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ABSTRACT

This paper presents a nonlinear 3-D finite element model highlighting the structural performance and strength of built-up cold-formed steel section laced columns. The pin-ended columns were axially loaded and consisted of two cold-formed steel (CFS) channels placed back-to-back at different center-to-center distances. The built-up columns had different geometries and different slenderness ratios. The nonlinear material properties of cold-formed steel, initial geometric imperfections and built-up section column components were considered in the finite element models. The finite element models were verified against tests conducted on built-up laced and battened columns collected from the literature. The column strengths, load-axial shortening, deformed shapes at failure, failure modes, load-axial shortening, load-lateral displacement and load-axial strain relationships were predicted from the finite element analysis and compared well against the test results. The verified finite element model was used to perform parametric studies investigating the effects of different parameters affecting the built-up column strength and behavior. The column strengths predicted numerically were compared with design strengths calculated using current codes of practice. The column strengths measured in the parametric study were compared against design strengths calculated using the North American Specification, Australian/New Zealand Standard and European Code for cold- formed steel columns.

Keywords: Built-up, Laced column, Finite element, Design strength, Buckling.

INTRODUCTION

The general term "built-up CFS members" refers to any compression member formed by two or more attached cold-formed steel elements. Built-up columns are commonly used in buildings and bridges to provide economic solutions in cases of large spans and/or heavy loads. Depending on the way that the chords are connected to each other, they can be grouped into laced and battened built-up columns. In recent years, developed manufacture techniques and increased strength of materials gave the edge to cold-formed steel over traditional hot-rolled steel in the construction of a wide range of structures. Cold-formed steel members are typically thin-walled, i.e. local plate buckling and cross-section distortion must be treated as an essential part of member design.

Despite the behavior and strength of built-up columns has been the subject of investigation by many researchers over the years, there is only a limited focus on built-up cold-formed steel columns.

Johnston [1] studied the spaced steel columns. In this study the spaced columns were defined as the limiting case of a battened column in which the battens are attached to the longitudinal column elements by hinged connections. End tie plates in battened columns may contribute significantly to the buckling strength. Their effect is accentuated by the study of a spaced column. The strengthening effect of the end tie plates is due to two factors: (1) a shortening of the length within which the column components can bend about their own axes and (2) the longitudinal components are forced to buckle in a modification of second mode shape and thus have elastic buckling coefficients that approach four times those of the first mode. In addition to their contribution to column strength, end tie plates perform their usual role of distributing the direct or moment applied loads to the component elements of either laced or battened columns. The out-of-plane buckling of battened columns under axial and/or moments was investigated by Toossi [2]. Temple and Elmahdy [3], carried out an experimental and theoretical study to investigate the behavior of battened columns made of standard channel steel sections. The number of connectors and the accompanying design strength for double-angle columns was determined by Zahn and Haaijer [4]. Temple and Elmahdy [5] investigated the buckling mode of built-up member. Their research also provides a brief derivation of the equivalent slenderness ratio equation and its applicability. Temple and Elmahdy [3] concluded that the slenderness ratio of the main member between connection points has a significant effect on the compressive resistance. Built-up columns experimental tests have been conducted by Dung et al. [6] and Liu et al. [7] using hot-rolled built-up columns. The slenderness ratio of built-up columns was investigated and the slenderness ratio formulas as specified in various design codes were discussed. Hashemi and Jafari [8, 9] investigated experimentally the elastic critical load of hot-rolled built-up columns. The two papers also provide an evaluation for some theoretical methods for predicting the elastic critical load and the compressive strength of built-up columns.

The stability of built-up thin-walled steel beams and columns was studied by Rondal and Niazi [10]. The aim of this study was to present experimental results on built-up elements composed of cold-formed C profiles with battened plates or C stitches. Eighteen tests were performed on columns with battened plates. Georgieva et al. [11] examined the validation of the direct strength method to be used in the design of built-up cold-formed steel columns. However, no experimental test data were found in the literature for built-up CFS battened columns. Built-up CFS battened columns were investigated experimentally and numerically by Dabaon et al. [12-15] and Ramzy [16] where new tests were conducted on welded built-up CFS battened columns, a new finite element model was developed to describe the behavior of these columns and the test and numerical results were compared to different design standards.

The behavior of CFS sections is different from that of hot-rolled steel sections. Steels produced by hot rolling are usually sharp yielding. For this type of steel, the yield stress is defined by the level at which the stress-strain curve becomes horizontal. Steels that are cold reduced or otherwise cold worked show gradual yielding. For gradual-yielding steel, the stress-strain curve is rounded out at the "knee" and the yield stress is determined by either the offset method or the strain-underload method [17, 18].

The finite element (FE) method is regarded by many engineers as an indispensable tool for achieving parametric studies, as for instance when modeling cold-formed structural members. In this paper the finite element modeling was used to simulate the behavior of the built-up CFS section laced columns. In order to assess the validity of the finite element model to simulate the actual behavior of built-up CFS section laced columns, results of experimental test have been verified to the results of the present finite element model (FEM). The verified FEM was used in the parametric study conducted on the BCFS laced columns.

As a part from the extensive study conducted by Ramzy [19] on built-up CFS laced columns, the objective of this paper is to study the behavior and strength of this form of constructions under axial loading through a finite element model which is able to perfectly simulate the behavior of these columns.

SUMMARY OF EXPERIMENTAL TESTS

Axial and Eccentrical Compression Tests Done by [20] and [21]

The experimental tests conducted on built-up laced columns by Bonab et al. [20], contained four built-up column samples with various lengths and various distances between the main chords while a total number of 10 simply-supported eccentrically loaded columns, grouped in five pairs of similar columns for repeatability purposes, were tested by Kalochairetis et al. [21]. Only the eccentrically loaded groups constructed using UPN 60 were included in the current study. The actual length of the chords was 202 cm while the effective length of all specimens was 234.5 cm with different lacing arrangements for each specimen. Both axially and eccentrically loaded columns consisted of two main chords which were constructed using hot-rolled channel section having the profile of UPN 60. In the axially loaded columns, the main chords were connected using lacing plates having the section of 3 mm by 10 mm while the main chords, in eccentrically loaded columns, were connected using lacing bars having an angle cross-section L25×25×3. Both lacing systems were welded on the chords. Lateral supports were placed at specimens' mid-height in order to restrict out-of-plane movement. Other specifications of the axially and eccentrically test specimens are given in [20] and [21], respectively.
In axially loaded columns, each test specimen was tested for several times. In each times the specimen was considered to be a column with different initial imperfection. The specimens were labeled as shown in the first column of Table 1, where the number after the letter L indicates the net length of the channel profile and the number after the letter B indicates the dimension of the column cross-section in the plane parallel to the lacing planes. The number after the letter R indicates the number of test repetitions. Both axially and eccentrically loaded specimens were pin-ended columns. The material properties of tested columns were obtained from tensile test and the obtained specifications are detailed in [20 and 21].
The finite element models of axially and eccentrically loaded built-up columns were verified against the test results [20 and 21] in [22]. A quite agreement between the tests and the numerical results was achieved.

Axially loaded built-up CFS battened columns tested by [16]

The experimental research on built-up columns conducted by Ramzy [16], consists of double U channels placed back-to-back with space distance between channels varying from B = 25 mm to B = 75 mm, the channels were connected by batten plates located at a distance (L_z) varying from 150 mm to 400 mm. The test specimen details measured dimensions of a built-up cold-formed battened column are summarized in Table 1. The channels have dimensions ($D \times b \times t \times r_i$), where D is the depth of channel of 100 mm, b channel width of 30 mm, t is the thickness of channel of 2 mm and r_i is the internal radius of 4 mm. The batten dimensions are summarized in Table 1, the channel is attached at the end with the thick plate of 20 mm, to ensure uniform load distribution. Figure 1 gives a full description of all the geometrical dimensions. The specimens were compressed between pin-ended supports and had a same nominal column length (L) of 2210 mm. To calculate the material properties, tensile coupons were tested until fracture. The measured static 0.2% proof stress ($\sigma_{0.2}$) was 310 MPa, the measured elongation after fracture (ε_u) based on gauge length of 50 mm was 24% and the initial modulus (E_o) was 210 GPa. The specimens were labeled according to the author's labels.

Table 1: Measured dimensions of built-up CFS column in [16]

Specimen label	Length (mm)	Channels' spacing (mm)	Measured (L_z) (mm)	Batten plates			
				a_b (mm)	b_b (mm)	$b_{b,End}$ (mm)	t_b (mm)
B2B25-300	2210	27	297	63	104	150	6
B2B50-300	2205	50	297	90	103	150	6
B2B75-300	2206	75	295	115	105	150	6
B2B50-150	2209	45	145	90	106	150	6
B2B50-400	2211	50	396	90	106	150	6

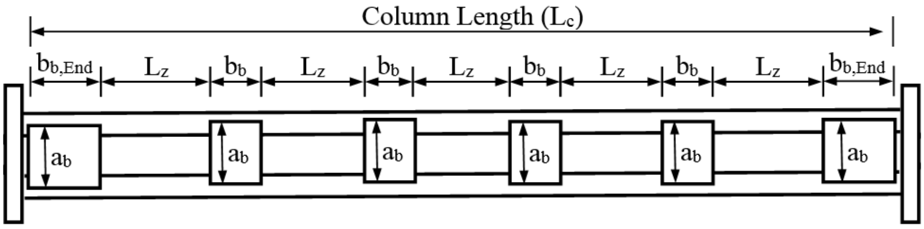

Fig. 1: Definition of CFS built-up test specimen [16]

FINITE ELEMENT MODEL OF BUILT-UP CFS COLUMNS

The finite element program ABAQUS [23] was used to simulate the behavior of the built-up CFS battened columns. The model used the measured geometry and material properties. Finite element analysis for buckling requires two types of analyses. The buckling modes of the columns are estimated, first, through the Eigenvalue analysis. This is a linear elastic analysis performed using the (*BUCKLE) procedure available in the ABAQUS library with the load applied within the step. The Eigenvalue analysis were performed for a number of buckling modes and the adequate buckling mode predicted from Eigenvalue analysis was used. A load-displacement nonlinear analysis is, then, carried out. In this analysis, the initial imperfections and material nonlinearity are included. From this analysis, the ultimate loads, failure modes, lateral displacements, axial strains and axial shortenings are determined.

The S4R shell element is used to model the channels and lacing bars. The S4R element has six degrees of freedom per node and provides an accurate solution for most applications. The mesh that provided adequate accuracy and minimum computational time in modeling the steel built-up section battened columns was chosen by selecting approximate global size equals to 6 mm. A finer mesh was used at the corners. Figure 2 shows the shape of the current finite element mesh. To simulate the upper and lower pin-ends, reference points were selected to simulate the centers of upper and lower hinged supports. These reference points were constrained to the channels by “Coupling” constraint. Coupling-constraint is a feature in ABAQUS by which a reference point can be coupled automatically to three-dimensional shell meshes, as shown in Fig. 2. The boundary conditions were assigned to the RPs, while the load was assigned to the RP of the upper support. The material properties and initial imperfections measured from the experimental tests were used in the model.

Residual stresses and the equivalent plastic strains in the sample carbon steel section can be calculated using the analytical solution presented by Quach et al. [24]. Predictions from these analytical models can be imposed into the FE model as the initial state using the ABAQUS (*INITIAL CONDITIONS, TYPE = STRESS) option. Previous studies by Young and Rasmussen [25], Ellobody and Young [26] and Young and Ellobody [27] on cold-formed plain channel, plain angle and unequal angle columns, have shown that the residual stresses has a negligible effect on the ultimate load, stiffness of the column and the failure mode. In general, the effect of residual stresses is neglected in cold-formed steel column modeling due to its small effect. Hence in the current modeling, the residual stresses were not included in order to avoid the complexity of the analysis.

COMPARISON BETWEEN EXPERIMENTAL AND NUMERICAL RESULTS

In order to assess the validity of the finite element model to simulate the actual behavior of CFS material, results of five experimental test results reported in Ramzy [16] have been compared to the results of the current finite element model. The deformed shape, load versus lateral-displacement, load versus longitudinal strain relationships were compared against the test results, as shown in Figs. 3 - 5. It can be seen that the finite element model modified by the authors provides a good prediction for the column strength and behavior of the built-up CFS battened columns. Table 2 shows a satisfactory agreement between the experimental ultimate loads and the corresponding values of the present finite element model.

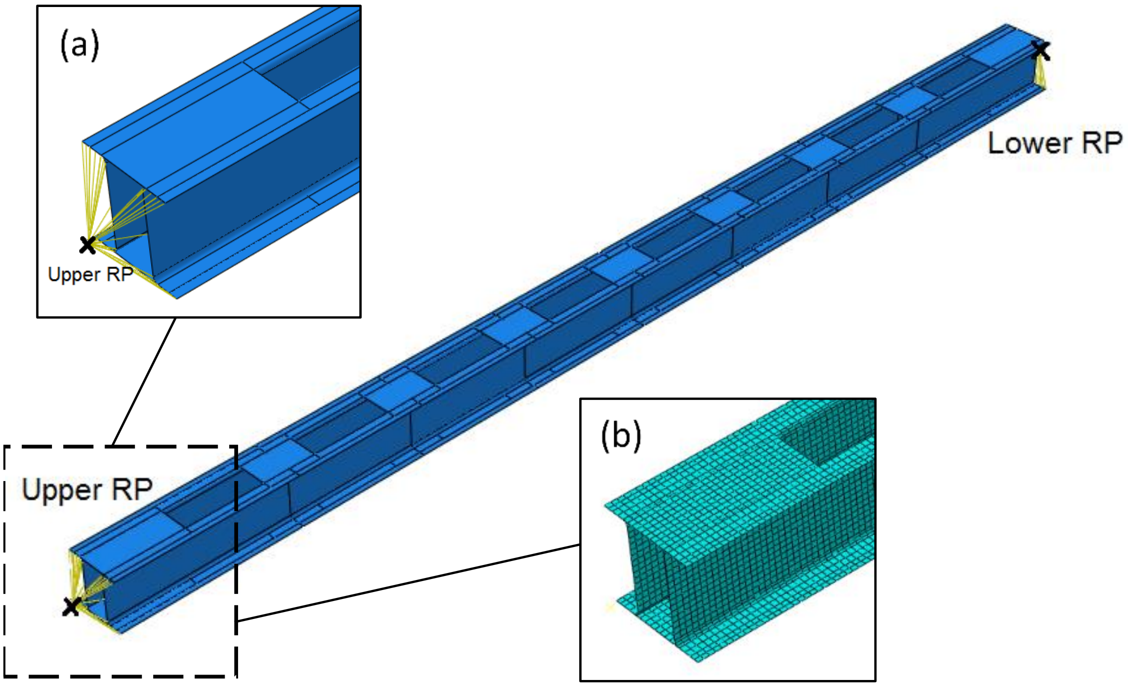

Fig. 2: Finite element model (a) Pin-end modelling, (b) Meshing

Table 2: Experimental results Vs. Numerical results

Specimen	Experimental	Numerical	Mode of failure	$\frac{P_{Test}}{P_{FE}}$
	P_{Test} (kN)	P_{FE} (kN)		
B2B25-300	109.90	107.60	F	1.02
B2B50-300	119.11	121.67	F+L	0.98
B2B75-300	125.26	126.90	L	0.99
B2B50-150	133.11	132.65	F	1.00
B2B50-400	112.29	111.50	L	1.01
Mean				1.00
COV				0.015

PARAMETRIC STUDY

The verified finite element model was used to investigate the effect of increasing the back-to-back distance and increasing the buckling length on the behavior and strength of built-up CFS laced columns. A total of 28 columns were analyzed in the parametric study, and the dimensions of the columns are illustrated in Fig. 6. The specimens were constructed using CFS channels with the dimensions of channel depth 120 mm, flange width 56 mm, thickness 2 mm and internal corner radius 3 mm. All specimens were connected using lacing bars with the section of 13 mm × 6 mm and end batten plates with the depth of 202 mm. the width of batten plates and lacing system was calculated based on the distance (s = 15 mm) left from the tip of the channel flanges, as shown in Fig. 6.

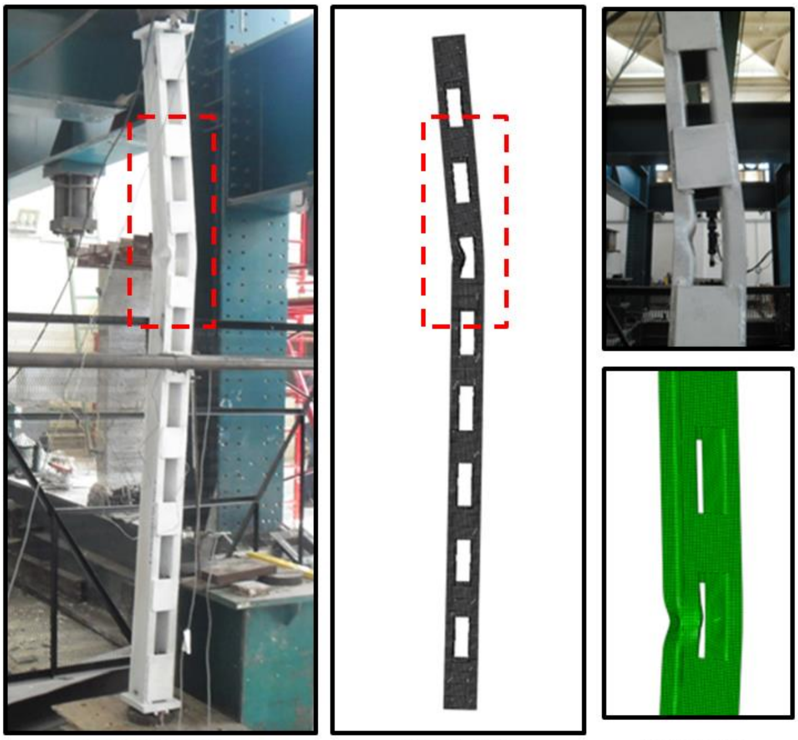

Fig. 3: Deformed shape of built-up CFS battened column B2B50-150

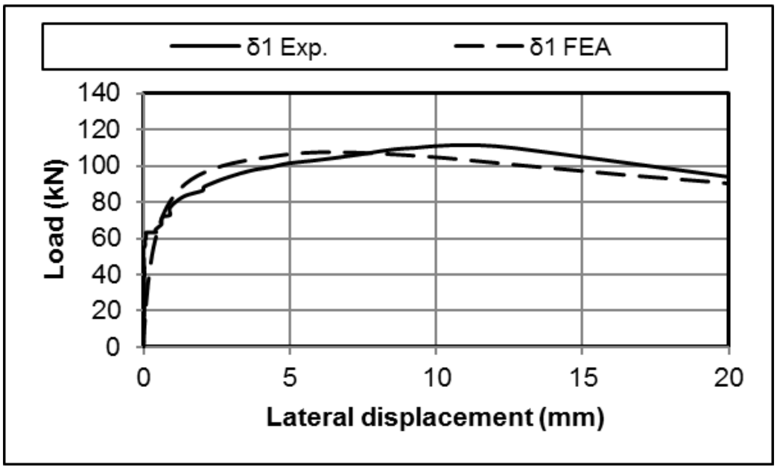

Fig. 4 Load-lateral displacements at mid-height for B2B25-300

The carbon steel grade S355 material properties were considered in this parametric study. Steel grade S355 has been modelled as a von Mises material with isotropic hardening. According to EN 1993-1-1 [28], S355 has a minimum yield (F_y) of 355 MPa and an ultimate strength (F_u) of 510 MPa. Currently, the bilinear elastic-plastic stress-strain curve with linear strain hardening was used to simulate the steel material. In the linear elastic part of the curve, the Young's modulus of E_o = 200 GPa and Poisson's ratio of 0.3 were used. The material properties in the corner of the channel section were extrapolated from the material properties of 1.5 mm thickness cold-formed steel plain angle column detailed in Ellobody and Young [26].

The parametric study was conducted using columns with various back-to-back clear distances and various column buckling lengths. The twenty-eight column specimens were divided into four groups. These groups are B25, B50, B75 and B100 with various back-to-back clear distances of

30, 60, 90 and 120 mm, respectively. This variation in the back-to-back clear distance provides back-to-back clear distance to width (a/D) ratios of 25%, 50%, 75% and 100%. Each group contained seven columns with the lengths of 732, 1060, 1388, 2372, 3028, 4340 and 4996 mm. The maximum initial overall geometric imperfection magnitude was taken as 1/1100 of column length for the columns having lengths less than 3000 mm and 1/1500 of column length for the columns having lengths from 3000 – 5000 mm. The local imperfections were taken as 0.5% of the channel thickness as recommended in [26]. All the four groups, considered in this parametric study, were tested between hinged ends. The finite element specimens were labeled such that the shape of the built-up cold-formed steel section and the variable parameters could be identified from the label. For example, the label "L1060B50-164" defines the built-up column length in mm (L1060), the percentage of back-to-back distance to width (a/D) ratio (B50) and the channel length between lacing bars in mm (164).

The column strengths (P_{FE}) and failure modes obtained from the finite element analyses for the built-up cold-formed steel section battened columns investigated in the parametric study are summarized in Table 3 and Fig. 7. Looking at Table 3 it can be seen that the column overall slenderness has clearly identified the failure modes of the built-up columns. Two slenderness values were monitored in this study to judge the built-up column buckling behavior as well as the failure mode as summarized in Tables 3. The first slenderness is the nondimensional critical slenderness (λ_c) calculated using the North American Specification [29] and Australian/New Zealand Standard [30]. While, the second slenderness is the nondimensional critical slenderness (λ) calculated according to the European Code [31].

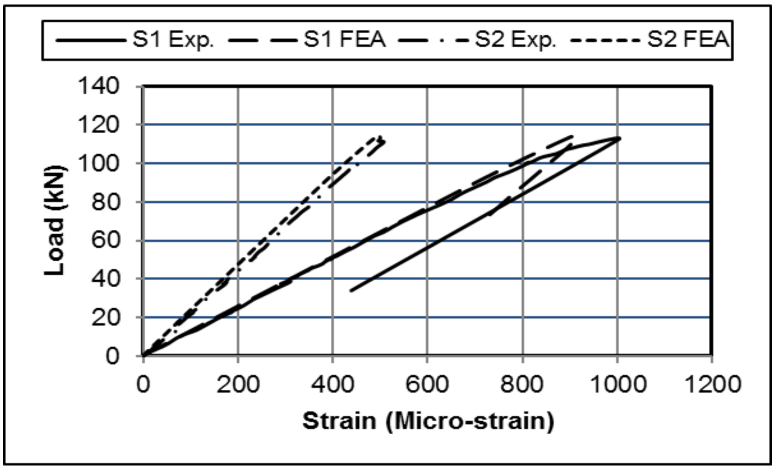

Fig. 5 Load-axial strain relationships for B2B50-400 (S1: Strain at mid panels, S2: Strain at 50 mm from the upper end plate)

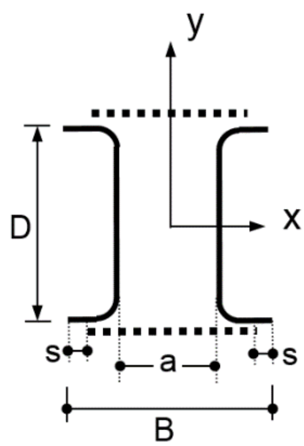

Fig. 6 Details of CFS laced sections considered in the parametric study

Table 3: Comparison between Design strengths and model strengths

Series	Specimen	FE Results		Design Strength				Design/FE results	
				NAS&AS/NZS		EC3			
		P_{FE} (kN)	Failure mode	P_D (kN)	λ_c	P_D (kN)	λ	NAS & AS/NZS	EC3
B25	L732B25-164	201.94	L	191.14	0.31	199.35	0.23	0.95	0.99
	L1060B25-164	195.13	L	186.65	0.43	191.91	0.33	0.96	0.98
	L1388B25-164	191.54	L+F	180.67	0.56	183.93	0.43	0.94	0.96
	L2372B25-164	171.80	L+F	155.25	0.93	153.62	0.74	0.90	0.89
	L3028B25-164	148.76	L+F	133.87	1.19	128.02	0.94	0.90	0.86
	L4340B25-164	95.91	F	88.49	1.70	81.60	1.35	0.92	0.85
	L4996B25-164	75.11	F	69.51	1.95	65.35	1.55	0.93	0.87
B50	L732B50-164	198.33	L	193.15	0.24	201.28	0.16	0.97	1.01
	L1060B50-164	198.29	L	190.81	0.32	198.70	0.24	0.96	1.00
	L1388B50-164	198.36	L	187.64	0.41	193.38	0.31	0.95	0.97
	L2372B50-164	186.10	L+F	173.64	0.68	175.41	0.53	0.93	0.94
	L3028B50-164	172.79	L+F	161.11	0.86	160.62	0.67	0.93	0.93
	L4340B50-164	153.59	L+F	130.81	1.22	124.46	0.97	0.85	0.81
	L4996B50-164	129.26	F	114.21	1.41	106.21	1.11	0.88	0.82
B75	L732B75-164	194.29	L	194.03	0.20	201.28	0.13	1.00	1.04
	L1060B75-164	199.19	L	192.62	0.26	201.28	0.18	0.97	1.01
	L1388B75-164	196.46	L	190.71	0.32	198.53	0.24	0.97	1.01
	L2372B75-164	196.96	L	182.15	0.53	185.80	0.41	0.92	0.94
	L3028B75-164	190.30	L+F	174.26	0.67	176.15	0.52	0.92	0.93
	L4340B75-164	176.17	L+F	154.27	0.95	152.44	0.75	0.88	0.87
	L4996B75-164	175.19	L+F	142.65	1.09	138.46	0.86	0.81	0.79
B100	L732B100-164	203.07	L	194.47	0.18	201.28	0.10	0.96	0.99
	L1060B100-164	202.85	L	193.54	0.22	201.28	0.15	0.95	0.99
	L1388B100-164	203.43	L	192.28	0.27	201.28	0.19	0.95	0.99
	L2372B100-164	200.41	L	186.57	0.43	191.79	0.33	0.93	0.96
	L3028B100-164	199.49	L	181.24	0.55	184.65	0.42	0.91	0.93
	L4340B100-164	186.85	L+F	167.39	0.77	168.04	0.60	0.90	0.90
	L4996B100-164	181.78	L+F	159.10	0.88	158.23	0.70	0.88	0.87
Mean								0.93	0.93
COV.								0.04	0.07

Looking at Table 3 summarizing the finite element analysis results for the built-up CFS laced columns, it can be seen that built-up columns having $\lambda_c \le 0.55$ failed mainly by local buckling (L) failure mode, built-up columns having $\lambda_c \ge 1.41$ failed mainly by overall flexural buckling (F) failure mode and the remaining built-up columns failed by a combined L + F failure mode. Similarly, it can be seen that built-up columns having $\lambda \le 0.42$ failed mainly by L failure mode, built-up columns having $\lambda \ge 1.11$ failed mainly by F failure mode and the remaining built-up columns failed by a combined L + F failure mode.

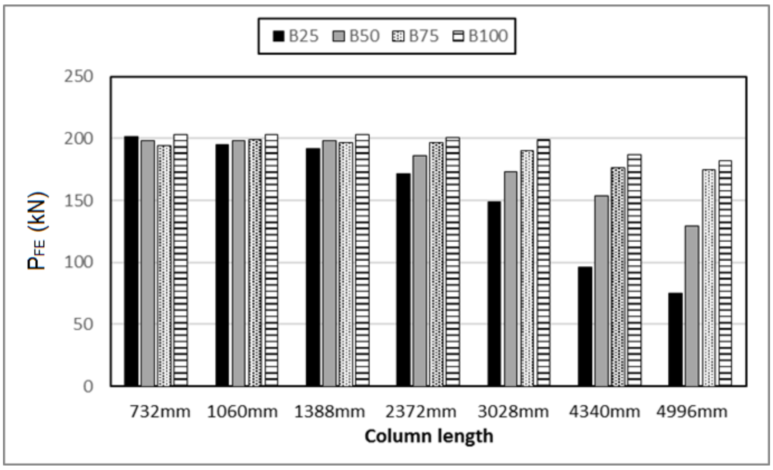

Fig. 7 Model results Vs. column length

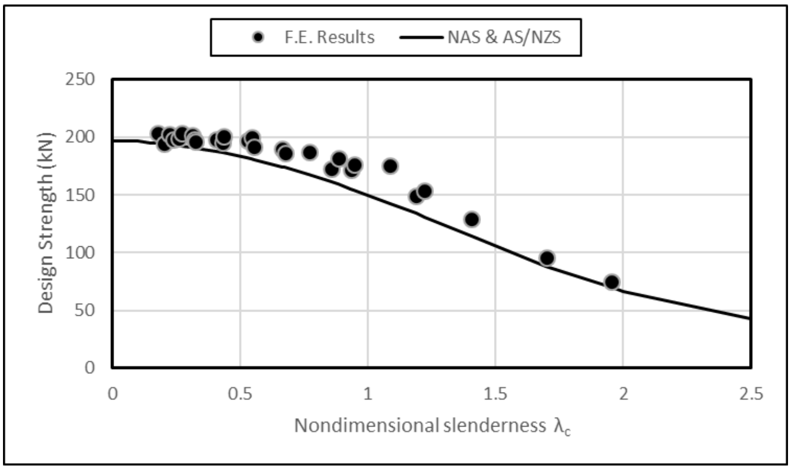

Fig. 8 Comparison of the finite element strengths and NAS&AS/NZS design strengths

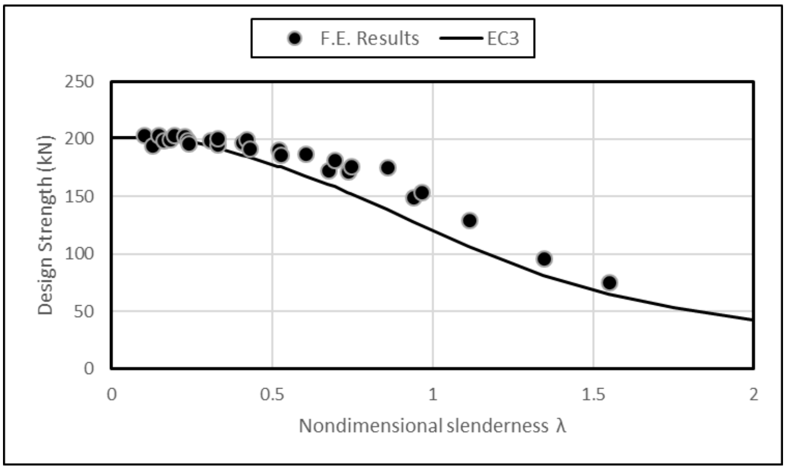

Fig. 9 Comparison of the finite element strengths and EC3 design strengths

COMPARISON WITH DESIGN RULES

The built-up column strengths predicted from the parametric study (P_{FE}) were compared with the unfactored design strengths calculated using the North American Specification [29], Australian/New Zealand Standard [30] and European Code [31] for CFS columns. Looking at Table 3 that summarized the finite element built-up column strengths (PFE) and design strengths calculated using NAS [29] and AS/NZS [30] as well as looking at Figs. 8 - 9 that plotted the built-up column strengths, generally, it can be seen that the specifications were conservative for the built-up cold-formed steel section laced columns, except for some columns failing by L failure mode. The mean value of design strength to FE strength ratio is 0.93 for both NAS & AS/NZS and EC3, with corresponding coefficients of variation (COV) of 0.04 and 0.07, respectively.

CONCLUSIONS

Nonlinear 3-D finite element models highlighting the buckling behavior and strength of built-up cold-formed steel section laced columns have been developed and reported in this paper. The finite element models carefully accounted for the nonlinear material properties of flat and corner portions of cold-formed cross sections, initial local and overall geometric imperfections, actual geometries and actual boundary conditions. The column strengths, failure modes, deformed shapes at failure, load-lateral displacement and load-axial strain relationships were predicted numerically and compared against that measured experimentally from the literature. The comparison of test and finite element results have shown that good agreement existed and the models accurately represented the complex buckling behavior of the built-up columns. The verified finite element models were used to perform an extensive parametric study investigating the effects on the built-up column strength and behavior owing to the change in column cross-section geometries, column lengths and column overall slenderness. The column strengths predicted from the finite element analyses were compared with the design strengths calculated using the North American Specification, Australian/New Zealand Standard and European Code for cold-formed steel columns. Generally, it has been shown that the specifications were conservative for the built-up cold-formed steel section laced columns, except for some columns failing by L failure mode.

REFERENCES

1. Johnston B. G. (1971), "Spaced steel columns", Journal of the Structural Division (ASCE), Vol. 97(5), pp. 1465-1479.
2. Toossi M. (1972), "On the out-of-plane buckling of battened columns", Pergamon Press, Vol. 14(8), pp. 511-521.
3. Temple M. C., Elmahdy G. (1993), " Buckling of built-up compression members in the plane of the connectors ", Canadian Journal of Civil Engineering, Vol. 20(6), pp. 895–909.
4. Zahn C. J., Haaijer G. (1998), "Effect of connector spacing and flexural-torsional buckling on double-angle compressive strength", Engineering Journal (AISC), Vol. 25(3), pp. 109–118.
5. Temple M. C., Elmahdy G. (1992), "Equivalent slenderness ratio for built-up members", Canadian Journal of Civil Engineering, Vol. 20(4), pp. 708–711.
6. Dung M. L., Yen T., Liu J-L (2006), "Experimental investigation on built-up columns", Journal of Constructional Steel Research, Vol. 62(12), pp. 1325-1332.
7. Liu J-L, Dung M. L., Ching H. L. (2009), "Investigation on slenderness ratios of built-up compression members", Journal of Constructional Steel Research, Vol. 65(1), pp. 237–248.
8. Hashemi B. H., Jafari M. A. (2009), "Experimental evaluation of elastic critical load in batten columns", Journal of Constructional Steel Research, Vol. 65(1), pp. 125–131.
9. Hashemi B. H., Jafari M. A. (2012), "Evaluation of Ayrton–Perry formula to predict the compressive strength of batten columns", Journal of Constructional Steel Research, Vol. 68(1), pp. 89–96.
10. Rondal J., Niazi M. (1990), "Stability of Built-up Beams and Columns with Thin-Walled Members", Journal of Constructional Steel Research, Vol. 16(4), pp. 329–335.

11. Georgieva I., Schueremans L., Vandewalle L., Pyl L. (2012), "Design of built-up cold-formed steel columns according to the direct strength method", Procedia Engineering, Vol. 40, pp. 119-124.
12. Dabaon M, Ellobody E, Ramzy K. (2015), "Experimental investigation of built-up cold-formed steel section battened columns", Thin-Walled Structures, Vol. 92, pp. 137–145.
13. Dabaon M, Ellobody E, Ramzy K. (6-9 April 2015), "New tests on built-up cold-formed steel section battened columns", ICASGE' 15, International Conference on Advances in Structural and Geotechnical Engineering, Hurghada, Egypt.
14. Dabaon M, Ellobody E, Ramzy K. (2015), "Nonlinear behaviour of built-up cold-formed steel section battened columns", Journal of Constructional Steel Research, Vol. 110, pp. 16–28.
15. Dabaon M, Ellobody E, Ramzy K. (6-9 April 2015), "Numerical modelling of built-up cold-formed steel section battened columns", ICASGE' 15, International Conference on Advances in Structural and Geotechnical Engineering, Hurghada, Egypt.
16. Khaled Ramzy (2014), "Effect of batten plates on the behaviour and strength of cold-formed steel built-up section columns", [M.Sc. Thesis], Tanta University, Tanta, Egypt.
17. American Society for Testing and Materials, "Methods and Definitions for Mechanical Testing of Steel Products", ASTM Designation A370, PA. latested, West Conshohocken.
18. Wolford, D. S. (1969 and 1970), "Mechanical Properties of Steel Used in Cold-Formed Steel Construction", lecture notes, AISIUMR Short Course on Design of Cold-Formed Steel Structures, University of Missouri-Rolla.
19. Khaled Ramzy (Under preparation), "Steel laced members with built-up cold-formed sections subjected to static and cyclic loading", [Ph.D. Thesis], Tanta University, Tanta, Egypt.
20. Bonab A. P., Hashemi B. H., Hosseini M. (2013), "Experimental evaluation of the elastic buckling and compressive capacity of laced columns", Journal of Constructional Steel Research, Vol. 86, pp. 66–73.
21. Kalochairetis K. E., Gantes C. J., Lignos X. A. (2014), "Experimental and numerical investigation of eccentrically loaded laced built-up steel columns", Journal of Constructional Steel Research, Vol. 101, pp. 66–81.
22. Dabaon M, El-Boghdadi M, Ramzy K. (25-28 March 2019), " Finite element modelling of axially- and eccentrically-loaded built-up laced columns", ICASGE' 19, International Conference on Advances in Structural and Geotechnical Engineering, Hurghada, Egypt.
23. ABAQUS Standard User's Manual (2016), The Abaqus Software is a product of Dassault Systèmes Simulia Corp., Providence, RI, USA Dassault Systèmes, Version 2016, USA.
24. Quach W. M., Teng J. G., Chung K. F. (2004), "Residual stresses in steel sheets due to coiling and uncoiling: a closed-form analytical solution", Engineering Structures, Vol. 26(9), pp. 1249–1259.
25. Young B., Rasmussen Kim J. R. (1998), "Tests of fixed-ended plain channel columns", Journal of Structural Engineering (ASCE), Vol. 124(2), pp. 131-139.
26. Ellobody E., Young B. (2005), "Behavior of Cold-Formed Steel Plain Angle Columns", Journal of Structural Engineering (ASCE), Vol. 131(3), pp. 457-466.
27. Young B., Ellobody E. (2007), "Design of cold-formed steel unequal angle compression members", Thin-Walled Structures, Vol. 34(3), pp. 330-338.
28. EN 1993-1-1. (2004), "Eurocode 3: design of steel structures – part 1-1: general rules and rules for buildings", CEN.
29. NAS. (2007), "North American Specification for the design of cold-Formed Steel Structural Members", American Iron and Steel Institute, Washington, DC.
30. AS/NZS. Australian/New Zealand Standard. (1996), "Cold-formed steel structures", Standards Australia, Sydney, Australia.
31. EC3. Eurocode 3 (2006), "Design of steel structures – Part 1-3: General rules – Supplementary rules for cold-formed members and sheeting", BS EN 1993-1-3, European Committee for Standardization, Brussels.