COMPORTAMENTO CICLICO DI GIUNTI TRAVE-COLONNA NELLE STRUTTURE METALLICHE PER ASCENSORI

CYCLIC RESPONSE OF BEAM-TO-UPRIGHT JOINTS IN STEEL FRAMES FOR ELEVATORS

Claudio Bernuzzi,
Marco Simoncelli,
Politecnico di Milano
Department of Architecture, Built environment and Construction engineering
Milan, Italy
claudio.bernuzzi@polimi.it
marco.simoncelli@polimi.it

Nadia Baldassino
Università di Trento
Department of Civil, Environmental and Mechanical Engineering
Trento, Italy
nadia.baldassino@unitn.it

Nicola Gabardi,
Civil Engineering,
Rovereto, Italy
nicola.gabardi@gmail.com

Igor Bovolo
Denis Ferrari,
MetalWorking Srl
Research and develop department
Pergine, Italy
ferrari@metalworkingweb.com
engineering@metalworkingweb.com

ABSTRACT

With the continuously rising world population, buildings are becoming taller and taller. For this reason, elevator systems are getting vital and worldwide engineers are pushing to design cost-effective tall steel structural systems used to sustain them. The key point is to guarantee safety and limited cost of these structures and, consequently, thin-walled steel members are frequently adopted to this purpose.

The paper presents and discusses the main results of an experimental-numerical investigation on the cyclic response of beam-to-upright bolted joints used to assemble the steel skeleton frame for elevators. Firstly, the monotonic response is discussed, which is essential to calibrate the loading rule to be applied in the cyclic tests. Then the cyclic response is presented. Two different cross-sections for the uprights and two for the beams were considered, for a total of four different combinations. Finally, finite elements models were created and calibrated against the experimental results with the aim to propose improvement useful to increase their resistance and stiffness.

SOMMARIO

A seguito del continuo aumento della popolazione mondiale, gli edifici stanno diventando sempre più alti. I sistemi di ascensore sono dunque diventati molto importanti e per questo motivo gli ingegneri di tutto il mondo devono riuscire a progettare sistemi strutturali in acciaio alti ed economicamente convenienti in grado di accogliere questi sistemi. Il punto chiave della progettazione è quello di garantire la sicurezza e il costo contenuto di queste strutture e, per questo motivo, nella loro costruzione vengono frequentemente adottati elementi strutturali in parete sottile.
Nel seguito si presentano e discutono i principali risultati di un'indagine sperimentale-numerica sulla risposta ciclica di giunti trave-montante bullonati utilizzati per assemblare la struttura in acciaio per ascensori. In primo luogo, viene discussa la risposta in campo monotono, che è essenziale per definire la legge di carico da utilizzare nei test ciclici. Successivamente viene presentata la risposta ciclica. Sono state considerate due diverse sezioni per i montanti e due per le travi, per un totale di quattro differenti accoppiamenti. Infine, sono stati creati modelli agli elementi finiti, calibrati sulla base dei risultati sperimentali, con l'obiettivo di proporre miglioramenti delle connessioni per aumentare la loro resistenza e rigidezza.

1 INTRODUCTION

In Italy, the steel structures for elevators (Fig. 1) were not considered as structural systems until 2008, when the new design rules for buildings (NTC2008 [1]) went out. From that moment, the design and therefore the production of frames for elevators has significantly changed. 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 the design of steel and cold-formed members.

Fig. 1. Structural system for a steel elevator (courtesy of Metal Working)

Due to its peculiarities, the global response of these structures can be evaluated only by using a *design-by-testing* approach [2], i.e. the key parameters to be used in the design must be evaluated by means a suitable experimental campaign on the isolated components (columns, beams, joints …). In the paper, the response of 4 different beam-to-columns connections is investigated, considering both the monotonic and the cyclic response. For the load profile assigned to cyclic tests, the prescriptions of ECCS [3] have been followed. The experimental results are then compared with the numerical ones in order the create refined model to be used in the future to improve the joints performance.

2 THE EXPERIMENTAL CAMAPAIGN

The experimental campaign was performed on two different beams (B1 and B2) joined to two different columns named C1 and C2, for a total of 4 different beam-to-column joints conventionally named in the following as B1-C1, B1-C2, B2-C1 and B2-C2. All the elements were mono- or non-symmetric cold-formed cross-section members. For each specimen 5 monotonic and 5 cyclic tests were performed for a total of 40 tests.

2.1 The tested specimens

Cantilever specimens were tested under monotonic and cyclic load (Fig. 2), in according to the prescription of the EN15512, §A.3.1 [4]. During the tests, the vertical force and the joints' rotation were continuously monitored

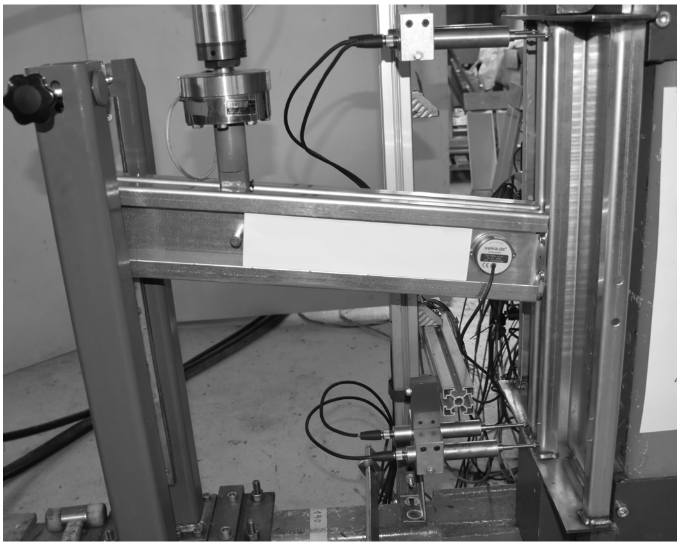


Fig. 2. Detail of the beam-to-column tests

The details of the cross-section of the members are reported in Tables 1 and 2, for columns and beams, respectively. The main dimensions of C1 and C2 columns and B1 and B2 beams are reported, together with the ratio between the gross cross-sectional area (A_g) and the thickness (t), and the ratio between the second moment of area (I_1/I_2), in the two main directions. All the key data, from the cross-section geometry to the overall response, are herein presented for commercial reasons.in non-dimensional form with respect to the 'a' dimension,

Table 1. Dimensions and main characteristics for the considered columns

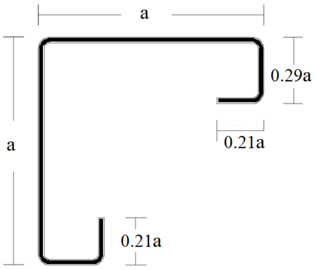
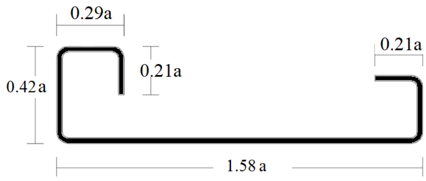
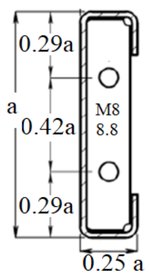
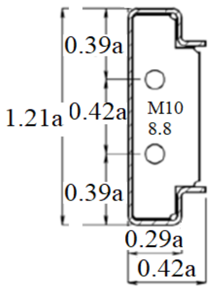
	C1	C2
		
A_g/t	334	334
I_1/I_2	17.11	2.81

Table 2. Dimensions and main characteristics for the considered beams

	B1	B2
		
A_g/t	230	240
I_1/I_2	14.40	10.80

The connection between the beams and the columns, was realized by means of a flush end-plate directly bolted, with two (M10 or M8) bolts, to the columns lip. To avoid torsional problems and out-of-plane displacements all the tests were performed on profiles coupled together and loaded in the middle (Fig. 2).

Tensile tests were performed on 3 back-bone samples extracted from the coil used to create the uprights (nominally S250GD steel). The mean values of the yielding and the ultimate strength were 344.4 MPa and 417.7 MPa, respectively for both beams and columns.

2.2 Monotonic tests

Monotonic tests were performed increasing the vertical load up to the collapse of the specimens. In Fig. 3 the mean curves obtained from all the specimens are plotted together in term of non-dimensional bending resistance (i.e. bending resistance of the joint, M_{jRd}, over the nominal one of the beam, M_{bRd},) vs the joint rotation, in mrad. It can be noted that the failure load is independent of the type of columns. As underlined by the collapse shape (Fig. 4) that the columns are not involved in the failure mechanism, which is completely concentrated in the flush end-plate of the beam and in the bolts.

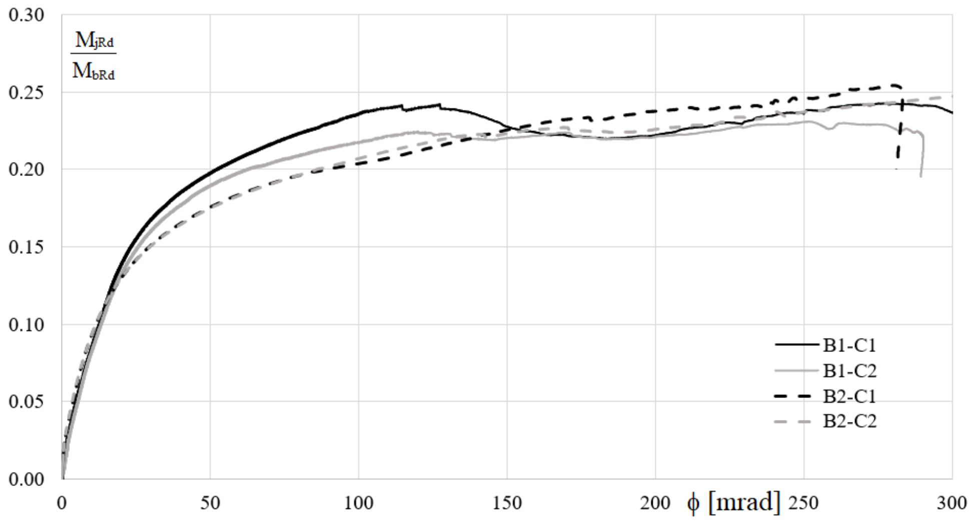


Fig. 3. Mean experimental curves for all the considered specimens

Fig. 4. Collapse mode of one specimen.

2.3 Cyclic tests

Cyclic tests were performed by following the ECCS recommendations [3] as already done in previous works [5]. The results of the monotonic tests were used to define the cyclic test procedure which was based on the elastic limit displacement. Looking into the monotonic curve, this elastic limit was defined as the intersection point between the initial tangent (E) and the tangent to the curve characterized by a slope equal to E/10. In Fig. 5 an example of the cyclic response of different specimens is reported, together with the associated monotonic curve. All the cyclic responses are characterized by a quite remarkable pinching that governs the hysteretic behavior.

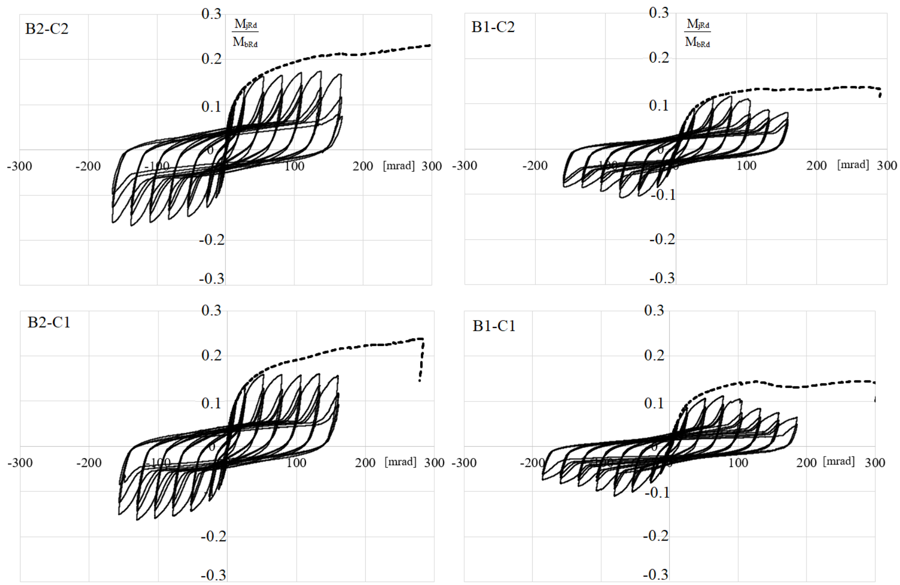


Fig. 5. Cyclic response of joints

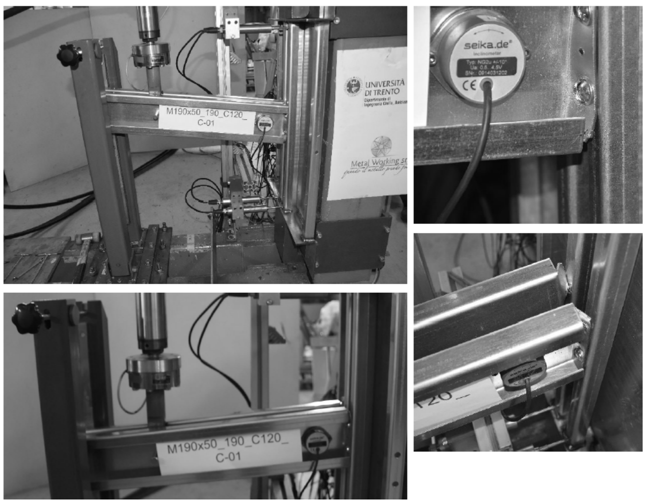


Fig. 6. Collapse scenario after cyclic tests

Joints realized by means of beam B1 are characterized by a significant drop of the resistance and stiffness during the cycles subsequent to the first one. Moreover, connections realized by means beam B1 are characterized by a lower dissipation energy, i.e. less area contained below the subsequent cycles. Also, in these tests the collapse was always observed in the beam and never in the columns (Fig. 6).

3 NUMERICAL MODELLING

The experimental results were simulated by means the use of ABAQUS [6], which is a well-known finite element software. *Brick* elements were adopted for the mesh, by dividing the thickness of the profile at least in 3 parts (Fig. 7).

The mesh size was calibrated in order to obtain good results in minor time. Simply supported boundary conditions were assumed (all rotations allowed on both ends). Explicit dynamic analysis by increasing the displacement of the beam was performed, considering both geometrical and mechanical non-linearities. The constitutive laws of the different steel grades characterizing the three components were implemented through elasto-plastic laws, according to the results of coupon tensile tests. In Fig. 7, an example of the obtained deformed shape is reported which can be observed is in agree with the real collapse mode. To simulate the boundary conditions of the tests, the displacement and rotations of the upright ends were prevented by suitable lateral boundary conditions, in accordance with the kinematic of the experimental set-up.

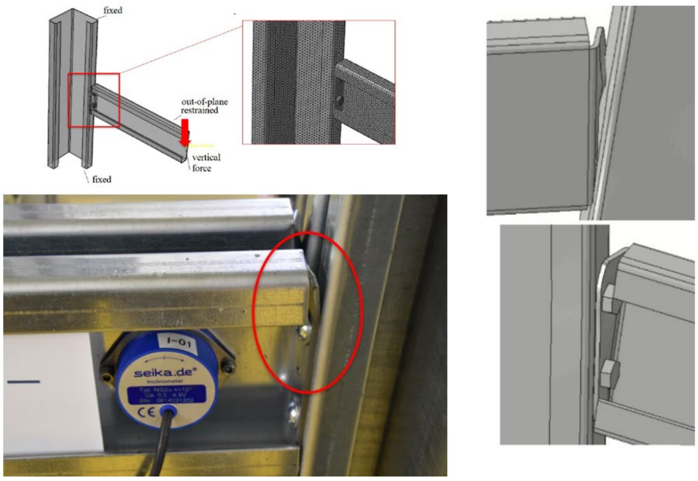


Fig. 7. Real and numerical collapse of the specimen under compression

The numerical and experimental monotonic curves are depicted in figure 8, for the monotonic load case, B1-C1 and B2-C2 combinations.

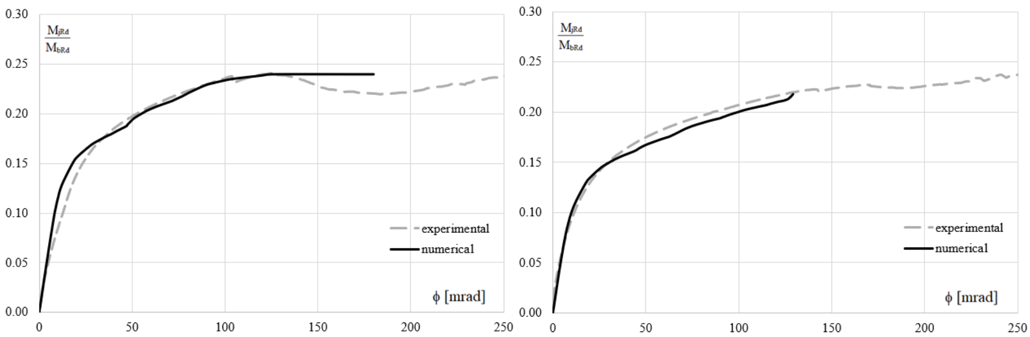


Fig. 8. Comparison between numerical and experimental (mean) monotonic curves

It can be observed a more than good agreement between the curves. It is worth noting that the numerical models can predict with good reliability the stiffness and the strength of the beam-to-column connection: the differences are quite negligible from an engineering standpoint.

CONCLUSIONS

In the paper an experimental campaign on four different beam-to-column joints used for steel skeleton frame of elevator has been presented. In particular, the monotonic and cyclic responses were presented and discussed. The collapse mode of such joints is always located in the flush end-plates of the beam never involving the columns. Moreover, in the cyclic response, joints made by B1 beams showed a great strength/stiffness degradation. Finally, the experimental results were simulated by means finite element models. All the presented models are able to reproduce the results obtained from the experimental monotonic tests with a good accuracy in terms of strength and stiffness. The numerical models can be suitably used to investigate future improvements of the actual connections. Moreover, future analyses will be focused on the cyclic response by modelling the damage function for steel material, contained in ref. [6].

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, "Approvazione delle nuove norme tecniche per le costruzioni", 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] EECS, Recommended Testing Procedure for Assessing the Behaviour of Structural Steel Elements under Cyclic Loads: Technical Report. ECCS, European Convention for Constructional Steelwork, Brussels, Belgium (1986)

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

[5] Balsassino, N., Zordan, M., Zandonini, R. Experimental study of the shear behaviour of floor diaphragms in light steel residential buildings. Thin-walled structures 167, 108099, 2021.

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

KEYWORDS

Thin-walled profiles, Eurocode 3 part 1-3, beam-to-column tests, cyclic response