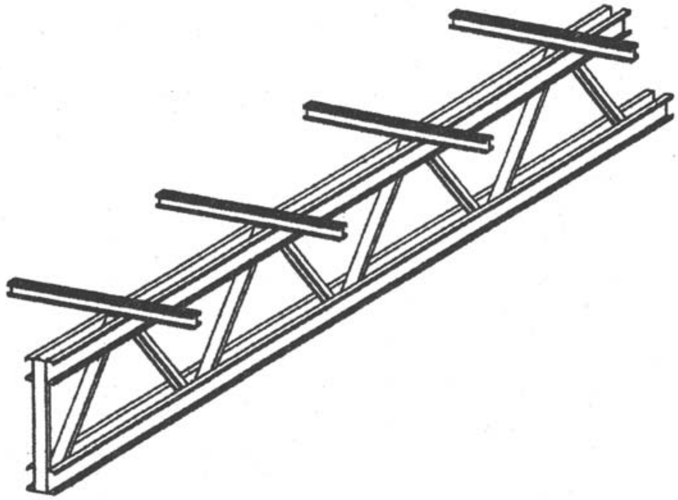

Fig. 1.– Built-up members – truss made of cold-formed C chords connected with bolted C stitches.

The European norm Eurocode 3 (prEN1993-1-1) does not contain specific provisions for such type of sections. However, the rules for classical battened columns could be used also for this particular case, provided that specific behaviour of thin-walled cold-formed sections is accounted for. Previous researches made by Rondal and Niazzi [7], [6], based on the formulas given by Johnston [5] for spaced hot-rolled columns in which the battens are attached to the chords by hinged connections, are the only dedicated recommendations to calculate the resistance of such cold-formed built-up members.

The present paper is aimed to calibrate a numerical model, able to reproduce the behaviour of built-up columns made by cold-formed C section elements *via* some experimental results and the above mentioned design methods.

2. Design Methods for Built-up Members with C Bolted Stitches

2.1. Eurocode 3 Method

The European norm Eurocode 3 provides that built-up compression members consisting of two or more main components connected together at intervals to form a single compound member, shall be designed incorporating an equivalent geometric imperfection comprising an initial bow of 1/500. The deformation of the compound member shall be taken into account in determining the internal forces and moments in the main components.

The chord force, $N_{f,Sd}$, at mid-length, should be determined from:

$$N_{f,Sd} = 0.5\left(N_{Sd} + \frac{M_s h_0 A_f}{I_{\text{eff}}}\right), \tag{1}$$

where

$$M_s = \frac{N_{Sd} e_0}{1 - N_{sd}/N_{\text{cr}} - N_{Sd}/S_v}, \tag{2}$$

$$(3) \qquad e_0 = \frac{l}{500}, \qquad (4) \qquad N_{\text{cr}} = \frac{\pi^2 E I_{\text{eff}}}{l^2}.$$

In Eq. (1) the effective in-plane second moment of area, I_{eff}, of the battened member should be taken as:

$$I_{\text{eff}} = 0.5 h_0^2 A_f + 2 I_f \qquad \text{if} \qquad \lambda = \frac{l}{i_0} \leq 75, \tag{5}$$

where A_f is the cross-sectional area of one chord, h_0 – the distance between centroids of chords and i_0 – the radius of gyration for the battened member, computed by means of I_{eff} from Eq. (5).

Provided that the connections of battens to the chords may be assumed as hinged, as shown further in the Rondal and Niazzi proposal (*op. cit.*) the shear stiffness, S_v, is zero. Thus, the chord force, $N_{f,Sd}$, from Eq. (1), becames half of the applied force:

$$N_{f,Sd} = 0.5N_{sd}. \tag{6}$$

In case of C cold-formed sections, the ultimate axial load capacity is reached when this chord load, $N_{f,Sd}$, is equal to the buckling resistance, $N_{b,Rd}$, computed considering the effective cross-section properties, according to Eurocode 3 Part 1.3 [4]:

$$N_{b,Rd} = \chi A_{\text{eff}} f_y. \tag{7}$$

The buckling length of the chord is equal to the distance between two battens. Buckling curve, B, should be considered, in case of C cold-formed sections, as Eurocode 3 Part 1.3 provides.

2.2. Rondal & Niazzi Proposal

This proposal is based on previous findings of Johnston (*op. cit.*) concerning the effect of the end-tie plates in spaced hot-rolled columns, in which the battens are attached to the column elements by hinged connection. Indeed, in the case of C cold-formed battened columns, the junction between the profiles, realized with bolted C stitches, is more flexible than the battened plates, and may be considered as hinged. Two modes of buckling for hinged columns are possible, as shown in Fig. 2.

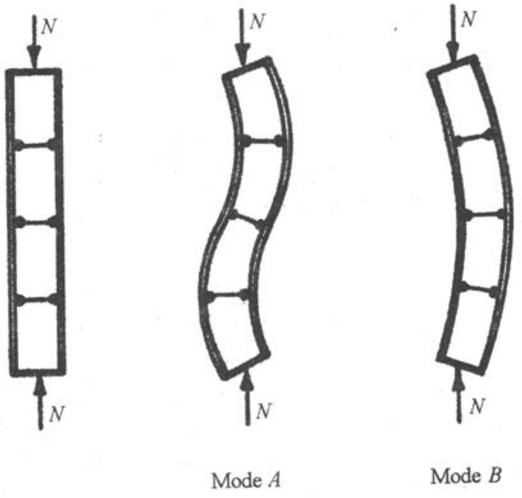

Fig. 2.– Model of a column with C stitches.

It must be noted that in Mode A buckling there is no differential change of length between the two members of the battened column. Thus, the two longitudinal column components may buckle in Mode A under identical loads, $P/2$, and the critical load is independent of the ratio I/I_1, where I is the moment of inertia of th whole column and I_1 is the moment of a single profile [5]. The critical load of the battened column in this mode is:

$$P_{\mathrm{cr},A} = 8\frac{\pi^2 EI_1}{l^2}. \tag{8}$$

When the column buckles in Mode B, the shortening under column load is greater on the concave side than on the convex one; thus, there is an added internal resisting moment due to direct forces in the components that is added to the bending moments induced in the components themselves [5]. The critical load of the battened column in this mode is

$$P_{\mathrm{cr},B} = C\frac{EI_1}{l^2}. \tag{9}$$

The coefficient C is given as a function of the ratio I/I_1 and can be approximated with relation:

$$C = 14.91\ln\frac{I}{I_1} + 18, \quad \text{for} \quad 6 \le \frac{I}{I_1} \le 42. \tag{10}$$

These critical loads should be used to calculate the reduction factor, χ, for the relevant buckling mode of the battened column. Rondal and Niazzi proposed that the buckling curve for the battened column should be the same with the one for the single profile, so in case of C cold-formed sections, the buckling curve, B, is to be considered.Further, Eq. (7) should be used to calculate the buckling resistance of the battened column, in which, in this case, A_{eff} is the effective area of the entire cross section of the battened member.

3. Numerical Study

The numerical study was performed in order to calibrate a FEM model suitable to predict the ultimate load of built-up columns made of C cold-formed elements connected with bolted C stitches. For this purpose, 12 test results from the experimental program performed by Rondal and Niazzi (*op. cit.*) were considered. Two different C sections with two different lengths of specimens were considered, and three or four C stitches were used to built-up the battened elements. For each set of parameters, three tests were performed. Table 1 shows the specimen characteristics.

Table 1
Specimen Characteristics

Specimen	Chords dimensions mm	Stitches dimensions mm	Yield limit f_y kN/mm^2	Number of stitches	Stitches distance mm
120.4.4s (4.00 m)	$C120 \times 60 \times$ $\times 18.7 \times 2.4$	$C80 \times 40 \times$ $\times 15 \times 2.5$	455	4	1,300
120.3.4s (3.00 m)	$C120 \times 60 \times$ $\times 18.7 \times 2.4$	$C80 \times 40 \times$ $\times 15 \times 2.5$	455	4	970
180.4.4s (4.00 m)	$C180 \times 70 \times$ $\times 25 \times 2.97$	$C120 \times 60 \times$ $\times 19 \times 2.45$	428	4	1,300
180.4.3s (4.00 m)	$C180 \times 70 \times$ $\times 25 \times 2.97$	$C120 \times 60 \times$ $\times 19 \times 2.45$	428	3	1,300

The numerical simulations were performed with ANSYS program. SHELL43 plastic large strain elements were used for meshing the two C cold-formed chords and the C cold-formed stitches. A bilinear elastic-perfect plastic behaviour for material law was considered. Fig. 3 shows the numerical model.

The non-linear stability analysis of the considered specimens was performed considering overall sinusoidal imperfections of 1/1,000, corresponding to the European Recommendations ECCS (1987), respectively 1/500, corresponding to Eurocode 3 provisions for battened columns. This global imperfection was introduced simultaneously with the local geometrical imperfections. For the local imperfection, the values sugested by Schafer and Pekoz [8] was considered, *e.g.*:

$$(11)\quad d = 6te^{-2t} \qquad \text{or} \qquad d = 0.006w,$$

where w and t are the width and, respectively, the thickness of relevant wall of C cold-formed cross-section.

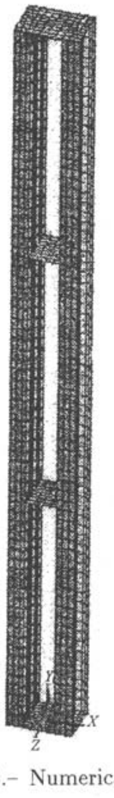

Fig. 3.– Numerical model.

4. Comparison Between Numerical Study, Experimental Results and Design Methods

Table 2 shows the comparison between the ultimate compression loads, P_u, computed with the Eurocode 3 provisions and Rondal and Niazi proposal, respectively, and with the ultimate loads given by the FEM analysis and tests. For the two design methods, both characteristic and design values, P_u/γ_{M1}, are given ($\gamma_{M1} = 1.1$). For Rondal and Niazi proposal and FEM analysis, the critical loads, P_{cr}, were also computed. The values between brackets, in ANSYS column of Table 2, represent the ultimate loads computed with an overall imperfection of 1/500, while the other ones are determined for 1/1,000.

Table 2
Ultimate and Critical Loads Obtained from Design Methods, Numerical Study and Tests, [kN]

Specimen type	EUROCODE 3		Rondal and Niazi proposal			ANSYS		Test
	P_u	P_u/γ_{M1}	P_{cr}	P_u	P_u/γ_{M1}	P_{cr}	P_u	P_u
120.4.4s	217	197	251	184	167	264	224 (178)	200 219 *188* $m = 202$ $s = 12.8$
120.3.4s	385	350	446	268	244	451	341 (232)	345 310 *308* $m = 321$ $s = 17$
180.4.4s	550	500	599	374	340	598	461 (406)	410 467 *330* $m = 402$ $s = 56.2$
180.4.3s	437	397	599	374	340	597	460 (405)	438 415 *435* $m = 429$ $s = 10.2$

It may be observed that there is a very good agreement between the critical loads obtained with the Rondal and Niazi proposal and the numerical study. For all specimens, Mode B of Fig. 2 was obtained as critical, in both design method and numerical study. This is a flexural mode. Lateral–torsional buckling can be considered restrained both by supporting conditions and stitches fastenings. The values of ultimate loads, obtained with ANSYS program, demonstrate that the numerical model is sensitive to the global imperfection. For the numerical analysis, a global imperfection of 1/500 should be adopted, as recommended by the Eurocode 3 procedure, in order to obtain conservative results, as the values from brackets in Table 2 demonstrate.

Rondal and Niazi proposal gives good results in comparison with the experimental values. It may be observed that only a single experimental result, for 180.4.4s specimen, is lesser than the design value, but this result is out of range, as the standard deviation for this specimen demonstrates. Thus, this method, dedicated to the design of built-up members made of two C cold-formed elements bolted connected with C stitches, may be successfully used in design.

The characteristic and design values obtained with Eurocode 3 method shows that this approach, dedicated to the battened compression members with plate battens, usually rigidly connected on the chords, leads to securitary results only for specimen 180.4.3s, having only one intermediate stitch. As suggested by Rondal and Niazi method, FEM analysis and experimental results, the number of intermediate stitches does not have an influence on the value of the ultimate load. Fig. 4 shows the identical deformated shapes, at the level of ultimate load, for specimens 180.4.4s and 180.4.3s.

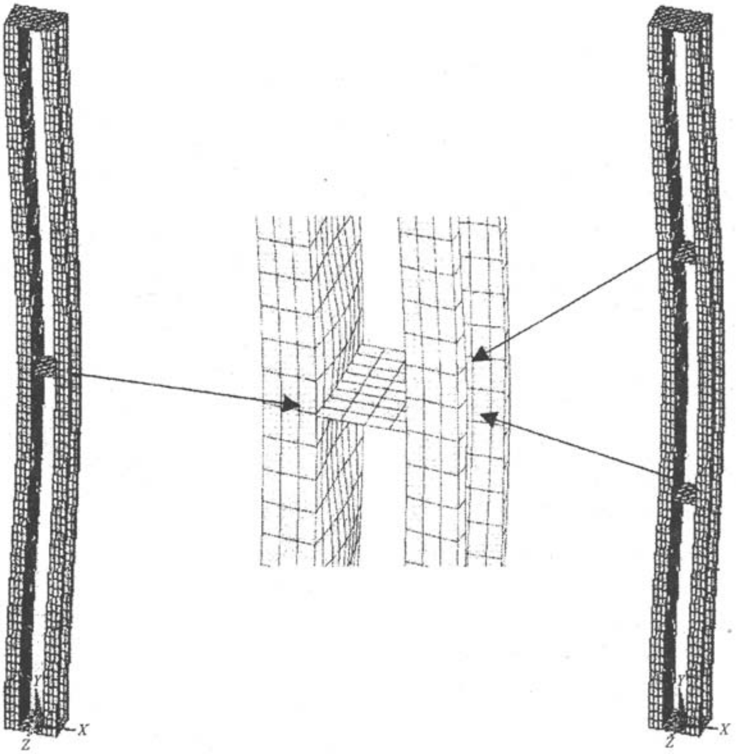

Fig. 4.– Deformated shape of specimens 180.4.3s and 180.4.4s.

5. Conclusions

The calibrated numerical model for cold formed built-up columns made of two C cold-formed elements, connected by means of bolted C cold-formed stitches, showed very good results at the level of the critical loads, compared with the values obtained using the Rondal and Niazi proposal. In order to obtain conservative results for the values of the ultimate loads, an overall sinusoidal imperfection of 1/500 should be adopted in the numerical analysis, as recommended by the Eurocode 3 design method. As demonstrated by the experimental results, and as considered in the Rondal and Niazi design method, the number of intermediate stitches does not have a significant influence on the load capacity. This phenomenon was also emphasized in the numerical simulation.

Concerning the available design methods for this type of built-up columns, Rondal and Niazi proposal give good results in comparison with the experimental values. Consequently, this design method may be used successfully in design, while Eurocode 3 provisions gives securitary results only in case of reduced number of stitches.

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ANALIZA NUMERICĂ A STABILITĂŢII STÂLPILOR CU SECŢIUNE COMPUSĂ DIN PROFILE FORMATE LA RECE

(Rezumat)

Se prezintă rezultatele unui studiu numeric al stabilităţii stâlpilor alcătuiţi din două profile C formate la rece, solidarizate prin cupoane din acelaşi tip de profil, îmbinate cu şuruburi. Normele europene actuale nu conţin recomandări specifice pentru acest tip de elemente, cu secţiune compusă. De aceea, validarea modelului numeric se realizează prin comparaţia cu câteva rezultate experimentale, precum şi cu o propunere de calcul existentă în literatura de specialitate. Se face de asemenea comparaţia cu metoda de calcul conţinută în normativul european Eurocode 3 pentru sâlpi compuşi din profile laminate, solidarizate cu plăcuţe. Modelul numeric dovedeşte un comportament bun în comparaţie cu rezultatele experimentale şi cu propunerea de calcul existentă.