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Italian experience in seismic retrofit of buildings through seismic isolation or energy dissipation

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ABSTRACT: The use of seismic isolation or energy dissipation in retrofit of buildings in Italy is continuously increasing since 2003, when a new seismic code including a chapter on seismic isolation was issued, and even more since 2009, after the L'Aquila earthquake. Seismic isolation has been used to retrofit both reinforced concrete buildings and masonry building, mainly those damaged by said earthquake. The use of seismic isolation allows to increase the seismic safety as required by the law for reconstruction, while limiting the intervention on the superstructure and associated costs. Energy dissipation is used mainly in dissipative braces, added to existing reinforced concrete framed buildings designed to non-seismic specifications or old seismic codes, and therefore lacking both ductility and stiffness. The supplemental damping offered by the dampers reduces the ductility demand in R.C. structural members and thus significantly reduces their damage. Most of the applications of dissipative braces in Italy concern school buildings.

1 INTRODUCTION

In Italy, since the 1990s until 2003, each design of a seismically isolated structure or a structure with passive energy dissipation devices needed to be reviewed by the Public Work Council. This requirement, being said review process very slow, practically stopped the use of seismic isolation and energy dissipation for about 10 years, despite Italy at the end of the 1980s was world leader for number of bridges protected through seismic isolation and energy dissipation devices. A new seismic code issued in 2003 eliminated said requirement and introduced a specific chapter about design with seismic isolation, based on Eurocode 8 Part 1. The use of energy dissipation devices inside the building structure, e.g. in braces, is not specifically regulated in the Code, but it is allowed without specific requirements. Consequently, since 2003, the use of seismic isolation and energy dissipation is continuously increasing, both in new and existing structures.

2 RETROFIT WITH SEISMIC ISOLATION

It is well known that seismic isolation is used for seismic retrofit of existing structures since the 80's of the past century [Bayley and Allen (1989)]. In Japan, about a hundred buildings are seismically retrofitted through seismic isolation, of which approximately one-third are public office buildings and 18% private office buildings [Masuzawa and Hisada (2012)]. In Italy, the first buildings retrofitted through seismic isolation were public buildings. On the other hand, in the last years, most of the seismic isolation retrofit interventions concerns private residential buildings, damaged and declared uninhabitable after the L'Aquila earthquake in 2009.

Table 1 lists the interventions completed since 2003 or in progress, in which isolators have been supplied, and in most cases installed as well, by FIP Industriale. It should be noted that seismic isolation retrofits of masonry buildings recently started in Italy as well [Vetturini et al. (2013); Mezzi et al. (2012)].

Table 1. Buildings retrofitted in Italy since 2003 through seismic isolation (supply by FIP Industriale and in many cases installation as well).

Building name and/or address	**City**	**Structure type**	**Year**	**Isolator type**
Palazzo Cricchi Ciuffini Volpi	L'Aquila	masonry	2015	Elastomeric isolators
Apartment house - via XX Settembre	L'Aquila	r.c.	2015	Double concave curved surface sliders
Apartment house - via Moscardelli 26	L'Aquila	r.c.	2014	Double concave curved surface sliders
Apartment house - via Moscardelli 28/42	L'Aquila	r.c.	2014	Double concave curved surface sliders
"Quadrifoglio" apartment house	L'Aquila	r.c.	2014	Double concave curved surface sliders
"Drago B" apartment house	L'Aquila	r.c.	2014	Elastomeric isolators
"Drago A" apartment house	L'Aquila	r.c.	2014	Elastomeric isolators
"Sorbo" apartment house	L'Aquila	r.c.	2014	Elastomeric isolators
Apartment house - via Piave, 2	L'Aquila	r.c.	2014	Double concave curved surface sliders
Apartment house - Colle Capo Croce	L'Aquila	r.c.	2014	Double concave curved surface sliders
"Fortuna 4" Apartment house - via Pasteur	L'Aquila	r.c.	2013	Elastomeric isolators
"S.Maria degli Angeli" School	L'Aquila	r.c.	2013	Elastomeric isolators
Apartment house - via Pratola Peligna, 2	L'Aquila	r.c.	2013	Double concave curved surface sliders
"SORIN GROUP" Office building	Mirandola	r.c.	2013	Double concave curved surface sliders
Industrial Building - University of Catania	Catania	precast r.c. + steel	2013	Double concave curved surface sliders
"D'Ovidio" Apartment house	L'Aquila	r.c.	2013	Double concave curved surface sliders
" Acrie" Apartment house - Building D1	L'Aquila	r.c.	2013	Elastomeric isolators
"Montecalvo 1" Apartment house	L'Aquila	r.c.	2013	Double concave curved surface sliders
"Paolucci" Apartment house	L'Aquila	masonry + r.c.	2013	Elastomeric isolators
"Prato Verde B" Apartment house	L'Aquila	r.c.	2013	Elastomeric isolators
"La Quercia" Apartment house	L'Aquila	r.c.	2013	Elastomeric isolators
"Prato Verde A" Apartment house	L'Aquila	r.c.	2013	Elastomeric isolators
"La Silvestrella" Villa	L'Aquila	masonry	2013	Elastomeric isolators
"Andromeda" Apartment house-via S.Giustino de Jacobis	L'Aquila	r.c.	2012	Elastomeric isolators
Former magistrates' court	Pescia	r.c.	2012	Double concave curved surface sliders
"Del Beato" Apartment house	L'Aquila	r.c.	2012	Elastomeric isolators
"Leonardo" Apartment house	L'Aquila	r.c.	2012	Double concave curved surface sliders
"Acrie" Apartment house - Building C2	L'Aquila	r.c.	2012	Elastomeric isolators
"Barattelli" Apartment house -via G. Vincenzo, 23	L'Aquila	r.c.	2012	Double concave curved surface sliders
"Amiterno" Apartment house - Via Sila Persichelli 1/B	L'Aquila	r.c.	2012	Double concave curved surface sliders
"Borgo dei Tigli" Apartment house	L'Aquila	r.c.	2012	Elastomeric isolators
"Il Melograno" Apartment house	Potenza	r.c.	2012	Elastomeric isolators
"Aguglia" Apartment house	L'Aquila	r.c.	2012	Double concave curved surface sliders
"Fortuna 2" Apartment house - via Pasteur	L'Aquila	r.c.	2012	Elastomeric isolators
"Habitat" Apartment house	L'Aquila	r.c.	2011	Double concave curved surface sliders
"Domus Prima" Apartment house	L'Aquila	r.c.	2011	Double concave curved surface sliders
"Giuly" Villa	Treviso	masonry	2010	Double concave curved surface sliders
Hospital - "Intramoenia" building	Avellino	r.c.	2009	Elastomeric isolators
"S.Quasimodo" School	Riposto	r.c.	2007	Elastomeric isolators
"Madonna delle Lacrime" Church	Siracusa	r.c.	2005	Flat surface sliders with steel hysteretic dampers
"IACP" Apartment houses	Solarino	r.c.	2003	Elastomeric isolators

The use of seismic isolation in an existing building allows to reach the safety levels required by the seismic code for a newly constructed building, significantly limiting the strengthening interventions on the superstructure in comparison to traditional techniques (such as introduction of shear walls or increase of strength and ductility of R.C. members through FRP).

The types of seismic isolators mostly used in buildings in Italy are elastomeric isolators and curved surface sliding isolators or friction isolation pendula [Castellano and Infanti (2010)]. With the latter it is easier to reach high values of fundamental period (necessary to reduce as much as possible the accelerations transmitted to the superstructure) in relatively light-weight structures, such as low-rise buildings, since the fundamental period is not substantially dependent on the supported mass, but mainly on the radius of curvature of the devices themselves. On the other hand, in case the isolation system is based on elastomeric isolators, in order to achieve a sufficiently high fundamental period, it is almost always necessary to combine them with multidirectional bearings. This is why almost all Italian buildings isolated with elastomeric isolators comprise a number of multidirectional bearings as well.

In the seismic retrofit design of an existing building through seismic isolation, the intervention technology constitutes a fundamental part. The existing building heritage diversity means that each case should be carefully analyzed; multiple factors, specific for each building, suggest to the Engineer the best solution in relation to:

- Positioning of the isolation level;
- Method of temporary transfer of the vertical load.

In respect to this, every choice made is mainly influenced by the following aspects:

- Intended use of the floor in which the isolators are installed (typically ground floor or basement);
- Adjacent constraints to the building;
- Type of existing foundations;
- Detail of stairwells and elevators.

The positioning level of the isolation system on the top of the columns is often practicable on parking floors or other technical areas where the presence of the horizontal joints and the enlargement of the existing columns, when needed, do not compromise the floor’s function. Such a choice usually guarantees the stiffness required above the isolators, provided by the existing floor, without the need for further intervention. The same request of sufficient stiffness in the substructure, i.e. below the isolators, is usually satisfied with an enlargement of the columns. Such column enlargement is often useful to satisfy the geometrical requirements of the overall plan dimensions of the isolators, which otherwise require the construction of a capital.

In the case in which the isolators are positioned at the base of the column, the same request of sufficient stiffness above and below the isolation level often introduce the necessity of a new constructed slab directly above the isolators. In this case, no additional stiff elements at the base are usually required since the isolators are found in correspondence with the foundation beams.

The position of the isolators on the upper part of the column simplifies the inspection and maintenance operations, which are imposed by current regulations. Conversely, in case the isolators are placed at the base of the column, it is necessary to carry out numerous floor hatches in order to ensure access to all the isolators. On the other hand, when isolators are positioned at the top of the column, especially those on the ground floor instead of the basement, often greater attention is needed on the horizontal joints, in particular in correspondence with the stairwell and elevator.

Another fundamental aspect concerns the method of the temporary transfer of the vertical loads during the cutting operation of the columns, the installation of the isolator and the possible future replacement operations. The load transfer takes place between the different parts of each column or between column and foundation, by means of two or more hydraulic jacks placed opposing upwards on the superstructure (suitable reinforced if necessary) and downwards on the foundation (direct loading) or on the columns transferring the load to the foundation (indirect loading). In case the isolators are placed at the base of the columns on the ground floor, a direct loading transfer is obtained by placing the jacks opposing downwards on the foundations and upwards on suitable steel brackets, attached to the columns; such steel brackets have a double function of temporary vertical load transfer and support of the new slab to be casted over the isolation level. In the case where the isolators are placed at the top of the columns, the jacks can oppose upwards on metal brackets, on adequate concrete blocks, or directly on the superstructure (suitably strengthened where necessary); the downward contrast is possible either directly on the foundations by means of steel props, directly on the columns (enlarged by a r.c. capital, if necessary) or once again with removable structural steel brackets, used also for future maintenance operations, transferring the load to the columns.

In some cases, regardless of the isolation level location, the installation of the isolators is achieved with the help of flat jacks. The flat jack is installed in series with the isolator allowing the loading of the isolator, thus avoiding excessive vertical settlements during the loading phase, and especially differential settlements between the isolators that could create problems to the superstructure. The use of the flat jacks is therefore strongly recommended especially for masonry structures, but can also be useful for other types of structure.

Chapter 4 describes one example of retrofit of an existing R.C. building, with particular attention to the procedure carried out during the vertical loading transfer and the installation of the isolators.

3 RETROFIT WITH ENERGY DISSIPATION

Energy dissipation is used in existing buildings mainly in dissipative braces, added to existing reinforced concrete framed buildings designed to non-seismic specifications or old seismic codes without the capacity design approach, and therefore lacking both ductility and stiffness. The use of dissipative bracings to improve the seismic behaviour of framed buildings was initially proposed for new buildings by Skinner et al (1975) and Pall and Marsh (1982). Since then, the use of dissipative braces continuously increased, mainly in new steel buildings, in particular in USA, Canada, Japan, Taiwan, etc. At the same time in Europe the research focused on the use of dissipative braces to retrofit existing r.c.-framed buildings [e.g. Ciampi et al (1992), Antonucci et al (2006), Di Sarno and Manfredi (2011)]. The dissipative braces exploit the interstorey drift of such frames - otherwise too large - to dissipate energy. The supplemental damping offered by the dampers inserted in the braces allows the reduction of the ductility demand in R.C. structural members and thus can significantly reduce their damage.

The dampers mostly used in Italy in dissipative braces are steel hysteretic dampers, in particular buckling restrained braces, or non-linear fluid viscous dampers.

Buckling Restrained Braces (BRBs) are braces in which a portion is designed to yield in tension/compression, and buckling in compression is avoided [Watanabe et al (1988)]. They have been extensively used first in Japan and then, starting at the end of the 1990s, in USA

[Tajirian et al (2003)]. The FIP Industriale's implementation of BRBs foresees a separation of the dissipating function and the bracing function: i.e. a Buckling Restrained Axial Damper (BRAD) is installed in series with a steel tube or beam (Fig. 1). This separation of functions allows a cost reduction and is possible because, when using BRB in R.C. frames (instead of in steel frames as usual in Japan and USA), the displacement is much lower, and thus the dissipating portion of the brace is much shorter.

Figure 1. Buckling Restrained Axial Dampers (BRAD) as installed in two different buildings.

The fluid viscous dampers (FVDs) typically used in dissipative braces in Italy have a force vs. velocity constitutive law of the type $F=C\cdot v^{\alpha}$, where F is the force, v is the velocity and $\alpha=0.15$. This highly non-linear behaviour permits greater dissipating energy efficiency when compared to linear FVDs or FVDs with higher α-exponent values. In fact, it guarantees significant energy dissipation even at low displacements as well as at velocities lesser than the maximum design value. Because of this type of behaviour, non-linear FVDs are particularly suitable to use in RC frames that cannot reach high inter-storey drifts.

The selection between BRADs and FVDs is mainly based on cost. In effects, for low values of displacement and force, and short length of the brace, BRAD are usually cheaper than FVDs.

Table 2 lists the retrofit interventions in buildings with dampers completed since 2003, in which dampers have been supplied by FIP Industriale. Most of the applications concern school buildings, but there is some application in hospitals and in residential or industrial buildings as well. Some examples of use of energy dissipation in Italy to retrofit buildings are described in Antonucci et al (2001), Antonucci et al (2007), Gattulli (2011), Castellano et al (2012).

4 EXAMPLE OF RETROFIT WITH SEISMIC ISOLATION: THE "LEONARDO" APARTMENT HOUSE

The "Leonardo" apartment house, located in L'Aquila, is a building complex consisting of three building parts, each with four storeys and a basement. The two main lateral buildings are connected to the central building housing the elevator shaft. The three building parts are structurally independent to each other, arranging an approximately "L-shaped" building. The bearing structure is made of reinforced concrete frames and reinforced concrete and hollow tiles mixed floor. The foundations are made of 70cm x70cm beams, that connect in both directions the columns of the superstructure.

As a result of the earthquake in 06/04/2009, the building was declared uninhabitable. The structure exhibited widespread damage to masonry infill walls especially on the ground floor, cracking at the joints due to hammering and limited capillary cracks at the nodes of the r.c. frame.

Table 2. Buildings retrofitted in Italy since 2003 through energy dissipation (supply by FIP Industriale): BRAD: Buckling-Restrained Axial Dampers; FVD: Fluid Viscous Damper.

Building name and/or address	**City**	**Structure type**	**Year**	**Damper type**
High school	Acri	r.c.	2014	BRAD
"G. Ferraris" high school	Vercelli	r.c.	2014	BRAD
"Leopardi" school	Ancona	r.c.	2014	BRAD
Residential building	Catania	r.c.	2014	BRAD
"S. Tommaso" school	Avellino	r.c.	2014	BRAD
"D. Ortolani" nursery school	Camerino	r.c.	2014	BRAD
"Prada" industrial building	Terranuova Bracciolini	r.c.	2014	BRAD
"S. Giuseppe in Ognina" parish house	Catania	r.c.	2014	BRAD
Nursery school - via Giorgione	Montegiorgio	r.c.	2013	BRAD
Cullurà residential house	Catania	r.c.	2013	BRAD
"D'Angelo" apartment house	L'Aquila	r.c.	2013	BRAD
"Città delle Stelle" shopping centre	Ascoli Piceno	precasted r.c.	2012	FVD
" Gentili" high school	Macerata	r.c.	2012	BRAD
Residential building	Gioia dei Marsi	r.c.	2012	BRAD
High school	Camerino	r.c.	2012	FVD
"M. Marano" elementary school	Riposto	r.c.	2012	BRAD
Airport terminal	Orio al Serio	precasted r.c.	2012	BRAD
"Rodari" nursery school	Porto Recanati	r.c.	2012	BRAD
"S. Benedetto" elementary school	Norcia	r.c.	2012	BRAD
Office building - corso Federico II	L'Aquila	r.c.	2012	BRAD
Apartment house - via Milonia	L'Aquila	r.c.	2012	BRAD
"Consolino" school	Vittoria	r.c.	2012	BRAD
"Aveja" apartment house	L'Aquila	r.c.	2012	BRAD
"La Casetta" apartment house	L'Aquila	r.c.	2012	BRAD
School - Ammeto	Marsciano	r.c.	2011	BRAD
"De Nino - Morandi" high school	Sulmona	r.c.	2011	BRAD
Industrial building	Imola	precasted r.c.	2011	FVD
High school	Corridonia	r.c.	2011	BRAD
University building	L'Aquila	r.c.	2011	FVD
Elementary school - Largo Madonna	Pescara	r.c.	2011	BRAD
School - Mocaiana	Gubbio	r.c.	2011	BRAD
Elementary school - via Milano	Pescara	r.c.	2011	BRAD
Hospital	Fermo	r.c.	2011	BRAD
"della Murgia" hospital	Altamura	r.c.	2011	BRAD
"Settebello" school	Tremestieri Etneo	r.c.	2010	BRAD
School	Rieti	r.c.	2010	BRAD
Elementary school	Rosà	r.c.	2010	BRAD
School	Arezzo	r.c.	2010	BRAD
"P.Pimonte" school	Linguaglossa	r.c.	2010	BRAD
"Livio Tempesta" school	Foggia	r.c.	2010	BRAD
"G.Verga" school	Vizzini	r.c.	2009	BRAD
"G. Acquapendente" school	Viterbo	r.c.	2009	BRAD
"Collodi" school	Fabriano	r.c.	2009	FVD
"Colle dei Frati" elementary school	Zagarolo	r.c.	2009	BRAD
"Garibaldi" nursery school	Umbertide	r.c.	2009	BRAD
"G. Pascoli" school	Monte S.Martino	r.c.	2008	BRAD
School - La Pezza	Lazise	r.c.	2008	BRAD
School - La Pezza	Catania	r.c.	2008	BRAD
School - via Cappuccini	Ramacca	r.c.	2007	BRAD
"PORRO" high school	Pinerolo	r.c.	2007	BRAD
"Perticari" high school	Senigallia	r.c.	2005	BRAD
Courthouse (former industrial building)	Perugia	masonry/steel	2005	FVD

On the basis of the vulnerability analysis of the building, it was decided to pursue the seismic retrofit by seismically isolating the entire complex through double concave curved surface sliding isolators (double pendulum isolators) inserted at the top of the basement columns. This technique was considered by the Engineer as the most suitable, because it is able to limit the intervention zone at the lower levels of the structure, where large-scale intervention on the damaged infill walls was necessary anyway. Otherwise, the strengthening and stiffening of the r.c. frames with traditional methods would require a large-scale action at all floor levels, and consequently the dismantling of the infill walls on the upper floors as well, where no damages were detected. The seismic isolation technique also enabled to secure the heavy infill walls from the risk of expulsion and overturning, significantly limiting the inertial forces associated with the event of an earthquake. The natural period of the structure was brought up to 2.75 s, starting from 0.75s for the fixed-based structure. In order to ensure adequate stiffness of the substructure, all columns of the basement were enlarged and the isolators were placed at the top of each column. The installation of the isolators, performed by FIP Industriale, required the following steps:

- Enlargement of the columns at the basement and simultaneous preparation of ferrules to be used for the anchoring of the lower lifting steel brackets and recesses to be used for the lower anchorage of the isolator with dowels (Fig. 2);
- Core drilling of the upper part of the column and provision of the ferrules for the anchorage of the upper lifting brackets (Fig. 3);
- Installation of metal brackets and placing of hydraulic jacks to unload the part of the column to be removed (Figs. 4 and 5);
- Diamond wire cutting, removal of the segment of the column, and levelling of the lower surface (Fig. 6 and 7);
- Insertion of the metal brackets for the anchorage of the upper part of the isolator (Fig. 8) ;
- Insertion and screwing of the isolator and subsequent grouting of the anchors and the collar with antishrinkage cement mortar (Fig. 9);
- Removal of jacks and consequent loading of the isolator (Fig. 10).

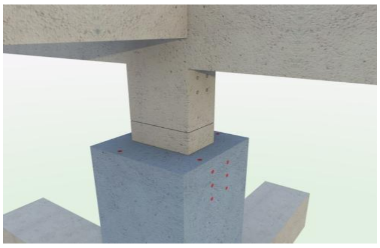


Figure 2

Figure 3

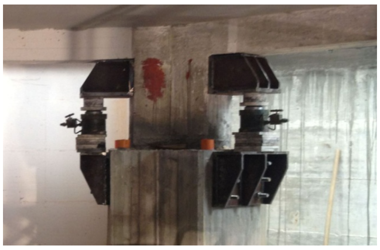


Figure 4

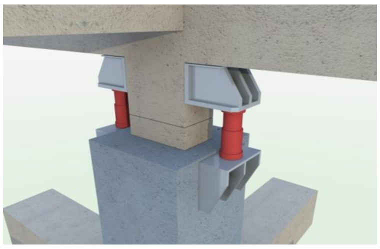
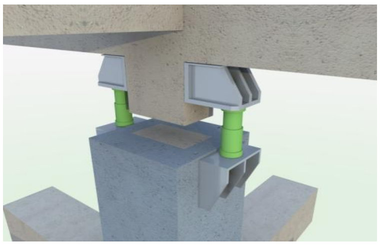


Figure 5



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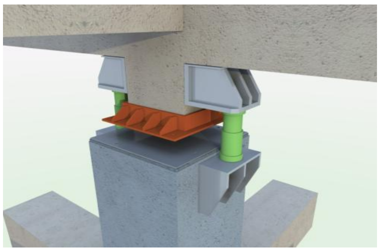

Figure 8

Figure 9

Figure 10

5 CONCLUSIONS

The Italian experience of use of seismic isolation and energy dissipation in retrofit of existing building show the reliability and cost effectiveness of such techniques.

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