ce/papers Proceedings in civil engineering

Ernst & Sohn A Wiley Brand

ORIGINAL ARTICLE

eurosteel AMSTERDAM 2023

Ernst & Sohn A Wiley Brand

Experimental campaign on components of steel frames for elevators

Nadia Baldassino[1] | Claudio Bernuzzi[2] | Marco Simoncelli[2]

Correspondence

Dr. Marco Simoncelli
Politecnico di Milano
Department of Architecture, Built environment and Construction engineering (DABC)
Piazza Leonardo da Vinci 32
20133 Milano, Italy
Email: marco.simoncelli@polimi.it

[1] Università di Trento,Trento, Italy
[2] Politecnico di Milano, Milano, Italy

Abstract

Architectural barriers are a very topical issue that affects the entire population, not just people with disabilities. In recent years, there is more and more talk of design of private and public spaces without architectural barriers that can hinder anyone's mobility. All of this concerns both new and existing structures. In new constructions the theme of accessibility is considered since the initial phase of the design process while in existing structures, depending on the specificity of the building 'ad hoc' solutions need to be identified and appropriately integrated into the building systems. In this last field, the problem of vertical accessibility is frequently solved by elevators which are frequently made of thin-walled steel structural elements.

This work presents an experimental-numerical investigation of thin-walled profiles used for building steel elevator. The performance of two different cross-sections under compression was studied. At this aim stub-column tests of specimens having an axial force applied to the cross-section centroid and with different eccentricities from the centroid were performed. Alongside the experimental study, a large numerical study was developed by using refined finite element models to simulate the experimental results. Numerical and experimental studies made it possible to draw the M_N sections domain which were compared with the theoretical ones obtained on the basis of the formulas provided by EC3-1-3. It is shown that for the considered profiles, the expression prosed by EC3-1-3 is from the safe side.

Keywords

Thin-walled profiles, Stub-column tests, Eccentric compression, M-N domain, FE models

1 Introduction

In recent years, the theme of accessibility is undoubtedly one of the most crucial from the point of view of liveability of the built spaces and therefore constitutes an essential qualitative characteristic of the building and of its equipment. All of this concerns both new and existing structures and for them different design approaches are adopted. In new constructions issues associated with accessibility are considered since the initial phase of the design process allowing the identification of integrated and optimal design solutions. In case of existing structures, the constraints associated with the specificity and the identity of the structure address the selection of design solution. In multilevel constructions the accessibility of the upper storeys is one of the issues which need to be first solved. At this aim elevators integrated inside the building system or built outside and connected to them. For this purpose, the structural solution commonly used consists in a framed steel tower frequently made of cold-formed steel profiles, supporting the elevator system (Fig. 1).

Figure 1 External elevator solution

https://doi.org/10.1002/cepa.2551

In Italy, the steel structures for elevators were not considered as structural systems 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 experience in the field, started adapting their production to the new needs, searching also for collaboration of engineers with expertise in steel structures with particular attention to cold-formed design. The peculiar characteristics of cold-formed profiles make, in fact, difficult to evaluate the global response of structures by the design approaches used for conventional steel systems and call for specific design skills. As well known for cold-formed design the *design-by-testing* approach [2] is commonly adopted. According to this approach, suitable tests on isolated components (columns, beams, joints …) allow the evaluation of the main mechanical parameters to be used in the design phase.

This paper reports of a study of two different profiles adopted as columns of framed elevators systems. The response of the profiles, characterized by an open cross section, was experimentally investigated under compression and by considering different eccentricities of the applied axial force, so that allowing investigating on M-N interaction. 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 Study cases

The study investigated on the response of two profiles made by press-brake of zinc-coated steel plates S250GD having a nominal thickness of 3mm. The profiles, whose section's geometry is presented in Figure 2 are in the following conventionally named as C1 and C2. In the figure the main section's dimensions are reported, together with the ratio between the gross cross-sectional area and the thickness A_g/t, and the ratio between the second moment of area, in the two main directions I_1/I_2. All the data are presented in non-dimensional form for reasons of commercial sensitivity. It is worth noting that for both cross-sections the principal axes (i.e axes 1-1 and 2-2) are rotated with respect to the geometrical ones (i.e axes x-x and y-y).

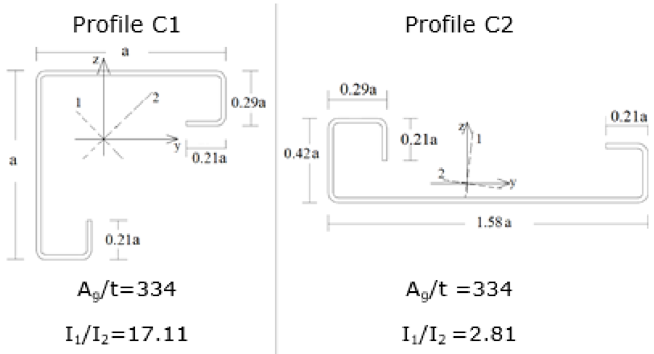

Figure 2 The cases study

According with the classification criteria of the EC3-1-1 [5], the C1 and C2 profiles belong to class 3 and class 4, respectively.

3 Experimental study

3.1 Main features of the experimental study

Compression tests were performed on stub specimens with a length of 400mm and 600mm for profile C1 and C2, respectively. Aiming at evaluating the interaction between axial force (N) and bending moment (M) for both the profiles simple compression tests (i.e. load applied to the centroid of the cross-section) and eccentric compression tests were carried out. The eccentric loading conditions were obtained by moving the point of load application along the direction of the principal axes. Both positive and negative eccentricities were considered (Table 1). A positive eccentricity identifies a movement of the point of load application with respect to the centroid of cross-sections along the considered principal axis in its positive direction.

Table 1 Load eccentricities

Profile	Eccentricity along 1-1	Eccentricity along 2-2
C1	+5mm/+15mm/+30mm -5mm/-15mm/-30mm	+15mm/+30mm
C2	+5mm/+10mm -25mm	+10mm -10mm/-25mm

In addition to the compression tests, ancillary tensile tests on 3 back-bone samples extracted from the coil used to produce the uprights (nominally S250GD steel, f_y = 250MPa) were performed. 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 was 215052 MPa.

3.2 Compression tests results

Tests were performed according to the prescription of the EN15512 §A.2.1 [6] (Fig. 3a)). To allow taking into consideration the natural scatter of experimental results for each loading condition at least five tests were performed. In all the tests, at collapse local buckling modes were observed (Fig. 3b)).

a) b)

Figure 3 Eccentric compression tests

In Figures 4-7, test results are reported 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 eccentricity value, for all the considered profiles. In the graphs, the markers identify the tests results while, the solid line indicates the average values. From the figure it is apparent 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.

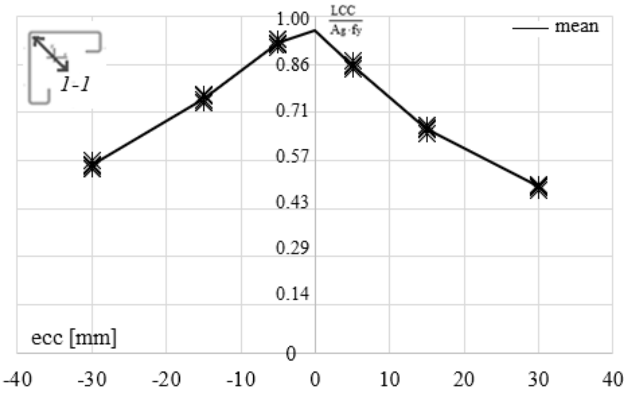

Figure 4 LCC/(Ag fy) ratios vs loading eccentricity, for C1 profile along principal axis 1-1

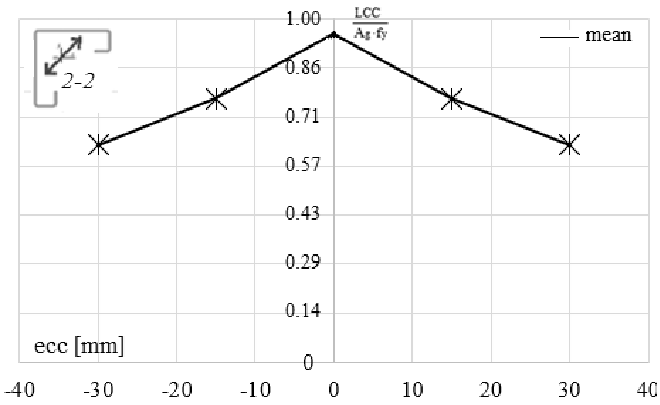

Figure 5 LCC/(Ag fy) ratios vs loading eccentricity, for C1 profile along principal axis 2-2

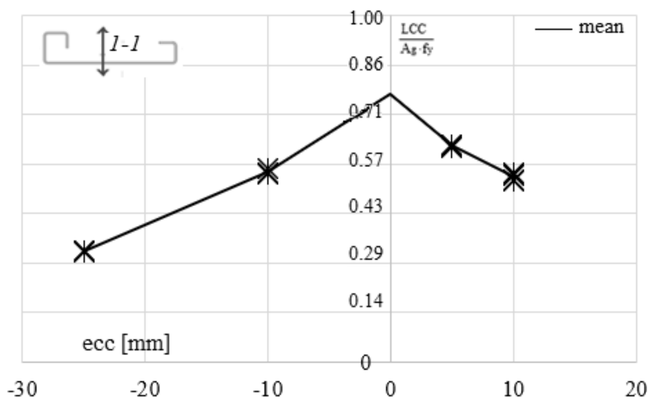

Figure 6 LCC/(Ag fy) ratios vs loading eccentricity, for C2 profile along principal axis 1-1

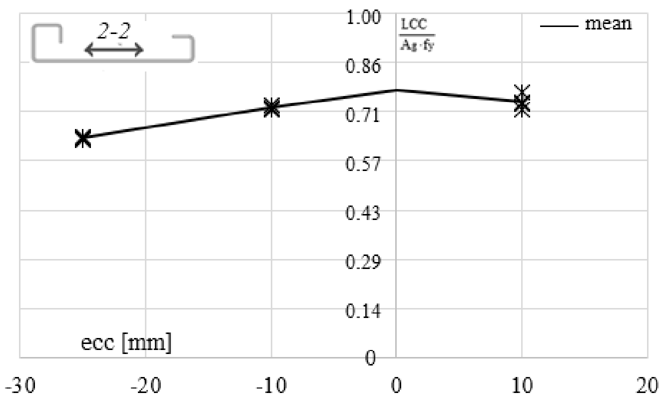

Figure 7 LCC/(Ag fy) ratios vs loading eccentricity, for C1 profile along principal axis 2-2

4 Numerical and theoretical study

The experimental results allowed for calibrating refined finite element (FE) ABAQUS models [7]. At this aim Brick elements were used for the mesh, by dividing the thickness of the profile at least in 3 parts (Fig. 8). The mesh size was calibrated balancing model accuracy and computational time required for the analyses. 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. As discussed in literature the selection of the initial imperfection is of paramount importance for the reliability of the results [8]. 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 [7] have been considered by increasing step by step the displacement of the centroid. In Figure 8 a comparison between the experimental and numerical results at collapse is presented: the good agreement between results is apparent.

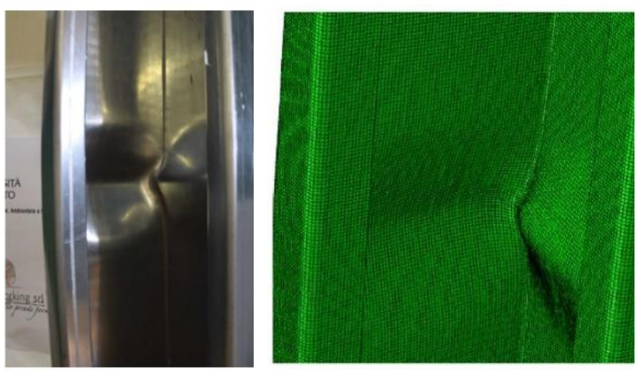

Figure 8 Experimental and numerical collapse of the specimen under pure compression

According to EC3 part 1-3 [3] the design load carrying capacity (LCC) can be evaluated by means of a suitably expression which considers the axial load – bending moment interaction, as:

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

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 EC3-1-3 [3] and NTC18 [4]. 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 Comparison between experimental, numerical and design value for profile C1

Eccentricity	LCC_{NUM}/LCC_{em}	LCC_{EC3}/LCC_{ek}
0	0.983	0.989
-30 mm dir. 1-1	0.965	0.138
-15 mm dir. 1-1	0.990	0.381
-5 mm dir. 1-1	0.991	0.641
+5 mm dir. 1-1	0.991	0.686
+15 mm dir. 1-1	0.965	0.431
+30 mm dir. 1-1	0.968	0.154
-30 mm dir. 2-2	0.952	0.433
-15 mm dir. 2-2	1.023	0.645
+15 mm dir. 2-2	1.023	0.645
+30 mm dir. 2-2	0.952	0.433

Table 3 Comparison between experimental, numerical and design value for profile C2

Eccentricity	LCC_{NUM}/LCC_{em}	LCC_{EC3}/LCC_{ek}
0	0.989	0.604
-25mm dir. 1-1	0.985	0.117
-10 mm dir. 1-1	0.991	0.348
+5 mm dir. 1-1	0.894	0.541
+10 mm dir. 1-1	0.841	0.362
-25mm dir. 2-2	1.168	0.561
-10 mm dir. 2-2	1.051	0.757
+10 mm dir. 2-2	1.122	0.766

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 [5] to describe the behaviour of these profiles especially when a combined axial-bending condition is considered. Finally Figures 9-10 represent the resistance domain according with equation 1 (black line) together with the characteristic points (orange points) obtained from the experimental activities. In addition, also the linearized resistance domain is reported too (dashed grey line). It can be noted that the experimental points are always from the safe side.

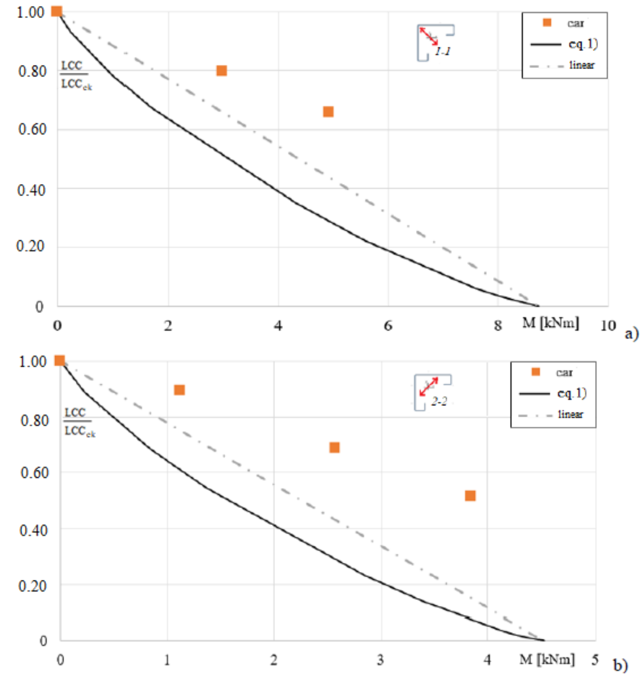

Figure 9 LCC/ LCC_{ek} ratio vs bending moment for C1 profile along: a) axis 1-1 and b) axis 2-2

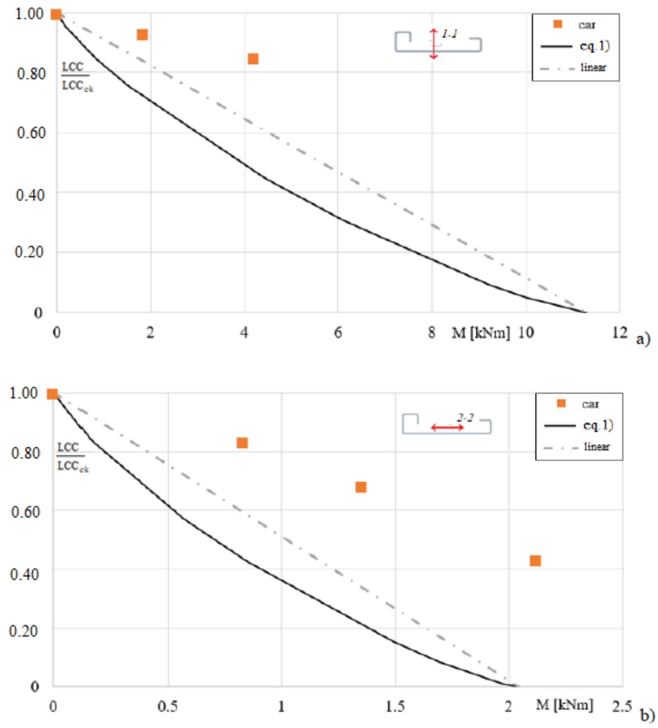

Figure 10 LCC/ LCC_{ek} ratio vs bending moment for C2 profile along: a) axis 1-1 and b) axis 2-2

5 Concluding remarks

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.

Acknowledgment

The study was funded by APIAE – Autonomous Province of Trento, Project MW21 - SISTEMI STRUTTURALI INNOVATIVI, NUOVO SISTEMA DI GIUNZIONE PER ELEVATORI. The tested components have been produced by METAL WORKING which with its 45 collaborators and 14 years of experience is a leader company in the elevator market. Authors would like to thank Mr. Stefano Girardi of the University of Trento for his valuable contribution to the development of the experimental part of the study.

References

[1] NTC2008 Ministero delle Infrastrutture e dei Trasporti, Decreto Ministeriale 14 gennaio 2008, supplemento ordinario n. 30, pubblicata sulla Gazzetta Ufficiale n. 29 del 04.02.2008.

[2] Baldassino, N., Bernuzzi, C., di Gioia, A., Simoncelli, M. An experimental investigation on solid and perforated steel storage racks uprights. Journal of constructional steel research 155, 409-425, 2019.

[3] CEN EN1993-1-3: EN1993, Design of steel structures, part 1-3: general rules – supplementary rules for cold-formed members and sheeting, 2005.

[4] NTC2018 Ministero delle Infrastrutture e dei Trasporti, Decreto Ministeriale 17 gennaio 2018, supplemento ordinario n. 8, pubblicata sulla Gazzetta Ufficiale del 20.02.2018.

[5] CEN EN1993-1-1: EN1993, Design of steel structures, part 1-1: general rules and rules for buildings, 2005.

[6] CEN EN15512, Steel static storage systems - Adjustable pallet racking systems - Principles for structural design, 2020.

[7] Abaqus finite element software version 2019. https://www.3ds.com/products-services/simulia/products/abaqus/abaquscae/ accessed 2022.

[8] Elias, G.C., de Almeida Neiva, L.H., Sarmanho, A.M.C., Alves, V.N., Barbosa e Castro, A.F. Ultimate load of steel storage systems uprights. Engineering Structures 170, 53-62, 2018