Experimental Tests on Buckling Inhibited Shear Panels

Giuseppe Brando, Federica D'Agostino & Gianfranco De Matteis
Department of Engineering and Geotechnology,
University "G. d'Annunzio" of Chieti-Pescara, Italy

SUMMARY
An innovative dissipative shear panel has been recently introduced. It is based on the use of special technological devices able to restrain the out-of-plane deformations of the base plate. They consist in additional steel plates properly dimensioned in order to avoid buckling phenomena of the base shear plate up to specific deformation demand.
In the current paper the main results of pilot experimental tests, carried out on two specimens for which the buckling of the plate is partially or completely inhibited, are carefully analyzed and presented. The first solution differentiates from the other because it is conceived in order that the inhibition system restrain only the parts of the base plate that are more sensible to the firsts and more important critical modes. On the contrary, the latter is equipped with devices able to restrain the out-of-plane displacements of the entire shear plate.

Keywords: Metallic Damper, Seismic Protection, Dissipative Device, Buckling Inhibited Shear Panels

1. INTRODUCTION

In the last decades metal shear panels have been fruitfully used as dampers for protecting buildings in earthquake prone areas. The contribution of these devices for the improvement of the structural dissipative capacity has been pervasively investigated and a significant numbers of national and international seismic Codes introduced design rules concerning their employment (AISC, 2010; FEMA 750-P, 2009; CSA, 2009).

Although it is widely recognized that whatever metal shear panel is able to significantly increase the building seismic performance by providing a high amount of both stiffness and ductility (Astaneh, 2001, Shishkin et al., 2005), its response could be limited by possible detrimental effects due to buckling phenomena which lead to a consequent reduction of dissipative capacity. In order to avoid this undesirable behaviour, metal shear plates are traditionally equipped with transversal stiffeners so to reduce the free length of the base plate portions which are most sensible to instabilities. In this way buckling phenomena can arise only for high shear demands and the panel's cyclic behaviour is characterized by large and almost rectangular loops which result in a high dissipative capacity.

On the other hand, it is to be considered that one of the main prerogatives of dampers is to activate the dissipative functions for limited structural demands, so to protect the other structural members by limiting their structural damage. For this reason, it is necessary to conceive shear panels characterized by low yielding capacity.

Two alternative main strategies for obtaining low yield strength shear panels are usually adopted. The first is based on the use of relatively thin plates with a small number of stiffeners and with a base material characterized by both low yield stress point and high ductility. This solution found, during the '90s, a large application in Japan, where the use of a special steel characterized by 100 MPa yield stress has been proposed (Nakashima, 1995), as well as in Italy (De Matteis et al, 2007 and 2010;

Brando et al., 2011), where the heath treated AW1054 aluminium alloy (conventional yield stress equal to about 20 MPa) has been applied by the authors (De Matteis et al., 2012).

The second strategy, on the contrary, consists in assuming conventional metal materials associated to very thin transversal sections of the base plate and a high number of transversal stiffeners to mitigate mitigating buckling phenomena. The problem related to this solution is that if a very low shear capacity is required, the number of transversal and longitudinal ribs to be adopted could lead to economical and technological counter-indications.

In order to solve these critical issues, recently, a new concept of buckling phenomena inhibition has been analyzed by the authors. It is based on the idea of using not connected additional plates that are arranged in parallel to the panel plane and that are able to work only in its out of plane direction. An innovative damper, named as "buckling inhibited panel" (BIP), has been therefore introduced.

In the current paper the main results of pilot experimental tests, carried out on specimens for which buckling phenomena are partially and completely inhibited, are analyzed and presented. The first solution, named with the acronym "t-BIP" (totally Buckling Inhibited Panel), differentiates from the other because it is conceived in order that the inhibition system restrains only the parts of the base plate that are more sensible to the firsts and more important critical modes. On the contrary, the latter, named with the acronym "p-BIP" (partially Buckling Inhibited Panel), is equipped with devices able to restrain the out-of-plane displacement of the entire plate.

2. THE PROPOSED DEVICES

In figures 1 the proposed buckling inhibited shear panels are shown. These are composed by a square articulated steel frame made by four rigid UPN120 built up members, obtained by coupling two channel shaped profiles, connected by means of 8.8 grade bolts (14 mm diameter - 50 mm pitch) to a 500 mm by 500 mm pure aluminium (5 mm thickness) plate. This is the dissipative elements of the system. A friction connecting system has been designed in order to avoid that the collapse of the bolts could jeopardize the panel performance.

In order to limit the detrimental effects of the dissipative capacity of the proposed devices, their possible buckling phenomena have been partially or completely restrained. In the first solution (p-BIP), in order to restrain the first fourth critical modes of the base plate two cross shape steel elements, having a thickness of 10 mm and a width of 140 mm, at both side along the diagonals of the plate, have been applied.

In the second technological solution ("t-BIP"), in order to completely inhibit buckling phenomena of the entire base plate, two octagonal shape 10 mm thickness steel plates have been used as restraining system.

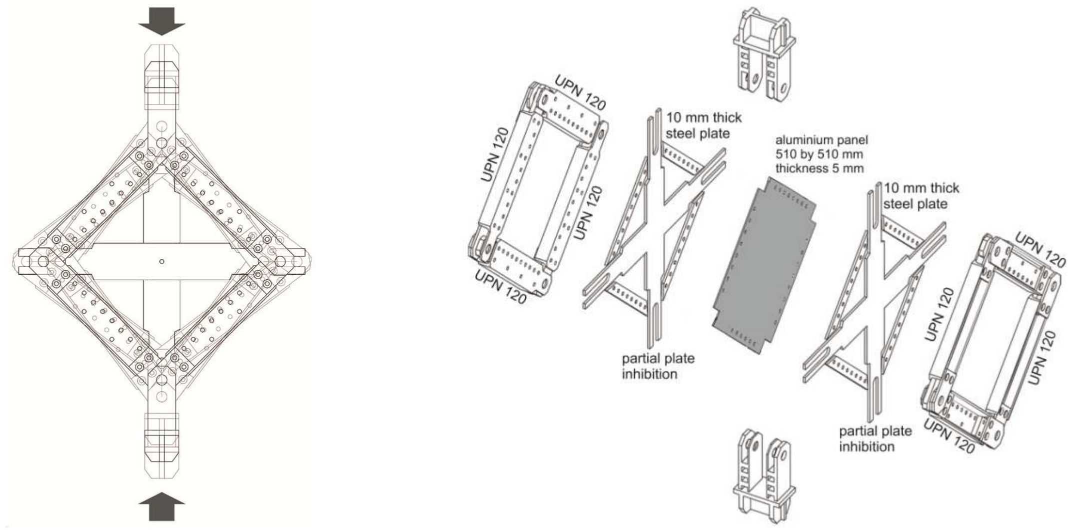
In both cases, lexan sheets have been employed in order to reduce the friction between the parts.

3. EXPERIMENTAL TESTS

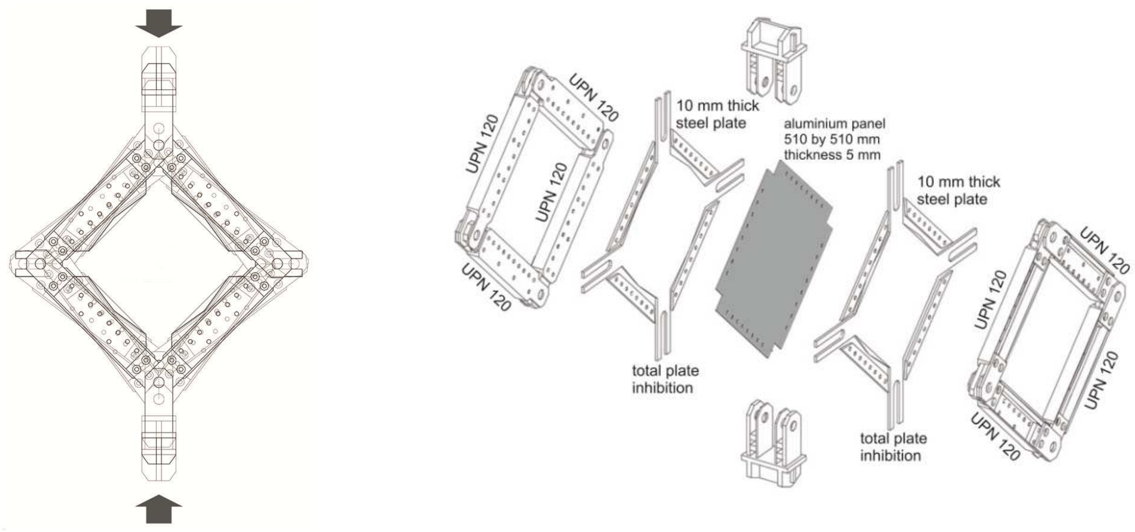
3.1. Loading process and measurement equipment

In figure 2 the two tested full scale specimens are shown. These have been diagonally loaded according to the cyclic protocol given by the ECCS_ECM provisions (1985).

The application of a mechanical transducer along the diagonal of both aluminium panels allowed registering the diagonal displacement of the dissipative elements. On the other hand, in order to measure the relative motion between the aluminium panel and the steel frame of the "p-BIP", four mechanical transducers have been applied along the edge of the system.

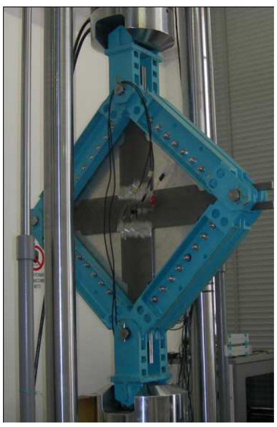


a)



b)

Figure 1. The studied (a) Partially Buckling Inhibited Panel (p-BIP) and (b) Totally Buckling Inhibited Panel (t-BIP).


a)


b)

Figure 2. The tested “p-BIP”(a) and “t-BIP” (b) specimens

These types of measurements have been not provided for the “t-BIP” specimen, as the inhibition devices did not allow the positioning of the transducers. A pair of uni-axial strain gauges has been glued at the centre of both “p-BIP” and “t-BIP” panels, one in vertical and the other in horizontal direction, to monitor the strain demand. For “p-BIP”, additional strain gauges have been glued also in the centre of the not restrained portion along the direction of possible buckling waves developing. The applied force has been directly measured by the loading cell of the testing machine.

3.2. Cyclic behaviour and experimental evidences

The tested dampers proved to be able to give back a high dissipative capacity, as testified by the large hysteretic loops shown in Figure 3, in which the cyclic response is represented in terms of shear stress-shear strain relationship. Significant strength degrading effects have been registered only when a shear strain demand of about 9.00% (±40.00 mm diagonal displacement) was achieved. This was due to failures which developed on the aluminium plates.

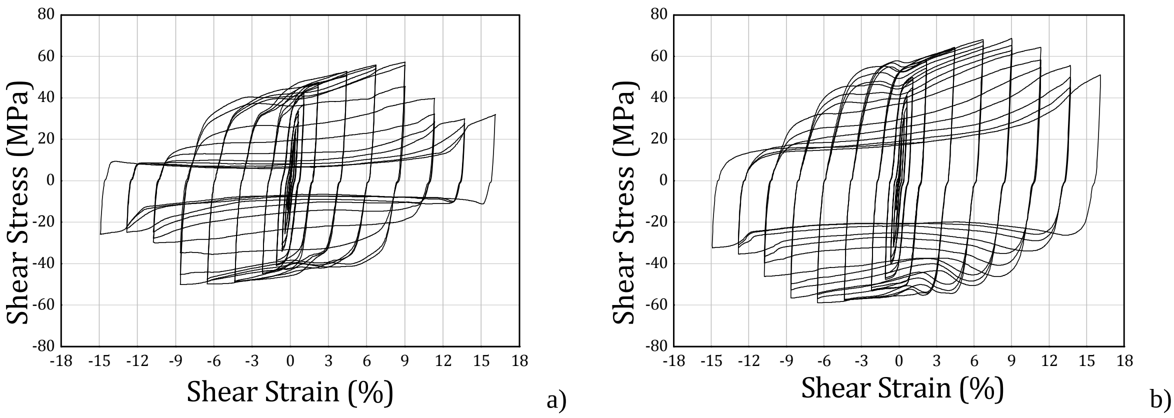


Figure 3. The obtained hysteretic cycle: a) “p-BIP” and b) “t-BIP”

As expected, among the two systems, “t-BIP” exhibited a better performance. This was due, on one hand, to the secondary buckling phenomena that influenced the partially inhibited solution and, on the other, to a sort of confinement adjustment factor that, at the same way of the “Compressive adjustment factor” given for buckling restrained braces (SEAOC, 2001), lead to a general increasing of strength when large deformations are attained.

By analysing more in detail the obtained results, an elastic behaviour of both panel can be approximately considered up to a diagonal displacement of ±0.50 mm. When achieved a strain shear demand of 0.66% (diagonal displacement of ±3.00 mm) the “p-BIP” underwent the first buckling of the not restrained portions, as revealed by the strain gauges measurement given for the centre of this part in figure 4.

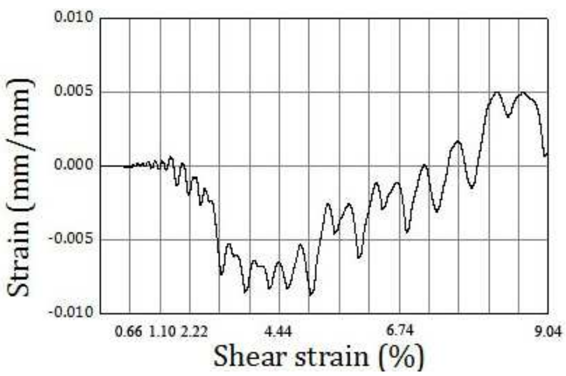


Figure 4. Diagonal strain measurements for the not restrained portion of “p-BIP”

When a shear strain of 2.20% has been attained, these instabilities were evident (Figure 5.a), starting to influence the hysteretic response with slight pinching effects (Figure 5.b).

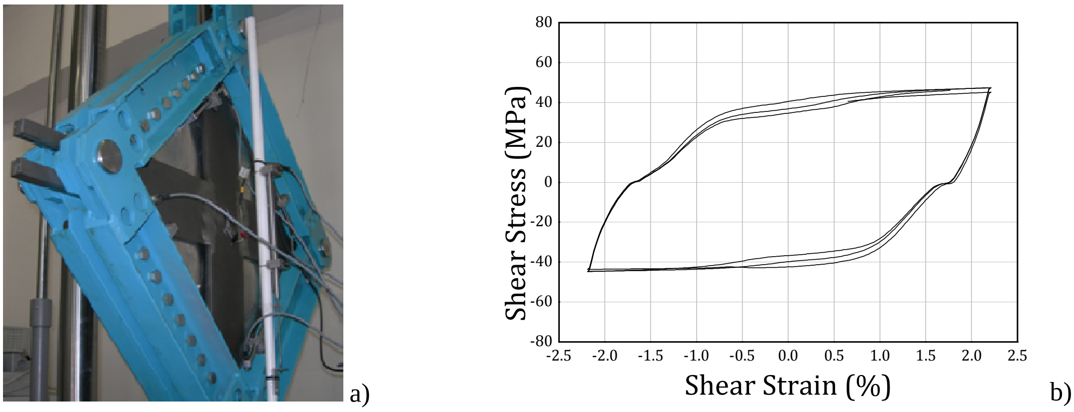


Figure 5. "p-BIP" experimental response for a 2.20% shear strain demand: a) experimental evidences and b) hysteretic cycles

On the contrary, at 2.2% shear strain, no particular degrading phenomena have been revealed on panel type "t-BIP" (figure 6.a), as well as the given hysteretic cycles did not present any particular detrimental effects (figure 6.b).

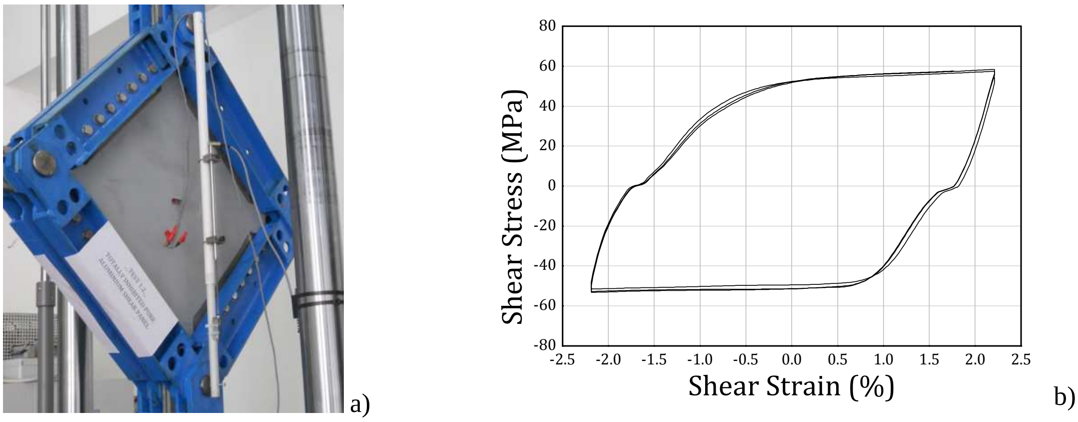


Figure 6. "t-BIP" experimental response for a 2.20% shear strain demand: a) experimental evidences and b) hysteretic cycles

For a shear strain demand of 4.40%, the instabilities of the not restrained plate portions of panel type "p-BIP" became relevant (Figure 7.a). Nevertheless, the shape of the hysteretic cycles was not still influenced by these phenomena (Figure 7.b). On the other hand, it has to be underlined that at the same shear strain level, "t-BIP" shoved the first buckling (Figure 8.a) on the small not restrained portion of the plate closed to the lateral connection. These caused some pinching effects on the hysteretic cycles, without entailing, nevertheless, a significant reduction of the dissipative capacity of the panel.

For a diagonal displacement of ±30 mm (shear strain of 6.74%) some small cracks were revealed at the vertexes of the base plate with some tears (see Figure 9). These were due to a sort of "clamp" action of the inhibition plates on the two faces of the devices which, being pushed in the out-of-plane direction at their centre tended to go toward each other at their ends.

Finally, for a diagonal displacement of ±40.00 mm (shear strain of 9.04%), the panels achieved their maximum strength, as evidenced by the failure of the base plate (see Figure 10).

From the analysis of the hysteretic cycles (see Figure 11), it is worth of being noticed that the nominal shear strength, obtained by dividing the shear force applied to the system by the shear area, is quite higher than the expected one. In fact, provided that the ultimate strength of the base material, including isotropic hardening, is f_u=80.0 MPa, this would have been equal to τ_u=80/√3=46.18 MPa. The revealed discrepancy is evidently due to a sort of confinement effect of the inhibition devices on the base plates. This leads to an increasing of the whole system resistance of 24.1% and 48.6%, in case of “p-BIP” and “t-PIB” respectively.

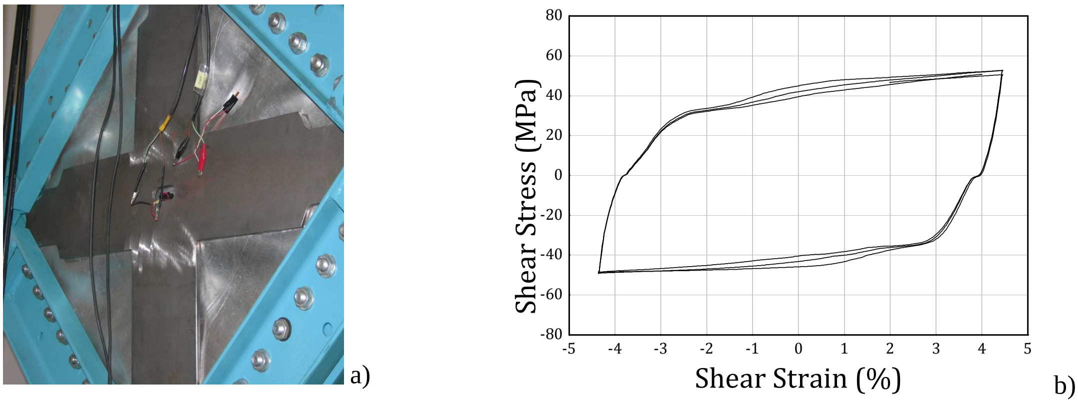


Figure 7. “p-BIP” experimental response for a 4.40% shear strain demand: a) experimental evidences and b) hysteretic cycles

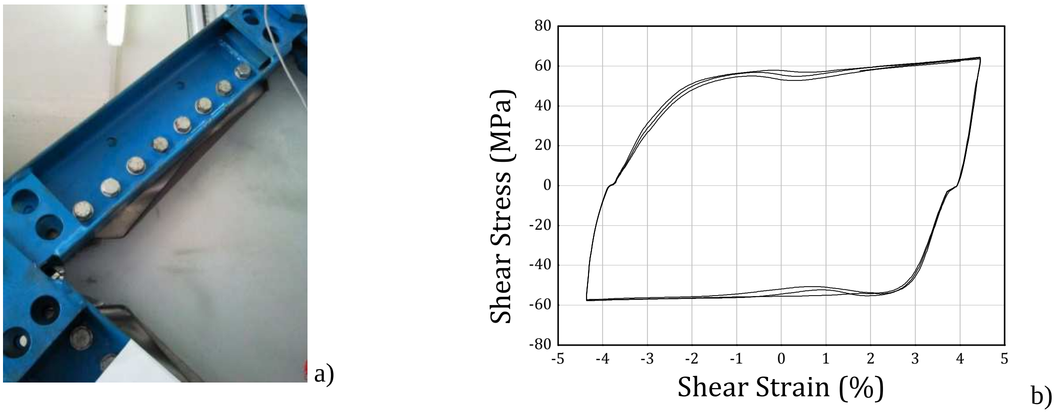


Figure 8. “t-BIP” experimental response for a 4.40% shear strain demand: a) experimental evidences and b) hysteretic cycles

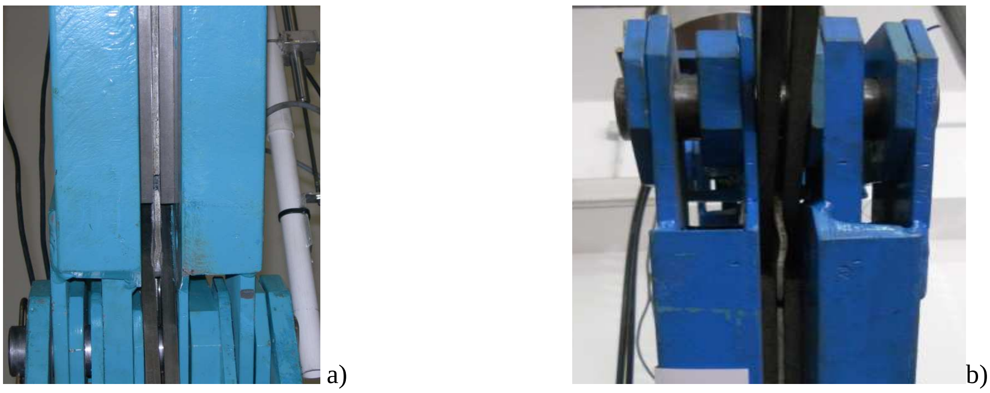
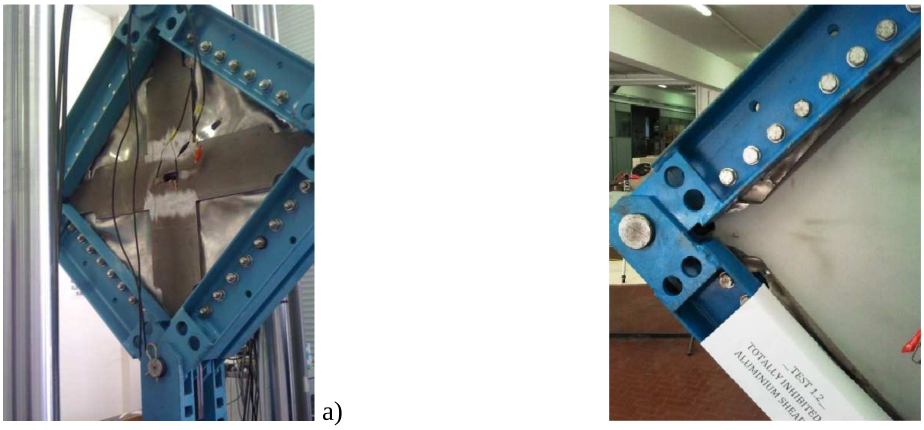


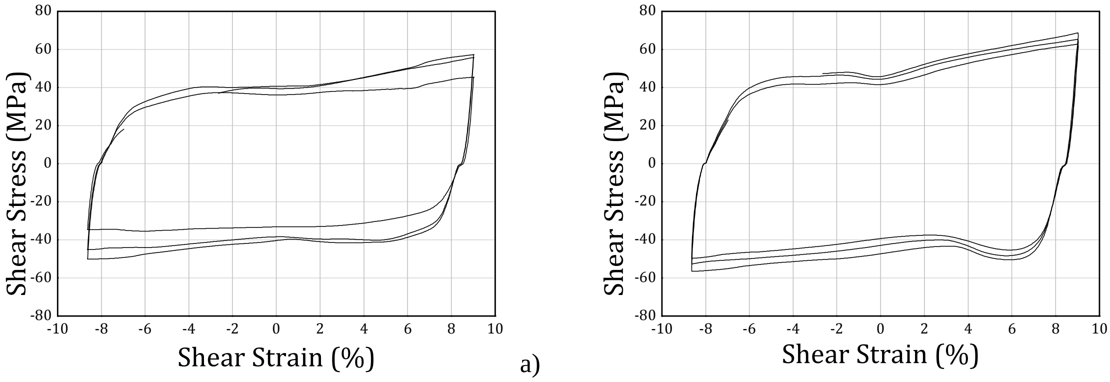
Figure 9. Local failure at the vertex of the systems for a) “p-BIP” and b) “t-PIB”

The complete collapse of the system arose when a diagonal displacement of ±60 mm (shear strain of 11.37%) was reached (see Figure 12). At this stage, a pure shear failure was evident, with fractures completely developed along the edges, with no tears in the centre of the panels and with the lateral connection system not damaged. The last remark allow to state that the friction connections designed as described in Chapter 2 worked properly.



a) b)

Figure 10. First failures of the tested systems: a) “p-PIB” and b) “t-BIP”



a) b)

Figure 11. Hysteretic cycles of a) “p-BIP” and b)” t-BIP” for a shear strain of 9.04%

3.3. Behavioural features

In order to prove the effectiveness of the proposed solutions, the results obtained from the above experimental tests have been outlined also in terms of dissipative capacity (figure 13) secant shear stiffness (figure 14.a), equivalent viscous damping factor (figure 14.b), and maximum hardening ratio (figure 14.c).

The two systems proved to be characterized by a large protection capacity, as proved by the equivalent viscous damping factor values of 40%-50% provided by both devices (Figure 13a). Furthermore the application of the steel inhibition systems allowed achieving a high secant stiffness (Figure 14b) for lower shear demand. On the contrary, accomplishing the stiff-flexible mix design criteria, for high deformation levels a very small stiffness resulted.

Comparing the two tested solutions, panel type “t-BIP”, particularly for shear demand bigger than 1%-2%, behaved always in a better way.

4. CONCLUSIONS

A new hysteretic damper has been proposed in the current paper. It is based on the use of metal shear panels improved by special systems able to partially or completely restrain the out-of-plane displacements of the base plate, so to inhibit the most significant buckling modes.

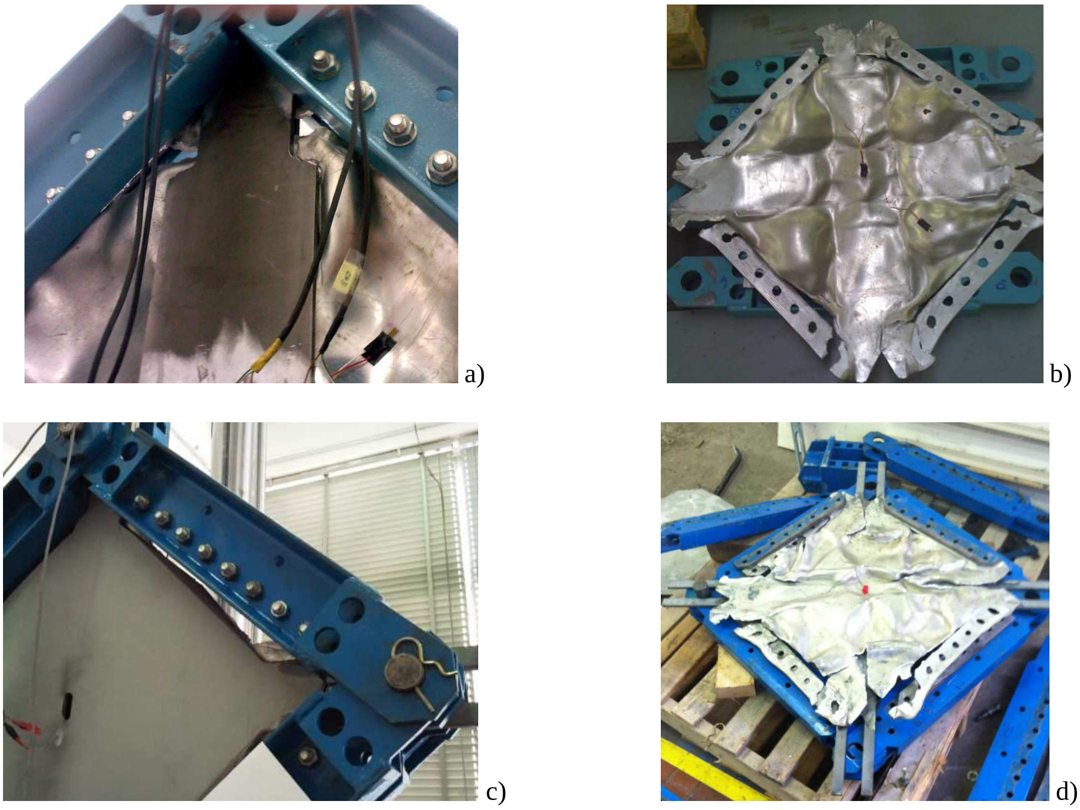


Figure 12. Collapse modes of a) “p-BIP” and b)” t-BIP”

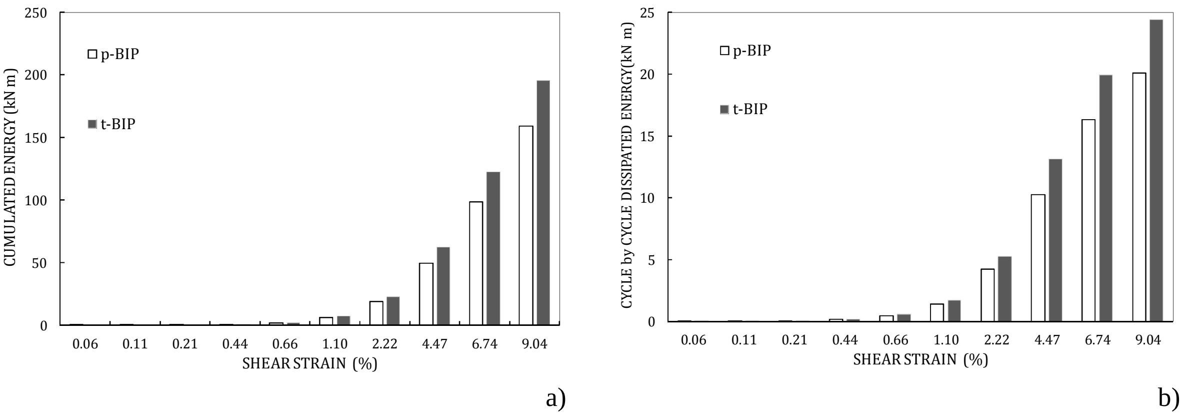


Figure 13. Comparison between “p-BIP” and ” t-BIP” in terms of a) cumulated energy and b) cycle by cycle dissipated energy

Two experimental tests, carried out on aluminium plates joined to two different inhibition technologies, have been presented. The obtained results clearly pointed out the potentialities of the proposed devices, which can be used as earthquake protection dampers for new and existing buildings, provided the high dissipative capacity (maximum equivalent viscous damping factor of around 50%) for large shear strain demands, the high initial stiffness and the significant value of the hardening factor.

It should be highlighted that the here presented inhibition technology has not to be necessarily associated to a low yield stress material, such as pure aluminium, as it could be profitably used also for common steel.

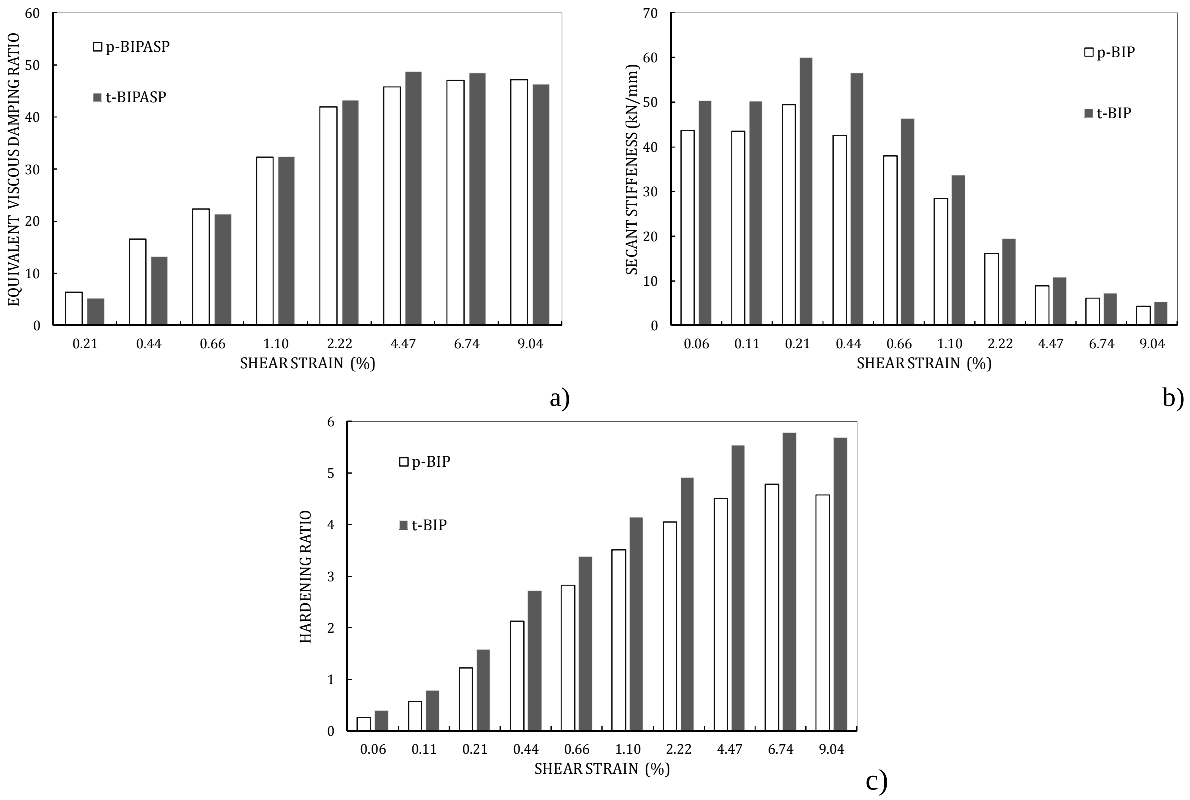


Figure 14. Comparison between “p-BIP” and ” t-BIP” in terms of a) equivalent viscous damping ratio, b) secant stiffness and c) hardening ratio

AKCNOWLEDGEMENT

The study has been developed in the framing of the RELUIS 2010-2013 Italian Research Project

REFERENCES

Astaneh-Asl A., (2001) Seismic Behavior And Design Of Steel Shear Walls, Steel Tip Report, *Structural Steel Educational Council*, Ca, January.

ANSI/AISC 341-10, (2010) Seismic provisions for structural steel buildings, Chicago (IL): American Institute of Steel Construction.

AISC/SEAOC, (2001) Recommended Provisions for BRB, Structural Engineers Association of California: Seismology and Structural Standards Committee and American Institute of Steel Construction, Inc.”.

Brando, G., De Matteis, G.,(2011) Experimental and numerical analysis of a multi-stiffened pure aluminium shear panel *Thin-Walled Structures* 49, 1277-128, ISSN 0263-8231

CAN/CSA-S16-01, (2009) Limit states design of steel structures, Toronto (Ontario, Canada).

De Matteis G., Mazzolani F.M. and Panico S., (2007) Pure aluminium shear panels as dissipative devices in moment-resisting steel frames, in *Earthquake Engineering and Structural Dynamics*, ISSN: 1096:9845, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, England, Wiley InterScience, DOI: 10.21002/eqe, vol. **36**: 841-859, 2007.

De Matteis G., Brando G., Mazzolani F.M., (2010) Hysteretic Behaviour Of Bracing-Type Pure Aluminium Shear Panels By Experimental Tests, *Earthquake Engineering & Structural Dynamics* Volume **40**, Issue **10**, Pages 1143–1162.

De Matteis G., Brando G., Mazzolani F.M., (2012) “Pure aluminium: An innovative material for structural applications in seismic engineering”, *Construction and Building Materials*, **26 (1)**,pp. 677-686.

ECCS-CECM, (1985) Recommended testing procedure for assessing the behaviour ofstructural steel elements under cyclic loads”.

FEMA 750-P (2004) NEHRP Recommended Seismic Provisions for New Buildings and Other Structures. 2009 Edition”, Federal Emergency Management Agency, Washington D.C.

Shishkin J.J., Driver R.G. and Grondin G.Y., “Analysis of steel plate shear walls using the modified stripmodel”, (2005) Structural Engineering Report No. 261, University of Alberta, Canada