The paper presents the whole dataset obtained during an experimental test campaign executed on the prototype of a new re-centering dissipative device, characterized by an asymmetric behavior, for the seismic protection of buildings. The experimental tests were performed on two different configurations: on the single prototype of the device (configuration 1) and one in which two prototypes are placed within a steel frame in an inverted V bracings configuration (configuration 2). The experimental tests were executed in displacement control, applying cyclic loading histories. Data are mainly reported in terms of force-displacement cyclic curves for the single prototype in the configuration 1 and for the whole braced system in the configuration 2.

© 2020 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
characterized by significant constant vertical loads, such as the industrial buildings, allowing to solve several issues related to the seismic improvement of those structures [4,5].

The paper presents the data in terms of hysteretic behavior of the single dissipative device set with different configurations of the constituting elements and the hysteretic behavior of a couple of devices placed in an inverted V bracings configuration within a steel frame that reproduces the intended working condition of the devices. Figs. 1–7 describes the geometry of the tested device. Fig. 8 and Table 1 report the tensile test data on the steel grade adopted for the dissipative elements. Fig. 9 and Fig. 10 shows the test layout and the measuring sensors adopted in the stand-alone configuration. Table 2 reports the configuration of the internal elements in the 5 tests carried out in the stand-alone configuration. Figs. 11 and 12 and Tables 3 and 4 reports the experimental data obtained in the 5 stand-alone configurations tested. Fig. 13 shows the test layout in the inverted V bracing configuration while Figs. 14 and 15 show the experimental data obtained.
2. Experimental design, materials, and methods

2.1. Description of the asymmetric re-centering dissipative device

The specimen tested is based on the one developed in the Department of Civil Engineering of the University of Pisa and described in details in Ref. [2], and the asymmetric behavior is obtained through the introduction of an additional “asymmetric” pre-stressing cable. Fig. 1 shows schematically the constituting elements.

The external carter, see Fig. 2, is composed by 10 mm thick plates welded together and it has three main functions:

1. Provide a means of connection of one end of the device to the structure;
2. Host all the other elements of the device, assuring the transmission of internal forces among them;
3. Force all the internal elements of the device to move only in the axial direction of the device itself.

Fig. 1. Scheme of the proposed asymmetric re-centering device.

Fig. 2. Dimensions of the external carter.
In particular, ten 8 mm thick sheets act as stops for the anchoring plates and allow movement of the internal sliding frame only in the longitudinal direction. Two 6 mm thick steel side panels are bolted to the carter on each side, avoiding buckling phenomena under compression and allowing, at the same time, the inspection of the interior and the replacement of dissipative elements.
The internal sliding frame is composed by two square tubular elements, Fig. 3, connected by 4 plates. The two external plates, directly welded to the tubular elements and whose thickness is respectively 50 mm (placed on the left side of Fig. 3) and 70 mm (placed on the right side of Fig. 3), are equipped with four rectangular holes and two transversal plate, to connect the frame with the dissipative elements in each side.

**Fig. 6.** Buckling restraining system.

**Fig. 7.** Detail of the pre-stressing cable anchoring system.

**Fig. 8.** Stress-strain curves for the steel grade adopted for the dissipative elements.

The internal sliding frame is composed by two square tubular elements, Fig. 3, connected by 4 plates. The two external plates, directly welded to the tubular elements and whose thickness is respectively 50 mm (placed on the left side of Fig. 3) and 70 mm (placed on the right side of Fig. 3), are equipped with four rectangular holes and two transversal plate, to connect the frame with the dissipative elements in each side.
Table 1
Geometrical and mechanical characteristics of the dissipative elements specimens.

| Specimen | b [mm] | h [mm] | L₀ [mm] | A [mm²] | Fy₀ [kN] | Fu [kN] | fy₀ [MPa] | fu [MPa] |
|----------|--------|--------|---------|---------|----------|---------|-----------|---------|
| 1        | 8.45   | 4.02   | 40      | 33.97   | 11.48    | 14.34   | 338       | 422     |
| 2        | 8.33   | 3.68   | 40      | 30.65   | 10.60    | 13.12   | 346       | 428     |
| 3        | 8.62   | 4.18   | 40      | 36.03   | 12.36    | 15.43   | 343       | 428     |
| Average values | | | | | 342 | 426 | | |

Fig. 9. a) Layout and b) picture of the test setup in the stand-alone configuration.

Fig. 10. Layout of displacement sensors (Ext.1, 2 and A to F) and strain gauges (from 1 to 18; strain gauges placed on the opposite side of the device are in brackets).
The end anchoring plates have the same thicknesses and a similar geometry of the above-mentioned plates of the internal sliding frame, having four rectangular holes and two welded plates for connecting four dissipative elements. The end anchoring plates “A” is 50 mm thick and has three circular holes, to allow the passage of the three pre-stressing cables. The end anchoring plate “B” is 70 mm thick and has two circular holes for the “symmetric” pre-stressing cables and one central circular hole for the passage of a tubular element used to connect the device to the structure. The central anchoring plate is 50 mm thick and has one circular hole for the “asymmetric” pre-stressing cable.

The dissipative elements are made up of dog-bone-shaped 4 mm thick plates, Fig. 5, and are connected to the endplates and the internal sliding frame by preloaded bolts. Each pair of dissipative elements is provided with a buckling restraining system to allow yielding of the dissipative elements under compression, Fig. 6.

The pre-stressing cables are made of open spiral strands with diameters of 10 and 12 mm (depending on the test configuration chosen) provided at both ends with adjustable cylindrical sockets with threaded rods and spherical nuts and washers, Fig. 7. The pretension force is applied through controlled fastening torque.

### 2.2. Mechanical characteristics of the steel grades

Common S355 structural steel ($f_{y,k} > 355$ N/mm$^2$ and $f_{u,t} > 510$ N/mm$^2$) was used for the steel grades of the external carter, internal sliding frame and the anchoring plates while for the spiral strands common pre-stressing steel was adopted ($f_{p,1}^{(1)} > 1670$ N/mm$^2$ and $f_{p,t}^{(k)} > 1860$ N/mm$^2$) and no mechanical tests were executed.
Table 3
Pretension force for the first two tests.

| Pretension Force [kN] | Tension | Compression |
|-----------------------|---------|-------------|
| Test 1 (Symmetric configuration) | -47 | -45 |
| Test 2 (Asymmetric configuration) | -38 | -66 |

Table 4
Mechanical characteristics derived from the experimental hysteretic cycles for Tests 2, 3 and 4.

|                               | Test 2 | Test 3 | Test 4 |
|-------------------------------|--------|--------|--------|
| Yielding force in tension [kN]| 95     | 95     | 110    |
| Yielding force in compression [kN]| 110    | 110    | 125    |
| Maximum force in tension [kN]| 170    | 170    | 190    |
| Maximum force in compression [kN]| 250    | 250    | 275    |
| Elastic stiffness in tension [kN/mm]| 145    | 150    | 275    |
| Elastic stiffness in compression [kN/mm]| 220    | 180    | 195    |
| Post-Elastic stiffness in tension [kN/mm]| 15     | 15     | 15     |
| Post-Elastic stiffness in compression [kN/mm]| 25     | 25     | 30     |
Three tensile tests were, on the contrary, performed on dissipative elements in order to evaluate the actual mechanical characteristics of the steel grade adopted. The tests were carried out in displacement control and the strains were obtained using Linear Variable Displacement Transducers (LVDT) sensors. Fig. 8 shows the experimental engineering stress-strain curve for the tested dissipative elements, while Table 1 provides the main geometrical and mechanical parameters.

2.3. Test setup and instrumentations in the stand-alone configuration

Fig. 9 shows the setup adopted for the tests on the stand-alone configuration. The external force was applied by means of one 450kN hydraulic jack equipped with a loading cell and displacement sensors. The jack was linked to the reaction wall and to the load transmission system, which allows only horizontal displacements. Six M22 8.8 class bolts connected the external carter of the tested device to the load transmission system and the internal sliding frame to the steel reaction frame, that avoid horizontal and vertical displacements.

In order to control the test and record displacements, deformations and loads, eight LVDT displacement sensors, eighteen strain gauges and one loading cell were used, Fig. 10.
A total of 5 tests was carried out adopting different configurations of the device, see Table 2, e.g. considering or not the presence of the dissipative elements and adopting different values of the initial pre-stressing forces on the cables. In particular, Tests n.1 and 2 were used to show the efficacy of "asymmetric" pre-stressing cable in inducing an asymmetric behavior even without the presence of the
dissipative elements and to relate the effective pre-tensioning force with the fastening torque. Tests n. 3, 4 and 5 demonstrated the actual behavior of the device adopting different pre-stressing forces.

2.4. Experimental behavior in the stand-alone configuration

Tests 0 and 1 were carried out without dissipative elements, in order to assess the pre-stressing load applied to the cables. In Test 0, the “asymmetric” cable, which reacts only to external compressive forces, was not present. The experimental behavior of the device, shown in Fig. 11, is symmetric and can be well approximated by a bi-linear elastic curve. Only a small part of energy is dissipated by friction phenomena. The Test 1 was performed applying a pre-tension in the “asymmetric” cable and the same figure shows the effectiveness in providing an asymmetric global behavior, with higher values of the overall pre-tensioning force in the case of external compressive, see Table 3 and Fig. 11. The overall pre-tensioning forces were evaluated as the one corresponding to the change of the system stiffness. Indeed, the first branch of the bilinear curves corresponds to the behavior of the device until anchoring end-plates are forced into contact with the internal sliding frame by the action of the pre-stressing cables. When the external forces exceed the pre-loads, the anchoring end-plates lose contact with one side of the internal frame and the stiffness decreases. The velocity of the actuator during the tests was set equal to 3 mm/min. The relative displacement between the external carter and the internal sliding frame is recorded by the “B” and “D” LVDTs of Fig. 10.

The three final tests were performed following the short testing procedure described by the EN15129 “Anti-Seismic Devices” [6], by imposing increasing amplitude cycles at 25%, 50%, 75% and 100% of the maximum displacement. In the first stage of the tests, small displacement increments (±0.5 mm) were used in order to execute five complete cycles before the yielding of the dissipative elements. Afterward, five cycles for each intermediate amplitude and at least ten cycles for the maximum amplitude were applied. Fig. 12 reports the history of the applied displacement and the observed mechanical behaviors of the device in the three configurations (Test 2, Test 3 and Test 4 of Table 2).

Table 4 reports the resulted main characteristics of the device in the three tested configurations.

2.5. Test setup and instrumentation in the inverted V bracings configuration

After the tests on the stand-alone configuration, the behavior of the device was tested in a configuration simulating the effective operative conditions, placing two devices in an inverted V bracing configuration within a steel frame. The overview of the test setup is shown in Fig. 13. The frame is composed by S355 HEB180 columns and a beam. The beam is connected to the columns by rigid joints, while the devices are connected by pinned joints to the center of the beam and to the base of the columns.

The horizontal external force was applied by means of two 450kN hydraulic jacks, both equipped with a loading cell and a displacement sensor. The jack was linked to the reaction wall and to the load transmission frame, which allows only horizontal displacements. By means of one more hydraulic jack, and two dywidag bars, a constant vertical load is applied in center of the beam, simulating the action of gravity loads. One loading cell is placed between the beam and the vertical load application system, in order to control and calibrate the vertical load applied.

2.6. Experimental behavior in the inverted V bracings configuration

Two tests were executed in the inverted V bracings configuration. The first test was performed placing the devices without dissipative elements, similarly to what done in Test 1 in the stand-alone configuration, using 12 mm diameter cables and applying a 150 Nm fastening torque to each cable. Before the application of the horizontal load in the frame, a 42 kN vertical load was applied to the center of the beam, simulating the action of the live loads. Afterward, the test was performed by applying incremental loading cyclic displacements to the top of the beam. The displacement history is reported in Fig. 14a) while the recorded force-displacement curve is shown in Fig. 14b).

The second test was performed adopting for the devices the same configuration already used in Test 4 in the stand-alone configuration, see Table 2. The test was performed following the short testing
procedure described by the EN15129 “Anti-Seismic Devices”, by imposing increasing amplitude horizontal displacement cycles. Similarly to what done in the first test, before the application of the horizontal displacements, a vertical load of 42 kN was applied to the beam, in order to simulate the presence of the live load. The history of the applied displacement and the hysteretic behavior of the whole frame and of the single devices are reported in Fig. 15.

Acknowledgments

Support for this research from the European Commission, Research Fund for Coal and Steel, Steel Technical Group TGS 8 (RFSR-CT-2010-00025) and from the Italian Department of Civil Protection within the Italian Research Project RELUIS-DPC 2014–2018, is gratefully acknowledged.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2020.105181.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] F. Morelli, A. Piscini, W. Salvatore, Development of an asymmetric re-centering dissipative device, J. Constr. Steel Res. 161 (2019) 227–243, https://doi.org/10.1016/j.jcsr.2019.07.004.
[2] A. Braconi, F. Morelli, W. Salvatore, Development, design and experimental validation of a steel self-centering device (SSCD) for seismic protection of buildings, Bull. Earthq. Eng. 10 (2012) 1915–1941, https://doi.org/10.1007/s10518-012-9380-9.
[3] C. Christopoulos, R. Tremblay, H.-J. Kim, M. Lacerte, Self-centering energy dissipative bracing system for the seismic resistance of structures: development and validation, J. Struct. Eng. 134 (2008) 96–107, https://doi.org/10.1061/(ASCE)0733-9445(2008)134:1(96).
[4] F. Morelli, A. Piscini, W. Salvatore, Seismic behavior of an industrial steel structure retrofitted with self-centering hysteretic dampers, J. Constr. Steel Res. 139 (2017) 157–175, https://doi.org/10.1016/j.jcsr.2017.09.025.
[5] F. Morelli, A. Piscini, W. Salvatore, Seismic retrofit of an industrial structure through an innovative self-centering hysteretic damper: modelling, analysis and optimization, in: ECCOMAS Congr. 2016 - Proc. 7th Eur. Congr. Comput. Methods Appl. Sci. Eng., 2016, https://doi.org/10.7712/100016.2224.8781.
[6] EN 15129 Anti-seismic Devices, 2009.