EXPERIMENTAL AND NUMERICAL INVESTIGATION ON ELEVATOR STEEL UPRIGHTS UNDER ECCENTRIC COMPRESSION

ANALISI SPERIMENTALE E NUMERICA DI MONTANTI IN ACCIAIO COMPRESSI ECCENTRICAMENTE PER ASCENSORI

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ABSTRACT

The increasing concentration of the population in urban areas and the need of a high residential capacity have led to the development of tall buildings in which vertical transportation is ensured by suitable elevator systems. In this context, engineers are pushing to design cost-effective tall structures which can guarantee, at the same time, safety and limited cost. Recently, the use of thin-walled structural steel elements is significantly increased for this purpose. The present paper presents an experimental-numerical investigation on steel thin-walled elements under compression used for steel elevators. Two different cross-section members were investigated, considering: i) specimens with an axial force applied in the cross-section centroid and different total lengths and ii) stub-column specimens having an axial force applied with different eccentricities from their centroid. Alongside the experimental study, a large numerical study was developed using finite elements to replicate the experimental results. Numerical and experimental studies made it possible to define the moment (M) – axial force (N) sections domain, which were compared with the theoretical ones obtained on the basis of the procedure provided by EC3-1-3 (and NTC18). It is shown that for the proposed profiles, the expression prosed by the current design provision is generally from the safe side.

SOMMARIO

La crescente concentrazione della popolazione nelle aree urbane e la necessità di ottenere una alta capacità residenziale hanno portato allo sviluppo degli edifici alti nei quali il trasporto verticale è assicurato da adeguati sistemi di ascensori. In questo ambito, i progettisti si stanno orientando verso la progettazione di strutture alte, che possano garantire contemporaneamente sicurezza e costi limitati. In tempi recenti, a tal fine, sono sempre più utilizzati elementi strutturali in parete sottile. Nel lavoro viene presentata un'indagine sperimentale-numerica su elementi in parete sottile in acciaio utilizzati per i montanti di ascensori. In particolare, sono state studiate due diverse sezioni trasversali, considerando la loro risposta in presenza di azione assiale centrata ed eccentrica. Lo studio in presenza di azione assiale è stato effettuato al variare della lunghezza dei profili. Accanto allo studio sperimentale è stato sviluppato un esteso studio numerico mediante l'uso di elementi finiti per replicare i risultati sperimentali. Studi numerici e sperimentali hanno permesso di tracciare il dominio momento flettente (M) – azione assiale (N) delle sezioni che sono stati confrontati con quelli teorici in accordo all'EC3-1-3 (e alla NTC18). Viene dimostrato che per i profili proposti, l'approccio progettuale correntemente in uso risulta essere a favore di sicurezza.

1 INTRODUCTION

In Italy, the steel structures for elevators (Fig. 1) were not considered as structural elements until 2008, when the new design rules for buildings (NTC2008 [1]) went out. The design and therefore the production of steel frames for elevators has consequently significantly changed.
From that moment on, elevator manufacturers, that already had many years of experience in the production of such structures, began to adapt the production to the new needs, searching also for collaboration of engineers with expertise on steel and cold-formed structural design.

Fig. 1. Structural system for a steel elevator

The global response of these structures can be evaluated only by using the *design-by-testing* approach [2], owing to their peculiar features. The main parameters to be used in the design phase must be, in fact, evaluated by means of a suitable experimental campaign on isolated components (columns, beams, joints …). In the paper the response of two different column specimens under compression is investigated, differing for the total lengths and the eccentricities of the applied axial force. The experimental results are then compared to the numerical results, obtained using finite element models and to the theoretical ones, based on the design equations contained in the actual version of the EC3-1-3 [3] and in the current structural Italian code, NTC2018 [4].

2 THE EXPERIMENTAL CAMAPAIGN

The experimental campaign was performed on members characterized by two different cross-sections (named, C1 and C2). The influence of the length of the specimen and of the load eccentricity have been investigated. For each type of specimen 5 specimens were tested for a total of 120 tests.

2.1 The tested specimens

The specimens were tested under a compression load (Fig. 2) according to the prescription of EN15512 §A.2.1 [5].

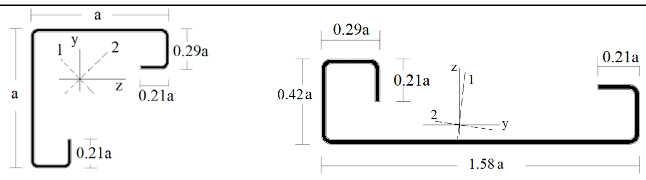
Fig. 2. Details of the compression tests

With the aim of investigate the influence of the different buckling modes (i.e, local, distortional and global buckling [6]) on the load carrying capacity (LCC), specimens of different length were considered: 400mm (stub-column), 800mm, 1200mm, 1500mm and 1800mm for C1 and 600mm (stub-column), 1200mm, 1500mm and 1800mm for C2. Moreover, with reference to the stub-columns, additional eccentric tests were performed to study the influence of the bending moment on the LCC, allowing for the definition of the M-N resistant domains.

In Table 1, the main geometrical dimensions of C1 and C2 profile are reported, together with the ratio between the gross cross-sectional area (A_g) and the thickness (t), and the ratio between the second moments of area in the two main directions I_1 and I_2. All the key data, from the cross-section geometry to the overall response, are herein presented in non-dimensional form, making reference to the non-dimensional *a* length, for reasons of commercial confidentiality. According with the classification criteria of the EC3-1-1 [7], the C1 and C2 profiles belong to class 3 and class 4, respectively.

Table 1. Dimensions and main characteristics for the considered columns

	C1	C2
A_g/t	334	334
I_1/I_2	17.11	2.81



Tensile tests were performed on 3 back-bone samples extracted from the coil used to produce the uprights (nominally S250GD steel, f_y = 250MPa). The mean values of the yielding and the ultimate tensile stress were 344.4 MPa and 417.7 MPa, respectively. Moreover, strains measured during the tensile tests allowed evaluating the Young Modulus, whose average value is 215052 MPa.

2.2 Influence of specimens' length on the LCC

Tests results of specimens with different lengths are depicted in Fig. 3 in terms of load carrying capacity (LCC) over the squash load (A_g f_y), i.e. LCC/(A_g f_y) ratio, versus the length of the specimen (L). Fig. 3a is related to C1 specimens while Fig. 3b is associated to C2 ones. In particular, in the graphs, for each length, test results are represented by markers, pointing out the quite limited scatter of the data, underling the great repeatability of the results. The dashed lines are associated with the mean values while the solid ones are related to the characteristic values, evaluated in agreement with the procedure reported in [5].

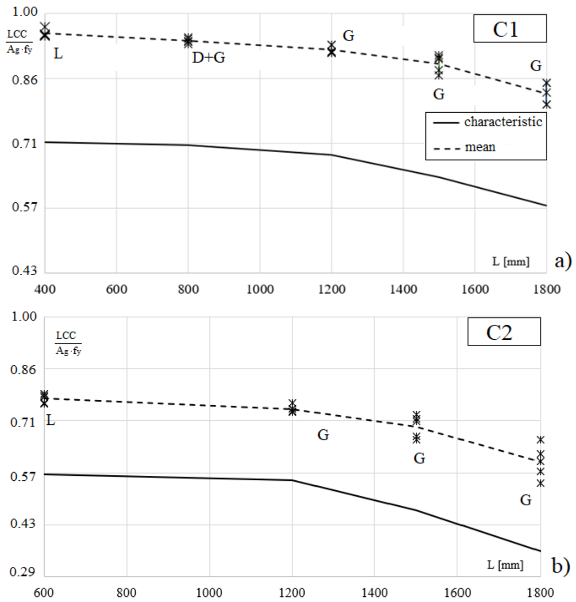


Fig. 3. LCC/(A_g f_y) versus length of the columns

Due to the high difference between the nominal and the effective yielding stress of the virgin material, the characteristic values appear greatly reduced from the mean ones, despite the tests showed as already mentioned, a good repeatability Moreover, in the same figure the collapse modes are indicated by letter where L stands for local, D for distortional and G for global buckling. It can be observed that, for stub-column specimens (i.e. lengths of 400mm and 600mm for C1 and C2 sections, respectively) the collapse mode was always of a local type. Specimens with length greater than 1200mm showed global collapse modes independently on the section type considered. Only for specimens C1 with a length of 800mm, collapse was associated with mixed distortional and global bucking modes. The LCC/(A_g f_y) ratio of the stub-column tests (i.e. the tests on the shorter specimens) allows for estimating the effective cross-section area. As it can be noted in Figure 3, for profiles C1, the one classified in class 3, the LCC/(A_g f_y) ratio is approximately equal to 1, pointing out that the effective area is coincident with gross one, i.e. no local buckling phenomenon affects the profile response, On the contrary, for C2 profile which belongs to class 4 of EC3-1-1, the effective area is on average 0.80 of the gross one.

2.3 The resistance domain for element under eccentric compression

Tests on the stub-column specimens (length equal to 400mm for C1 and 600mm for C2) were performed by considering different eccentricities of the axial load. To this aim, the axial load was moved along the principal axes in both positive and negative direction, The following eccentricities were investigated:

- C1 profile in principal direction 1, eccentricities of -30mm, -15mm, -5mm, +5mm, +15mm, +30mm;
- C1 profile in principal direction 2, eccentricities, of -30mm, -15mm, +15mm, +30mm;
- C2 profile in principal direction 1, eccentricities of -25mm, -10mm, +5mm, +10mm;
- C2 profile in principal direction 2, eccentricities of -25mm, -10mm, +10mm.

In all the tests, local buckling modes were observed at collapse. In fig. 4, test results are reported in terms of LCC/(A_g f_y) ratios versus the eccentricity value, for all the considered profiles. In graphs, the markers identify the tests results while, the solid line indicates the average values.

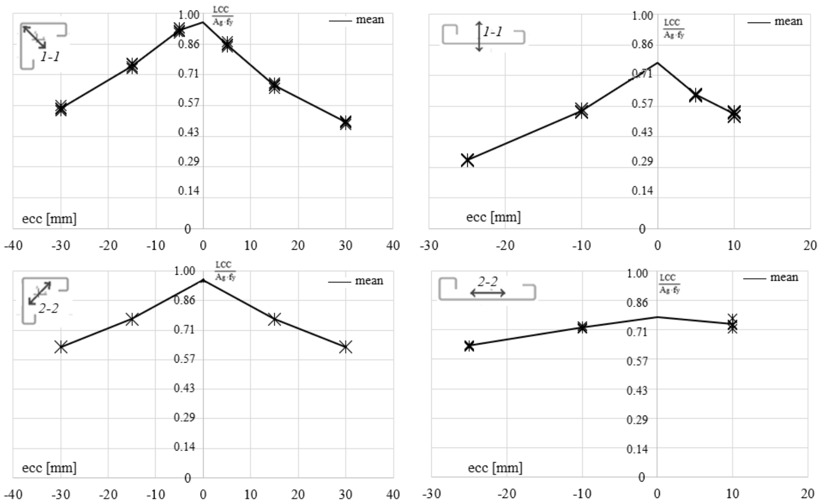


Fig. 4. LCC/(A_g f_y) ratios over the eccentricity on stub-column specimens

The graphs clearly show, for both the C1 and C2 cross-sections, a remarkable interaction between axial load and bending moment. As expected, greater the eccentricity lower is the LCC/($A_g f_y$) ratio.

3 NUMERICAL MODELLING

The experimental results allowed for calibrating refined finite element (FE) ABAQUS models [8]. At this aim *Brick* elements were used for the mesh, by dividing the thickness of the profile at least in 3 parts (Fig. 5). The mesh size was calibrated in order to obtain the best accuracy in the lowest computational time. Simply supported boundary conditions were assumed (all rotations allowed on both ends), according to the supports in the tested specimens. In the models, both geometrical and mechanical non-linearities have been accounted for. In detail, the material was assumed as elastic-plastic according to the tensile tests results (Tab. 2). As discussed in literature the selection of the initial imperfection is of paramount importance for the reliability of the results [9]. At this aim the first buckling mode according with the experimental outcomes (scaled by the value of the thickness) was assumed as initial deformed shape. *Static riks* analysis [8] have been considered by increasing step by step the displacement of the centroid. In Fig. 5 a comparison between the experimental and numerical results at collapse is presented: the good agreement between result is apparent

Fig. 5. Experimental and numerical collapse of the specimen under pure compression

According to EC3 part 1-3 the design LCC can be evaluated by means of a suitably expression which considers the axial load – bending moment interaction

$$\left(\frac{N_{Ed}}{N_{Rd}}\right)^{0.8} + \left(\frac{M_{Ed}}{M_{Rd}}\right)^{0.8} < 1 \quad (1)$$

where N_{Ed} and M_{Ed} are the axial and bending actions while N_{Rd} and M_{Rd} are the axial and bending resistance evaluated, when appropriate (i.e. in case of sections of class 4) by considering the effective properties of the section. The procedure for the evaluation of the effective section is the same in both EC3-1-3 and NTC18. The comparison between numerical (LCC_{NUM}), design (LCC_{EC3})

and experimental results (mean, LCC_{em} and characteristic, LCC_{ek}) is proposed, in Tables 2 and 3 for C1 and C2 specimen, respectively.

Table 2. Experimental, numerical and design value comparison for C1 specimens

Length (ecc)	LCC_{NUM} / LCC_{em}	LCC_{EC3} / LCC_{ek}
400 (0,0)	0.983	0.989
800 (0,0)	0.988	0.837
1200 (0,0)	0.963	0.713
1500 (0,0)	0.932	0.630
1800 (0,0)	0.910	0.548
mean	*0.9552*	*0.743*
400 (-30,0)	0.965	0.138
400 (-15,0)	0.990	0.381
400 (-5,0)	0.991	0.641
400 (5,0)	0.991	0.686
400 (15,0)	0.965	0.431
400 (30,0)	0.968	0.154
400 (0,-30)	0.952	0.433
400 (0,-15)	1.023	0.645
400 (0,15)	1.023	0.645
400 (0,30)	0.952	0.433
mean	*0.982*	*0.459*

Table 3. Experimental, numerical and design value comparison for C2 specimens

Length (ecc)	LCC_{NUM} / LCC_{em}	LCC_{EC3} / LCC_{ek}
600 (0,0)	0.989	0.604
1200 (0,0)	0.988	0.528
1500 (0,0)	0.962	0.495
1800 (0,0)	0.942	0.604
mean	*0.970*	*0.655*
600 (-25,0)	0.985	0.117
600 (-10,0)	0.991	0.348
600 (5,0)	0.894	0.541
600 (10,0)	0.841	0.362
600 (0,-25)	1.168	0.561
600 (0,-10)	1.051	0.757
600 (0,10)	1.122	0.766
mean	*1.007*	*0.493*

Results in the tables show the good agreement between the ABAQUS LCC values and the mean value of the experimental results. Differences lower than 5% can be observed; otherwise, if the characteristic values of test results are considered the differences are up to 31% and 36% from the unsafe side, for C1 and C2, respectively. The LCC values obtained from eq. 1, are always from the safe side but the differences with respect to the experimental data are non-negligible, pointing out the ineffectiveness of EC3-1-1 [7] to describe the behavior of these profiles especially when a combined axial-bending condition is considered.

CONCLUSIONS

In the paper, an experimental and numerical study of two cold-formed thin-walled columns used for building steel elevator is discussed. In particular, the influence of the specimen lengths and load eccentricities on the load carrying capacity has been investigated. The experimental results were then compared with the FE ABAQUS numerical results and the results of design expressions proposed by the EC3-1-3. The numerical results are in a quite good agree with the experimental ones if the mean values are considered. On the contrary, the EC3-1-3 expression is not able to suitably predict the experimental results, staying generally from the safe side.

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KEYWORDS

Thin-walled profiles, Eurocode 3 part 1-3, eccentric compression, stub-column tests, FE models.