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Data Article

Experimental tests on real-scale EBF structures with horizontal and vertical links

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ABSTRACT

The paper presents data achieved during an experimental test campaign executed on real-scale one storey/one bay EBF steel structures with vertical and horizontal links. Experimental tests were executed in displacement control by applying cyclic loading histories following ECCS45 protocol and constant amplitude-imposed displacements. Data provide indications concerning the energy dissipated by each prototype during tests, the corresponding shear force - angular distortion curves of the dissipative link and, besides, the force-displacement behavior of the steel prototypes until failure.

Specifications table

Subject area	*Engineering*
More specific subject area	*Earthquake engineering*
Type of data	*Tables, images, figures*
How data was acquired	*Forces were acquired from load cell; deformations through displacement sensors (LVDT) located on the samples.*
Data format	*Analyzed*

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Experimental factors	*Real-scale prototypes were realized by an external steel company following the executive drawings provided by University of Pisa. The mechanical characterization of material was made before the execution of tests.*
Experimental features	*Cyclic shear/displacement or shear/angular distortion curves from cyclic tests executed following ECCS45 or constant amplitude displacement protocol*
Data source location	*University of Pisa, Department of Civil and Industrial Engineering, Largo* *L. Lazzarino 1, 56122 Pisa (Italy).*
Data accessibility	*Data is with the article*
Related research article	*S. Caprili, N. Mussini, W. Salvatore. Experimental and numerical assessment of EBF structures with shear links, Steel and Composite Structures, Vol. 28, No. 2 (2018) 123–138.* DOI: https://doi.org/10.12989/scs.2018.28.2.123

Value of the data

- Data allow the deep evaluation of the experimental cyclic behavior of EBF steel structures designed following EN1998–1:2005 prescriptions.
- Data provide indications about the dissipative capacity of the link in terms of cyclic shear/angular distortion relationship, the failure mechanism associated to different loading protocols and the corresponding degradation behavior.
- Data can be used to calibrate mechanical and numerical models for the cyclic behavior of links in EBF structures.

1. Data

Data coming from a wide experimental test campaign executed on real-scale (1:1) one storey/one bay Eccentrically Braced Frames (EBF) with horizontal and vertical links are presented. Cyclic tests, performed by adopting two different loading protocols (i.e., ECCS45 and constant amplitude), allowed to understand the behavior of dissipative shear links; results of experimental tests, aligned with what presented in the current scientific literature, well highlighted the structural performance of links, with stable behavior until the initiation of cracks in correspondence of the web and the following degradation of the bearing capacity.

2. Experimental design, material, and method

2.1. Design of the specimens

One storey/one bay EBF real-scale prototypes with horizontal and vertical short-shear links were designed, realized, and tested at the laboratory of Pisa University. The EBF prototypes have a span length equal to 5.0 m and a storey height up to 3.0 m. Steel grade S355 was used for all the elements [1].

The prototypes were designed following the prescriptions imposed by Eurocode 8 and, besides, by Italian Standard for Constructions (EN1998–1:2005 [2], D.M.14/01/2008 [3]), taking into account the possibility to simply replace the dissipative elements after damage: To do this, easiness in joints and connections were pursued [4]. The capacity of the laboratory equipment at the Laboratory of Pisa University was considered for the design: The maximum horizontal force that can be applied using the hydraulic jack is equal to 200 kN and the links, both in the vertical and horizontal EBF configurations, were sized to exploit their maximum angular distortion, assumed equal to 110 mrad applying an additional safety factor equal to 1.30. HEA100 profiles with length equal to 300 mm for the horizontal link and HEB120 profiles of length equal to 150 mm for the vertical link were selected. The design of non-dissipative elements was executed following the EN 1998–1:2005 and in agreement to what specified in the current literature [5–7]. The ratio $V_{y,link}/V_{Ed}$ was assumed unitary considering the achievement of the complete plastic deformation of the link during the tests; eventual higher over-strength was accounted for assuming Ω factors equal to 2.0.

Columns and beams were realized using HEB180 sections; for braces 2UPN160, coupled with three bolted connections equally spaced, were employed. Web stiffeners, equally spaced, in correspondence of horizontal links to avoid buckling phenomena of the web in the plastic field were introduced; no stiffeners were, otherwise, used in the case of vertical links. All the connections were designed to work in friction adopting a safety factor equal to 1.50. For the link elements tensile tests on dog-bone specimens extracted from the web and from the flanges were performed, resulting in average values of yielding strength equal to 355 MPa.

Table 1
Main dimensions of the EBF specimens' elements.

EBF	Vertical link	Horizontal link
Columns	HEB 180	HEB 180
Beams	HEB 180	HEB 180
Braces	2UPN 160	2UPN 160
Links	HEB 120	HEA 100
Link length	120 mm	300 mm
Column height	3000 mm	3000 mm
Span length	5000 mm	5000 mm

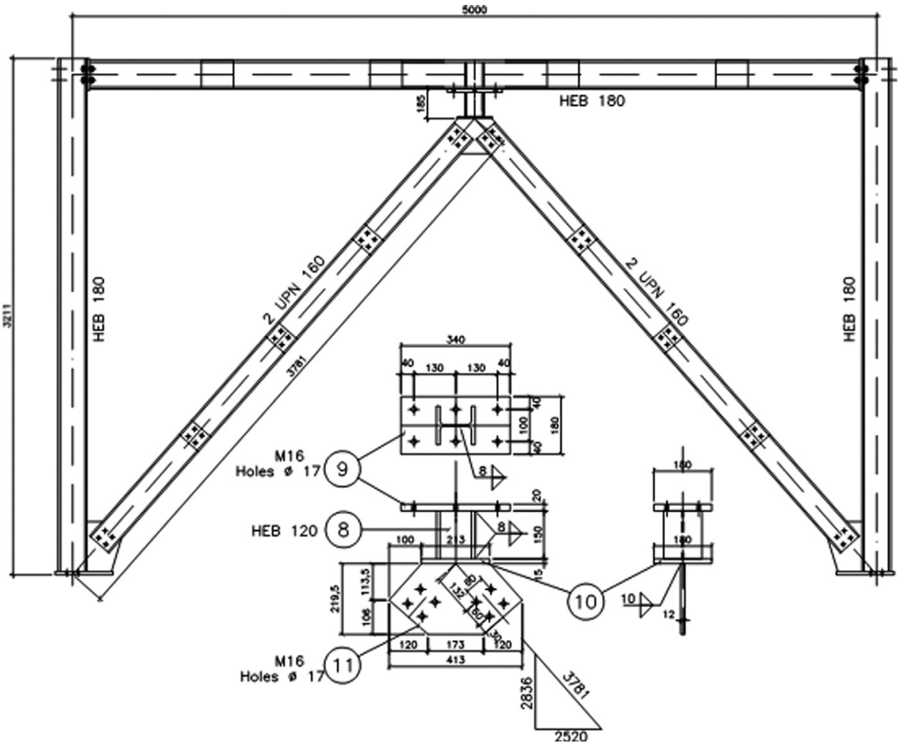

Fig. 1. EBF and details of vertical link.

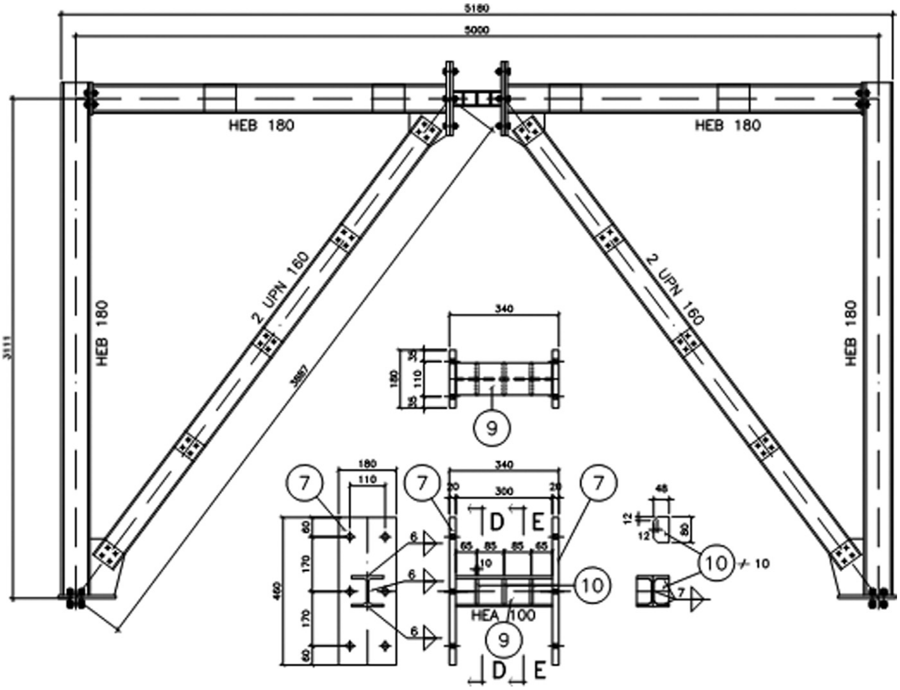

Fig. 2. EBF and details of horizontal link.

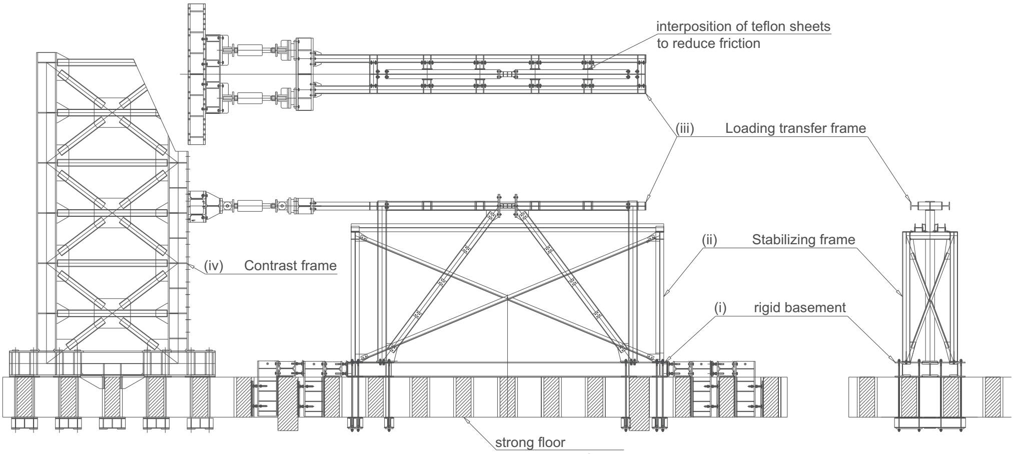

Fig. 3. General setup of the test.

Table 1 summarizes the profiles and the main dimensions of the prototypes. Figs. 1 and 2 show the final configurations of the EBF. For the link elements tensile tests on dog-bone specimens extracted from the web and from the flanges were performed, resulting in average values of yielding strength equal to 355 MPa.

Fig. 4. General overview of the test setup.

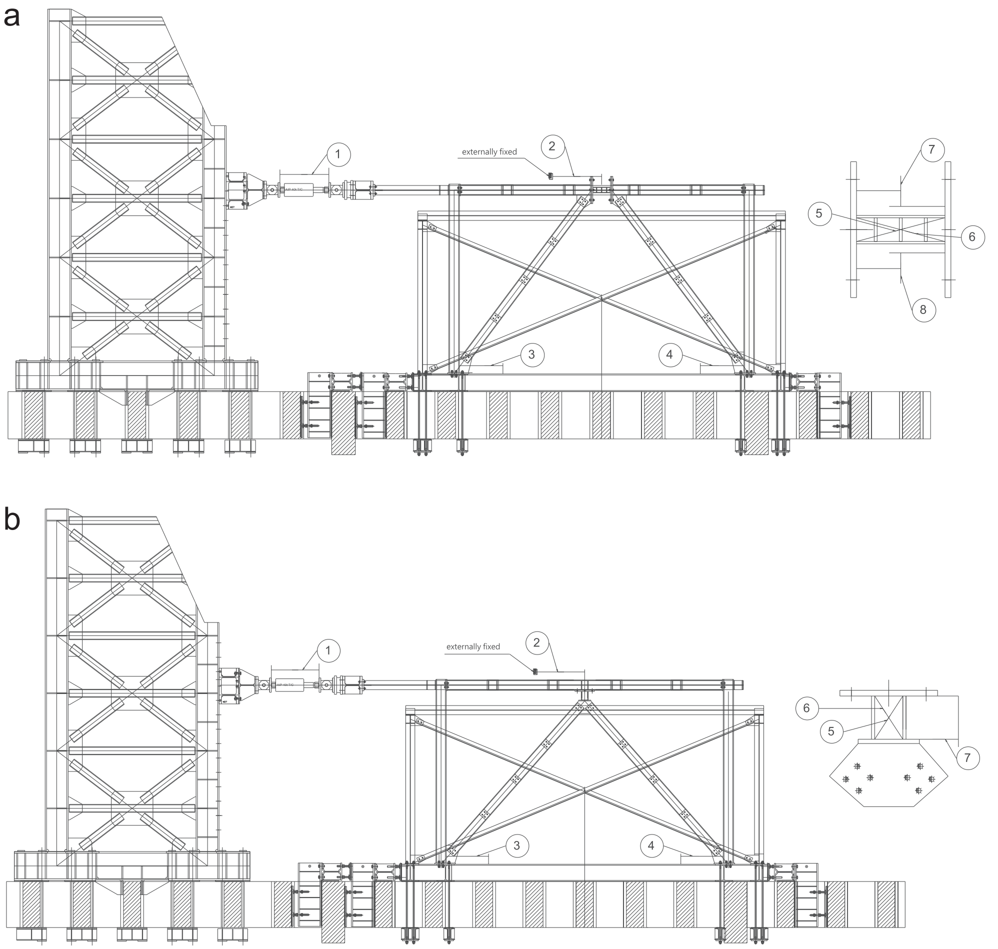

Fig. 5. Scheme of LVDT disposition for EBF prototypes with: (a) Horizontal and (b) vertical link. For the numbering of LVDT the following is assumed. LVDT1: Displacement of the actuator; LVDT2: Displacement of the top beam; LVDT3–4: Relative displacement at the basement connection; LVDT5–6: Displacement of the diagonals of the link; LVDT7–8: Transversal displacement of the link.

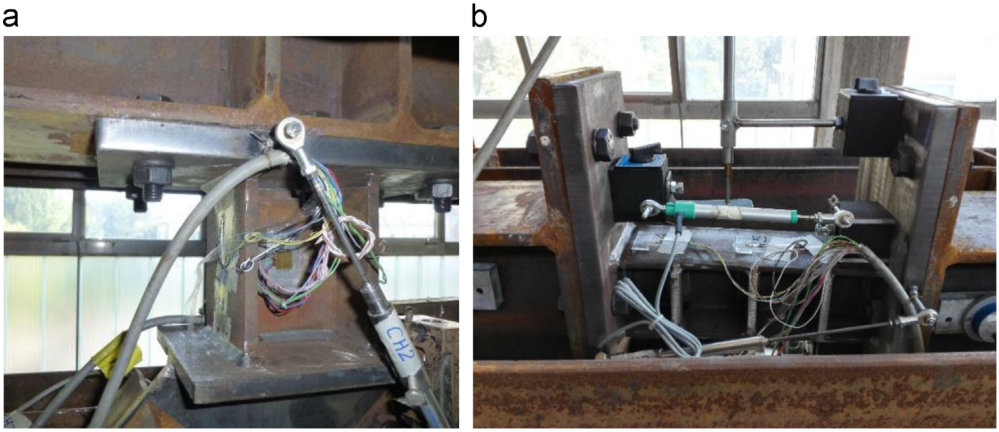

Fig. 6. Disposition of the LVDTs on the (a) vertical and (b) horizontal link.

Table 2
Summary of experimental tests executed.

Prototype	ECCS45 protocol		Constant amplitude	
	no. tests	e_y	no. tests	Amplitude
EBF Vertical link	2	0.6 mm	1	± 16.9 mm
EBF Horizontal Link	2	0.8 mm	1	± 21.5 mm

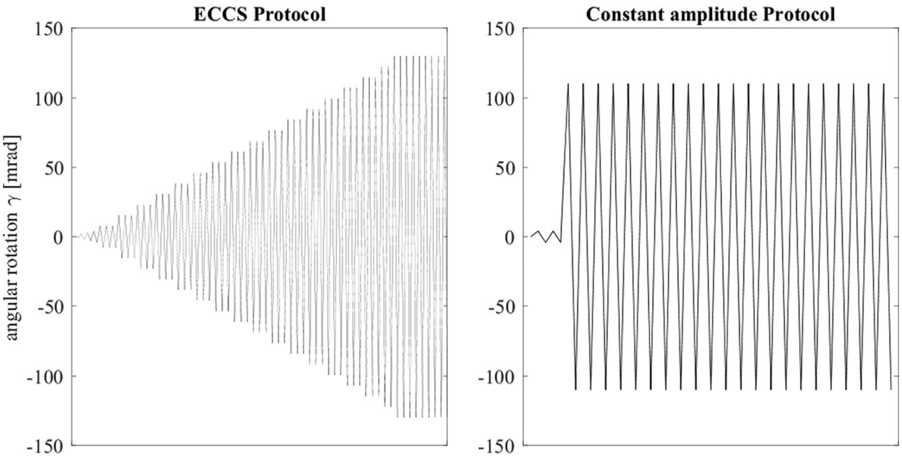

Fig. 7. ECCS45 and constant amplitude loading protocol applied to the EBF prototypes.

2.2. Organization of the test setup for real-scale prototypes

To connect the EBF real-scale prototypes to the bidirectional concrete slab floor of the Laboratory avoiding possible out-of-plane mechanisms and buckling phenomena, additional components were used. As visible from Figs. 3 and 4, a *loading transfer frame* was applied to connect the prototype to the hydraulic jacks, avoiding the buckling of the top beam and of the whole frame. A *contrast frame* was used to fix the actuators and, besides, an additional *stabilizing frame* allowed to exclude the warping of the columns. A *rigid basement* finally connected the prototypes to the concrete slab of the laboratory.

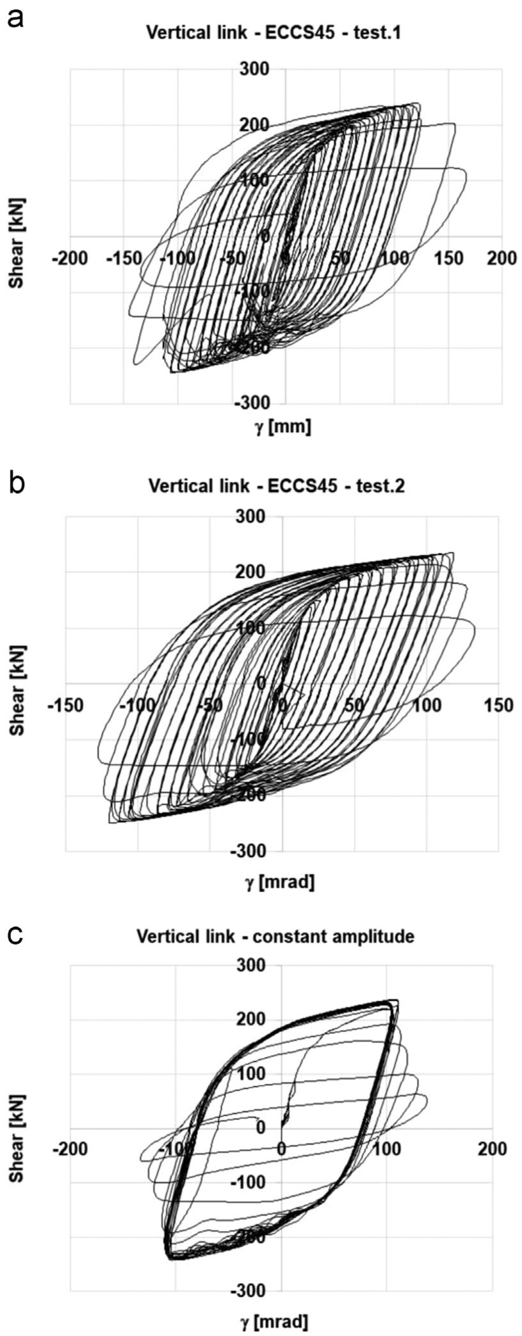

Fig. 8. Angular distortion/shear force curves for EBF with vertical links: a-b) ECCS45 protocol and c) constant amplitude protocol.

The load was applied at the height of the top beam using two hydraulic jackets with maximum stroke equal to ± 150 mm and maximum load capacity equal to ± 200 kN. Tests were performed by applying monotonic and cyclic loading histories. Two load cells placed between the hydraulic jackets and the loading transfer frame controlled the load applications.

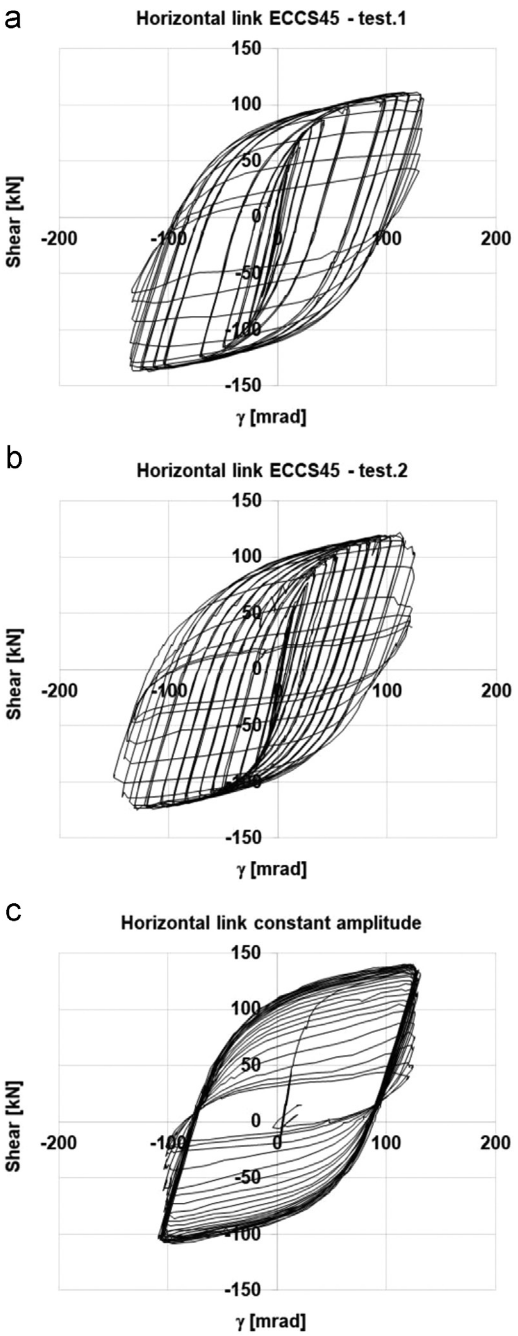

Fig. 9. Angular distortion/shear force curves for EBF with horizontal links: (a and b) ECCS45 protocol and (c) constant amplitude protocol.

The monitoring system was planned to guarantee a suitable amount of recorded information (i.e., applied force, deformation, global, and local displacements), recording the shear force-displacement behaviour of the links (or the shear - angular deformation behaviour). Triaxial strain gauges were

Fig. 10. Progressive damage in the (a) horizontal and (b) vertical links due to the execution of experimental tests.

Table 3
Data coming from experimental tests on EBF prototypes.

Vertical link	γ_{max} [MPa]	V_{max} [MPa]
Test 1 ECCS 45	125	244.03
Test 2 ECCS 45	119	248.73
Constant amplitude	110	245.69
Horizontal link	γ_{max} [MPa]	V_{max} [MPa]
Test 1 ECCS 45	128	172.62
Test 2 ECCS 45	123	175.95
Constant amplitude	110	166.73

applied on the link web to assess the evolution of the plastic deformation due to the shear force within the link's web. Uniaxial strain gauges were placed on the top and bottom flanges at the link's ends of the link, to check eventual flexural mechanisms due to elevated angular rotations. Fig. 5 provides the overview of the sensors' disposition. LVDTs were organized to account for the possible slip due to hole-to-bolt tolerances. One LVDT on the actuator and one on the top beam were used to monitor the global displacement. The effective displacement of the link due to shear deformation, depurated from eventual slip, was evaluated monitoring the transversal deformation and the displacement of the diagonal through the equation below.

$$\gamma = tg^{-1} \cdot \left[\sqrt{h_i^2 + L_i^2} \cdot \frac{\Delta U_{LVDT,1} + \Delta U_{LVDT,2}}{2 \cdot (h_i + L_i)} \right]$$

being $\Delta U_{LVDT,1}$ and $\Delta U_{LVDT,2}$ the relative displacement measured in correspondence of the two LVDT instruments placed along the two diagonals of the link, L_i and h_i the length and the height of the shear

Table 4
Dissipated energy/cycle and total for each executed cyclic test.

Cycle n.	Horizontal Link			Horizontal Link		
[-]	ECCS45 [MPa]	ECCS45 [MPa]	Const.Ampl. [MPa]	ECCS45 [MPa]	ECCS45 [MPa]	Const. Ampl. [MPa]
1	40,9	38,3	6500,0	70,0	27,1	7298,4
2	73,2	26,1	6609,9	115,2	18,4	8782,2
3	251,9	50,0	7017,5	263,0	35,3	8804,1
4	640,9	410,8	6629,3	1091,9	290,4	8786,0
5	1462,5	1573,8	6458,0	2106,3	1112,4	8847,7
6	2844,2	3424,9	6623,2	5145,2	2420,8	8870,9
7	4402,7	5588,5	6048,1	6038,1	3950,0	8795,8
8	5204,3	8304,9	6414,1	7647,4	5870,1	8847,1
9	6784,4	11702,7	6306,4	9939,8	8271,7	8861,0
10	8705,3	15421,3	6263,1	13010,1	10900,1	8822,9
11	10724,7	17982,8	6674,7	15389,0	12710,6	8839,3
12	13348,8	21810,9	5837,7	21155,2	15416,3	8897,4
13	15896,0	26224,9	6119,9	21110,0	18536,2	9730,6
14	16368,0	30907,3	6028,8	23477,0	21845,8	8930,8
15	18527,5	34369,5	5995,9	27072,4	24293,0	8850,2
16	20608,6	38311,3	5297,5	29309,9	27079,1	8848,4
17	17818,4	42312,9	5570,0	21499,4	29907,5	8783,6
18			4920,0		32724,0	8814,9
19			4565,1			8520,4
20			4147,1			
Total	143702,0	258460,8	120026,3	204440,0	215408,8	166931,9

panel of the link. Fig. 6 shows the position of the monitoring instrumentation on link elements. As visible, the slip at the bottom of columns was opportunely measured to control the lack of relative slip.

2.3. Loading protocol

Experimental cyclic tests were executed using two different loading protocols: ECCS45 [8] and constant amplitude displacement histories were adopted. The displacement increment e_y adopted for the ECCS45 protocol was fixed equal to, respectively, 0.6 mm and 0.8 mm for the vertical and the horizontal link. The amplitude of the cyclic constant amplitude test was imposed equal to the 85% of the displacement causing the crack initiation in the link during the application of the ECCS45 protocol, respectively equal to ± 16.9 mm and ± 21.5 mm for the vertical and the horizontal links. Two tests following ECCS45 protocol and one constant amplitude test were executed for each EBF configuration. Table 2 summarizes experimental tests' parameters adopted, while Fig. 7 shows schematically the loading protocols adopted.

3. Results

Figs. 8 and 9 show the experimental shear/angular distortion behavior of vertical and horizontal links achieved from ECCS45 and constant amplitude loading protocols.

The vertical and the horizontal links evidenced yielding, respectively, for a force equal to 90 and 145 kN. Specimens experienced a crack within the web propagating parallel to the flanges. In the case of EBF prototypes with horizontal links subjected to ECCS45 protocol, the specimens reached an average angular rotation γ close to 125 mrad; adopting the constant amplitude displacement, crack initiation was observed at the last cycle. In the case of EBF with vertical links, ECCS45 tests resulted in an average ultimate angular rotation equal to 122 mrad; following the constant amplitude protocol, collapse was achieved in correspondence of the last

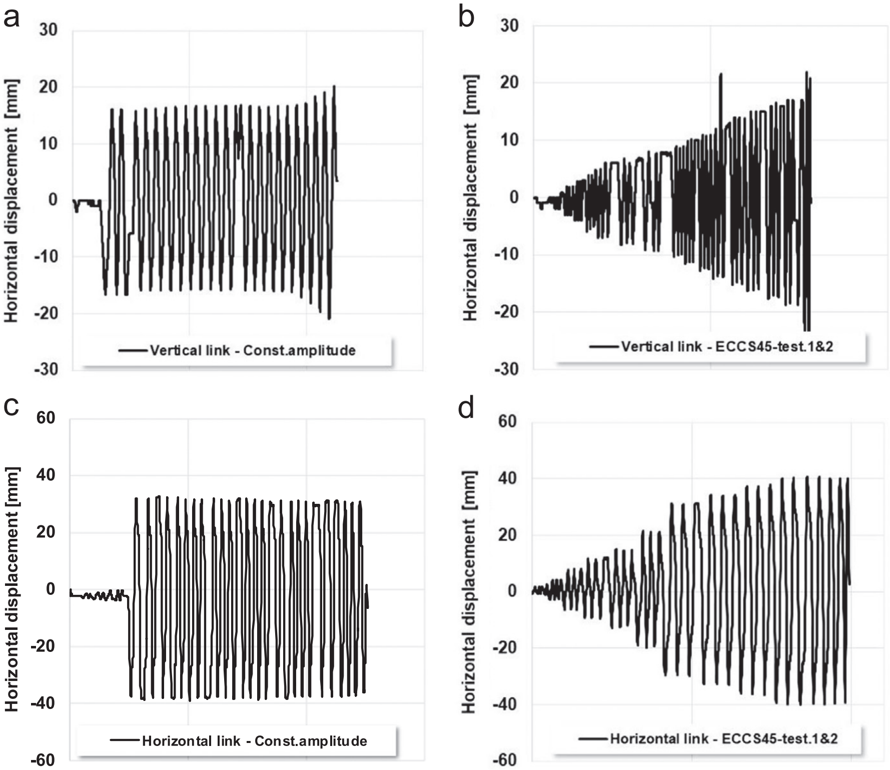

Fig. 11. Lateral horizontal displacement during experimental tests: (a), (b) vertical links for constant amplitude and ECCS45 protocol; (c), (d) horizontal link for constant amplitude and ECCS45 protocol.

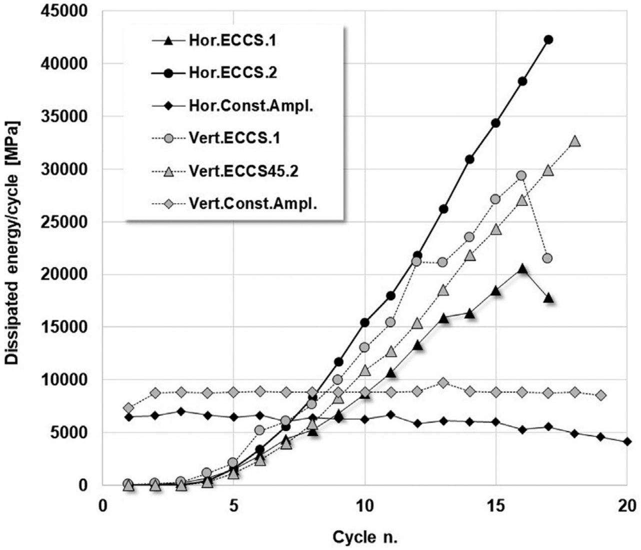

Fig. 12. Dissipated energy per cycle for each experimental test performed.

cycle. Fig. 10 provides pictures, respectively for the horizontal and vertical links tested, of the damages undergone by the specimens. Table 3 summarizes the results of tests when collapse occurred; Table 4 provides data concerning the dissipated energy, per cycle and total, achieved from each executed test. Fig. 11 shows the measured horizontal lateral displacement for the different tested specimens and for the two adopted protocols. Fig. 12 shows the energy dissipated by the structure for each executed cycle, being the energy per cycle evaluated as the area below the shear/angular distortion curve; as visible from Fig. 12, the energy per cycle increases in the case of ECCS45 protocol while is almost constant till collapse in the case of constant amplitude test.

Acknowledgments

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Transparency document. Supporting information

Transparency data associated with this article can be found in the online version at https://doi.org/10.1016/j.dib.2018.10.126.

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