COMPDYN 2011
3rd ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis, V. Plevris (eds.)
Corfu, Greece, 25–28 May 2011

SEISMIC RETROFIT OF EXISTING BUILDINGS BY MEANS OF SEISMIC ISOLATION: SOME REMARKS ON THE ITALIAN EXPERIENCE AND NEW PROJECTS

A. Martelli[1] and M. Forni[2]

[1] Director, Bologna Research Centre of ENEA,
President, GLIS, Past President, *ASSISi*, and Coordinator, EAEE-TG5
Via Martiri di Monte Sole, 4, I-40129 Bologna, Italy
e-mail: alessandro.martelli@enea.it

[2] Head, Technical Unit on Seismic Engineering, and Secretary General, GLIS and *ASSISi*
Via Martiri di Monte Sole, 4, I-40129 Bologna, Italy
e-mail: massimo.forni@enea.it

Keywords: Seismic Isolation, Buildings, Bridges, Plants, Cultural Heritage, Retrofit.

Abstract. *Seismic isolation (SI) has been used in Italy for several applications, which include important retrofits of civil structures and cultural heritage. Some new hospitals, all new civil defence centres and most new schools have already been (or are being) isolated, together with a significant number of dwelling buildings and other constructions. The 2009 Abruzzo earthquake caused an increase of the number of the Italian isolated buildings from about 70 to over 300. Prior to the aforesaid event, the Italian SI systems consisted in High Damping Rubber Bearings (HDRBs) or Lead Rubber Bearings, to which plane surfaces steel-PTFE Sliding Devices (SDs) were added in the last years. Now, Curved Surface Slider devices are also in use. The first Italian building to be retrofitted with SI was a reinforced concrete (r.c.) civic centre in Naples in 2004. Its foundation pillars and walls were cut, approximately 600 HDRBs were installed and a steel beams floor was added above the isolators to stiffen the superstructure base as necessary. In the same year, two 4-storey r.c. dwelling buildings were retrofitted, each with 12 HDRBs and 13 SDs, in Solarino, near Syracuse. In 2005 the first European retrofit with SI in a sub-foundation was completed: it concerned a 3-storey r.c. house in Fabriano that had suffered severe but non-structural damage in the 1997-98 Marche & Umbria quake. For this intervention 56 HDRBs were used. Further retrofits with SI were also performed for churches, schools, further dwelling buildings, tanks, single masterpieces, etc. The significant extension of the use of SI after the Abruzzo quake concerns this and other Italian regions. The new applications include numerous retrofits: at L'Aquila they mainly concern civil and monumental buildings damaged by the quake. In the latter, the SI system will be inserted in a sub-foundation, not to cut the structural elements or existing foundations, and a new method patented by ENEA and Polytechnic of Torino in 2010 will also be used.*

1 INTRODUCTION

Over 16,000 structures in the world have been protected by anti-seismic (AS) systems and devices, mainly by the seismic isolation (SI) or energy dissipation (ED) ones [1-11]. They are located in over 30 countries (Figure 1) and concern both new constructions and retrofits of existing structures of all kinds: bridges and viaducts, civil and industrial buildings, cultural heritage and industrial components and installations, including some high risk nuclear and chemical plants. The use of the AS systems in a civil context already includes not only the strategic structures (civil defence centres, hospitals) and the public ones (schools, churches, commercial centres, hotels, airports), but also residential buildings and even many small private houses. Everywhere, the number of such applications is increasing more and more, although it is strongly influenced by earthquake experience and the availability and features of the design rules used [9].

Most SI systems rely on the use of rubber bearings (RBs), namely High Damping Rubber Bearings (HDRBs), or Lead Rubber Bearings (LRBs) or (mainly in Japan) Low Damping Rubber Bearings (LDRBs) in parallel with dampers of various kinds; in buildings, some plane surfaces steel-teflon (PTFE) Sliding Devices (SDs) are frequently added to the RBs to support their light parts and/or minimize the torsion effect if they are significantly asymmetric in the horizontal plane [9].

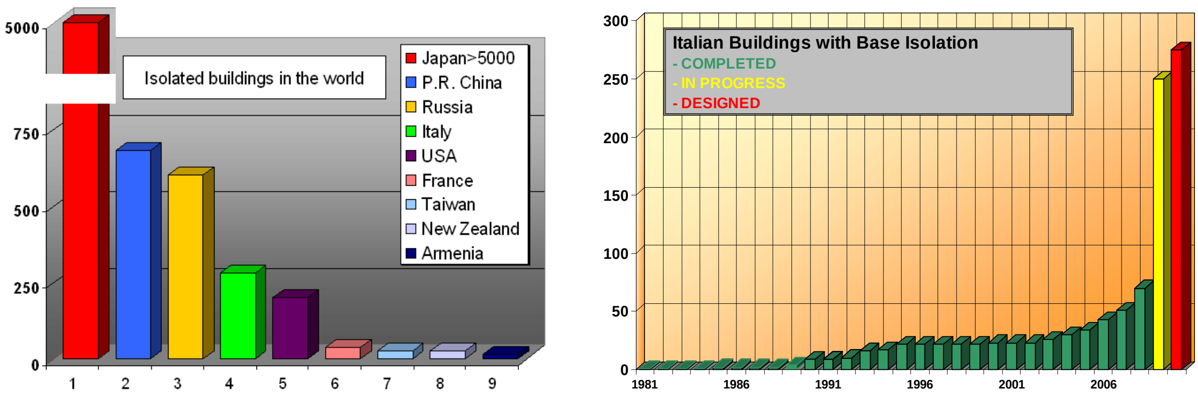


Figure 1: Overall number of building applications of seismic isolation in the most active countries (left); overall number of building applications of SI in Italy during years (right). Data refer to the end of 2009.

2 WORLDWIDE APPLICATION OF THE ANTI-SEISMIC SYSTEMS & DEVICES

Japan is largely the worldwide leader for the number of applications of the AS systems (Figure 1). This occurs also thanks to an adequate code and the excellent behaviour of numerous buildings protected by SI during an already significant number of earthquakes (starting from the 1995 *Hyogo-ken Nanbu* event, of magnitude M = 7.3). More precisely, in Japan there are now over 6,000 isolated buildings or houses [11, 12], besides several isolated bridges & viaducts and (at the end of 2009) about 3,000 constructions protected by dampers [9, 10]. There the trend is to isolate, on the one hand, even high-rise buildings and sets of buildings supported by common “artificial ground” slabs and, on the other hand, even small private houses. Moreover, recent projects concern three-directional (3D) SI of civil buildings, retrofit of cultural heritage, protection of industrial factories (e.g. for semi-conductors), etc.

The USA are second, with “only” 100÷200 large, new and retrofitted, civil and historical, isolated buildings, but over 650 isolated bridges or viaducts and approximately 1,000 applications of dampers at the end of 2009 [9, 10]. Building application of SI is relatively limited (in spite of the excellent behaviour of some isolated ones during the 1994 *Northridge* earthquake), due to a very penalizing code [9, 10].

The Peoples' Republic (P.R.) of China is third, with about 690 isolated buildings and over 100 ones with ED or other systems (at the end of 2009), besides numerous isolated bridges & viaducts [9, 10]. There too application is rapidly increasing. It includes several reinforced concrete (r.c.) and also masonry dwelling buildings, as well as SI of some Liquefied Natural Gas (LNG) tanks. Like in Japan, the use of 3D SI and "artificial grounds" started, together with retrofit of cultural heritage and roof SI of large span structures. The excellent behaviour of some isolated r.c. and masonry buildings during the 2008 *Wenchuan* earthquake (of magnitude M close to 8.0), although this had been largely underestimated [7, 9, 10], is further accelerating the use of AS systems in China.

Forth is the Russian Federation, with about 600 isolated buildings (including retrofits of some important historical constructions) and several new ongoing projects, concerning even high-rise buildings (one, the 27-storey *Sea Plaza* Hotel in Sochi, is protected by Italian HDRBs) [9, 10].

Italy remains fifth and first in Western Europe for the overall number of applications of the AS systems (Section 3) [5, 9, 10, 11]. It is followed by South Korea, Taiwan, Armenia, New Zealand, France, Mexico, Canada and Chile [9, 10]. In Taiwan the present significant use of the AS systems is due to the 1999 *Chi Chi* earthquake and the subsequently enforced new seismic code, which promotes the use of the AS systems. In Armenia the adoption of SI began after the 1988 *Spitak* event and the number of applications per inhabitants is the largest in the world after that in Japan, although this country is still developing [6]. In New Zealand, one of the motherlands of AS devices (in particular of those based on the use of lead) and third for the number of their applications per inhabitants, the isolated structures had an excellent behaviour in the 2010 *Canterbury* earthquake of M = 7.1 [10, 11]. In France SI has been used to protect the *Jules Horowitz Reactor* and has been planned for the *ITER* plant for the controlled nuclear fusion in the mainland, while it is obligatory for schools and other public buildings in its Martinique island. Finally, similar to New Zealand, the isolated structures in Santiago had an excellent behaviour in Chile too, during the 2010 *Maule* earthquake of M = 8.8 [10, 11].

Important applications of the AS systems also began in Turkey (after the 1999 *Kocaeli* and *Duzce* earthquakes) and other European countries [8-11]: many of them make use of Italian AS devices (in Turkey, Greece, Portugal, Spain) or Italian designs too (in Cyprus, Romania). Italian devices have also been installed in Taiwan, South Korea, Venezuela, Indonesia, the USA, Canada, Iran (where a huge project is in progress for isolating the whole new town of Parand, near Tehran), etc. Finally, Macedonia shall be cited, because it hosts the first modern application of SI worldwide, that to the *Pestolazzi* school in Skopje, erected after the destructive 1963 earthquake: its original poorly laminated and very deteriorated rubber isolators were replaced by HDRBs in 2007 [9-11].

3 APPLICATION OF THE ANTI-SEISMIC SYSTEMS & DEVICES IN ITALY

As mentioned above, Italy is fifth at worldwide level and first in Western Europe for the overall number of applications of the AS systems (Figure 1). There, the use of such systems began in 1975 for bridges and viaducts (*Somplago* viaduct of the *Udine-Tarvisio* freeway, which survived intact the second shock of the 1976 *Friuli* earthquake) and in 1981, namely 4 years before Japan and the USA, for buildings (main building of the new *Fire Command Centre* of Naples, the design of which was "retrofitted" with isolators, dampers and other AS devices as a consequence of the seismic classification of the Naples area in seismic category 3 after the 1980 *Campano-Lucano* earthquake) [1, 2].

In 2009, Italy passed the USA for the number of isolated buildings [5, 8, 9]: those in use were about 70 before the *Abruzzo* earthquake of April 6 of that year (M = 6.3), with further

20÷30 under construction or design, and are now approximately 300 (Figure 1). In fact, in Italy, after many years of a rather limited use of the AS systems (due to the lack of design rules to the end of 1998, then to their inadequacy and very complicated and time-consuming approval process to May 2003 [1, 2]), there has been a large increase of the number of new projects in the last years [3, 8-11].

Figure 2: Collapse of the *Francesco Jovine* primary school of San Giuliano di Puglia (Campobasso) during the 2002 *Molise & Puglia* earthquake and search of survivors amid the debris. Prior to the aforesaid earthquake the San Giuliano di Puglia area was not seismically classified (now it is classified in seismic zone 2).

Figure 3: The *Prefettura* building (provincial headquarters of the national government) of L'Aquila, a symbol of lack of prevention of the seismic risk in Italy until 2009 (left), and the *Santa Maria Paganica Church* (right), collapsed after the 2009 *Abruzzo* earthquake.

This occurred first thanks to the new Italian seismic code, enforced in May 2003, which freed and simplified the adoption of the AS systems [1, 2, 5, 8, 9]. This code, which became of obligatory use after the 2009 *Abruzzo* earthquake, was mostly a consequence of the collapse of the *Francesco Jovine* school in San Giuliano di Puglia (due to its bad construction and even worse raising) during the 2002 *Molise & Puglia* event (Figure 2).

An even larger use of the AS systems is now in progress, as a consequence of the heavy damage caused by the 2009 *Abruzzo* earthquake to the conventionally founded civil structures and cultural heritage (Figure 3 and 4) [5, 10, 11]: in particular, 184 pre-fabricated houses were erected in L'Aquila, each on a large isolated large r.c. slab to provisionally host 17,000 homeless persons (at least in the first years). These have been isolated using Italian Curved Surface Slider (CSS) devices, but the use of the traditional HDRBs or LRBs, in conjunction with some SDs, is also going on, for both new constructions and retrofits (Section 4). In particular, the new *Francesco Jovine*, protected by a SI system designed with the collaboration of ENEA and formed by HDRBs and SDs (Figure 5), which has been first Italian isolated school, has been followed by several further projects of this kind: seismic protection of schools by means of SI, besides that of hospitals and other strategic structures, is now a “priority 1” objective in Italy (see Section 5) [9-11].

Figure 4: Collapse of statues in the L’Aquila Museum after the 2009 *Abruzzo* earthquake. Such a disaster should make the opponents of the development and installation of an adequate seismic protection system for the marble statue of *David of Michelangelo* think it over (this worldwide known masterpiece, exhibited in the *Galleria dell’Accademia* in Florence, is severely fissured at its ankles, which makes it very vulnerable to both seismic and even environmental vibrations [1-4]).

Figure 5: The new *Francesco Jovine* primary school and the *“Tre Torri”* multifunctional complex in San Giuliano di Puglia (now seismic zone 2), supported by a common isolated artificial ground slab, which was certified as safe by A. Martelli in September 2008 (left); their SI system, formed by 61 HDRBs and 12 SDs donated by the Italian manufacturers, during construction (right). These buildings will be seismically monitored [10, 11].

Moreover, the use of the AS systems is going on for bridges and viaducts (those with such systems were already at least 250 in 2009 [4]) and cultural heritage [9-11]: new retrofit techniques using SI, applicable to monumental buildings, will be applied for the reconstruction of L’Aquila (Sect. 4).

It is noted that the application of the AS systems in Italy has greatly benefitted from the collaborations in progress in the framework of the national association GLIS (“GLIS – Isolamento ed altre Strategie di Progettazione Antisismica”, namely “GLIS – Isolation and other Anti-Seismic Design Strategies”) since 1989 at national level and in that of *ASSISi* (*A*nti-*S*eismic *S*ystems *I*nternational *Soci*ety) since 2002 at international level.

4 ITALIAN RETROFITS WITH SEISMIC ISOLATION

As previously stressed, the *Abruzzo* earthquake of April 6, 2009 caused an increase of the number of the Italian seismically isolated buildings from about 70 to over 300. Several new Italian hospitals, all new civil defence centres and most new schools have already been (or are already being) seismically isolated, together with a significant number of dwelling buildings and other constructions [9-11]. SI has also been used for some important retrofits of civil structures and precious masterpieces. Prior to the aforesaid event, in almost all applications, the Italian SI systems consisted in HDRBs or LRBs, to which some SDs were added in the last years. Now, as mentioned in Sect. 3, CSS devices are also in use (mainly at L'Aquila).

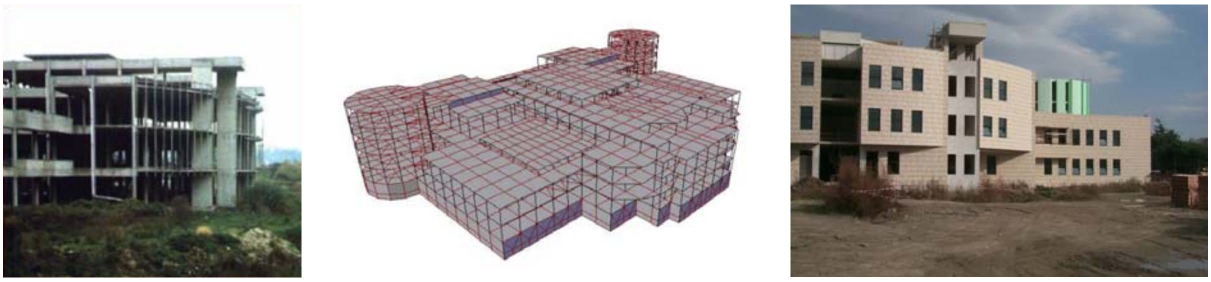


Figure 6: The *Rione Traiano Polyfunctional Centre* in Soccavo (Naples) before being retrofitted (left); its finite-element model, which stresses its large asymmetries (at the centre); completion of its external parts, which was carried out in parallel to the insertion of the SI system (right).

Figure 7: Phases of the retrofit of the building of Figure 6, with installation of 4 hydraulic jacks to provisionally support the weight after removal of the pillar part to be replaced by an isolator and to locally lift the building, so as to allow for the subsequent insertion of the isolator (left), and cut of the pillar with a linear saw (at the centre); view of the isolator after its installation and its mechanical fixing to the upper and lower pillar parts (right).

Figure 8: Installation of the steel beams floor in the building of Figure 6 just above the isolators and reinforcement of the pillars (left); the lower floor after cut of the building supporting pillars and walls (at the centre); the building after retrofit completion (right).

4.1 Rione Traiano Polyfunctional Centre in Naples

The first Italian building to be retrofitted with SI was the *Rione Traiano Polyfunctional Centre* in Naples in 2004. It is a large (100,000 m^3 volume, 33,000 m^2 living area), very asymmetric, 4-storey r.c. building with piled foundations, erected in the years '70s, when the Naples area was not yet considered as seismic, then left incomplete, due to lack of funds (Figure 6) [1, 2]. The intervention was designed by the GLIS members Prof. R. Sparacio of the University of Naples "Federico II", his collaborator F. Cavuoto, Prof. P. Pinto of the University of Rome "La Sapienza" and A. Dusi of NUMERIA (Cremona).

Retrofit with SI was found by the designers to be the only way to avoid demolition and reconstruction. Thus, the foundation pillars and walls were cut (Figure 7), approximately 600 HDRBs were installed, the pillars were reinforced and a steel beams floor was added just above the isolators to provide the stiffness necessary to allow for the correct transmission of the horizontal forces to the isolators themselves and to the superstructure (Figure 8). The retrofit method was similar to that used in 1991 for the Rockwell International Building in Seal Bach, near Los Angeles (California, USA).

This retrofit was designed and performed according to the seismic code applicable before the enforcement of the new one in 2003. As required at that time for the isolated buildings, the design was submitted to the approval of the High Council of Public Works ("Consiglio Superiore dei Lavori Pubblici" or CSLLPP) of the Italian Ministry of Constructions. The overall cost of the intervention was 2.5 M€, namely 80 €/m^2. Of the total costs, 1.3 M€ concerned the isolators and their insertion, 0.6 € the steel slab, 0.5 € the ground retaining walls and the structural gaps and 0.1 € accessories. In normal conditions 20 HDRBs per week were installed by each workers team (with up to 3 teams, in the most busy period).

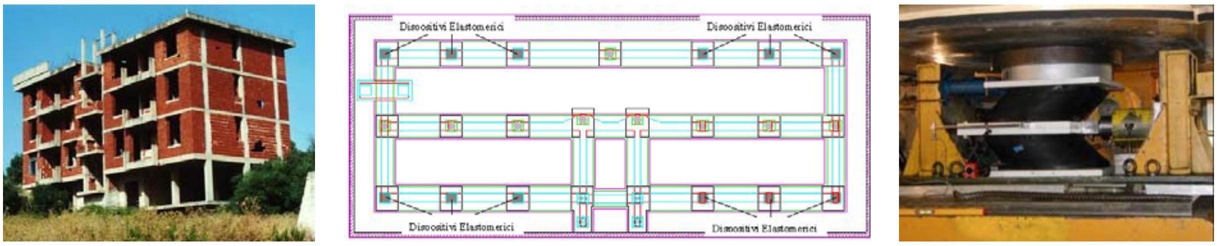


Figure 9: The two dwelling buildings in Solarino before being retrofitted (left); horizontal section of one of the buildings, with location of the isolators (at the centre); two superposed HDRBs during their acceptance tests concerning the application of transverse deformations under the design vertical load (right).

Figure 10: A HDRB during its installation in one of the buildings of Figure 9 (left); this building after retrofit completion (at the centre); an isolator laterally deformed during the on-site tests (right).

4.2 Solarino dwelling buildings

The second Italian building retrofit with SI was performed again in 2004. It concerned two 4-storey r.c. dwelling buildings in Solarino (Syracuse), which had also been left incomplete for some years due to lack of funds (Figures 9 and 10) [1, 2]. Each of them was retrofitted by means of 12 HDRBs and 13 SDs. This retrofit too was performed (by Prof. G. Oliveto of Catania University and others) according to the seismic code applicable before the enforcement of the new one in 2003.

After completion of the intervention, one of the buildings was subjected to free vibration pull-back on-site tests (similar to those previously performed in 1990 for one of the 5 isolated buildings, 25 m high, of the *Telecom Italia Regional Centre* in Ancona and, later, for one of the isolated buildings of the *University of Basilicata* in Potenza and an isolated house in Rapolla, near the same town [1, 2]).

4.3 Fabriano house

In 2005 the first European retrofit with SI in a sub-foundation was completed: it concerned a rather asymmetric 3-storey r.c. dwelling house (11 apartments), which had suffered severe but non-structural damage during the 1997-98 *Marche & Umbria* quake (Figures 11-12).

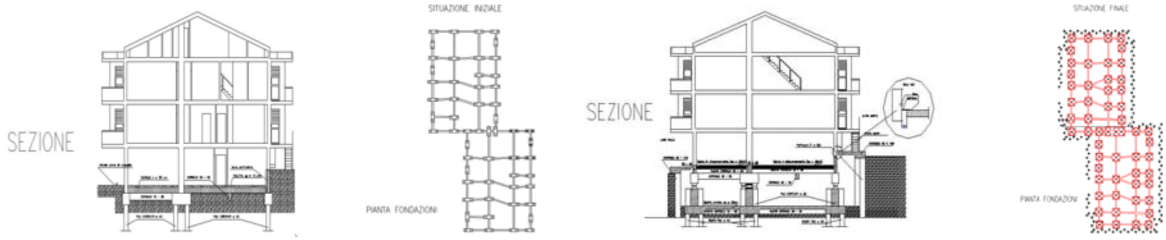


Figure 11: Vertical and horizontal sections of the original and the retrofitted dwelling house in Fabriano (from left to right).

Figure 12: External and internal non structural damage suffered by the house of Figure 11 in the 1997-98 *Marche & Umbria* earthquake.

Figure 13: Creation of the structural gap around the house of Figure 11 (left); view from the top of the original lower floor and the new underground one after excavation of the latter and construction of new curbs (at the centre); view from the bottom of the new underground floor, the original foundation piles and the new foundations under constructions (right).

This type of intervention (Figure 13-20), which made use of 56 HDRBs of two sizes (400 mm and 450 mm diameters – see Figure 16), was selected by the designer (the GLIS and *ASSISi* member G. Mancinelli of Fabriano) and funded by the government for economic reasons: in fact, its cost was demonstrated to be 20% lower than that of a conventional intervention (which would have required the demolition of all non-structural elements, reinforcement of pillars and beam-pillar nodes and not easy insertion of shear walls); it also enabled to considerably improve the foundations (which consisted of couples of piles) and to obtain a new underground floor. For this building too, the design was completed before the enforcement of the 2003 new seismic code, thus it was submitted for approval to the CSLLPP (it was necessary to wait more than 2 years before obtaining such an approval, although this was given based on the documentation that had been provided to CSLLPP since the beginning!).

Figure 14: Newly built foundation piles, in the part of the house of Figure 11 where the original ones were failing (left and at the centre); pillar eccentric with respect to the original foundation piles (right).

Figure 15: Setting up of the reinforcement of the lower stump of the new pillar (by means of a dummy isolator) and of the lower plate for connecting the isolator in the new underground floor of the house of Figure 11.

The planned construction phases consisted in:

- realization of the ground retaining wall around the house (Figure 13);
- reinforcement or reconstruction of curbs at the existing basement level (Figure 13);
- excavation under the existing basement level at the side of the original foundation piles (Figure 13);
- injection of the new foundations piles around the base of the original ones and realization of the basement of the new underground floor (Figures 13 and 14);
- construction of the r.c. upper stumps of the pillars in the new underground floor, by encompassing the upper part of the original foundation piles, with the upper connection plates for the isolators attached through shanks (Figure 15);
- setting up of the steel reinforcement of the lower stumps of the pillars in the new underground floor, with the lower connection plate for the isolators attached through shanks, using a dummy isolator to correctly fix the distance between the two stumps (Figure 15);

- subsequent construction of the lower stumps of the pillars in the new underground floor;
- construction of the first r.c. slab above the new underground floor (Figure 16);
- insertion of the isolators (Figure 16), superposed to flat jacks (Figure 17), and injection of epoxy resins inside the latter to release the original foundation piles and let the vertical load be carried by the isolators;
- cut of the original foundation columns at the side of the isolators, by leaving the two resulting stumps in place to create a vertical fail-safe system (separated by a few centimetres, in order to avoid contact when the isolated superstructure lowers due to its transverse motion) and completion of the lateral structural gap around the house (Figure 17);

Figure 16: New r.c. slab of the ground level floor of the house of Figure 11 (left); the HDRBs before their installation in the new underground floor (at the centre and right).

Figure 17: Lateral structural gap of the house of Figure 11 before the installation of its protection plates (left); the new underground floor after installation of the HDRBs, but before demolition of the parts of the original foundation piles which were not encompassed by the new pillars (at the centre); an installed HDRB superposed to an epoxy flat jack (right).

Figure 18: HDRBs installed between two original (left) and two newly built (at the centre) foundation piles of the house of Figure 11, before demolition of their parts which were not encompassed by the new pillars; the underground floor after demolition of the aforesaid parts (right).

- installation of the various pipe lines, provided with suitable fixing systems and adequate joints for the interface ones, to let them remain undamaged during the isolated superstructure motion (Figure 19) and of the protection plates of the structural gap (such as not to hinder both the lateral and the small vertical motions of the isolated superstructure during an earthquake).

However, some unexpected problems were detected during the works, which considerably complicated them and delayed the retrofit completion, e.g.:

- the absence of about 50% of the foundation piles in one of the house two halves (evidently due to the presence of large water quantities in the ground during the initial construction), which may at least partly explain the damages caused by the earthquake and made it necessary to build these piles before going on with the retrofit intervention (Figures 14 and 18);
- eccentricities between the foundation piles and the house original pillars, in some positions (Figure 14), which made it impossible to set up the aforesaid planned fail-safe systems through the simple cut of the old foundation piles at the side of the isolators and forced, on the contrary, to fully demolish the parts of such piles that were not encompassed in the new upper and lower pillar stumps (Figure 18 and 19).

Furthermore, some "classical" construction errors were found, for instance holes in the beams to realize passages for pipes (Figure 20).

Figure 19: A HDBR installed, after demolition of the parts of the original foundation piles which were not encompassed by the new pillars (left); the new underground floor in the aforesaid conditions and after the installation of the pipe lines (at the centre and right).

Figure 20: Holes and breaks in the beams of the house of Figure 11, made during the initial construction to create passages for the pipe lines (left and at the centre); the house after retrofit completion (right).

The building safety was certified by A. Martelli, after the full construction completion (i.e. including the installation of the protection plates of the structural gaps and that of all pipilines). It is noted that, according to the construction permissions obtained, the use of the new underground floor is not permitted (it is considered as a "technical volume"), although its spaces would allow for its utilization as garage and/or cellars. Should this change of use be permitted in the future, protections of the HDRBs from fire shall be inserted.

4.4 Further retrofits performed or designed before the 2009 *Abruzzo* earthquake

Further retrofits with SI have also concerned other types of buildings, like churches (starting from that of the dome of the *Sanctuary of Madonna delle Lacrime* of Syracuse in 2006, see Figure 21), r.c. and masonry dwelling buildings (starting from that of one at Rocca di Castell'Ottieri, Grosseto, in 2007), schools (starting from that of the *Quasimodo* school at Riposto, Catania, in 2009), hotels (Figure 22), etc. [5].

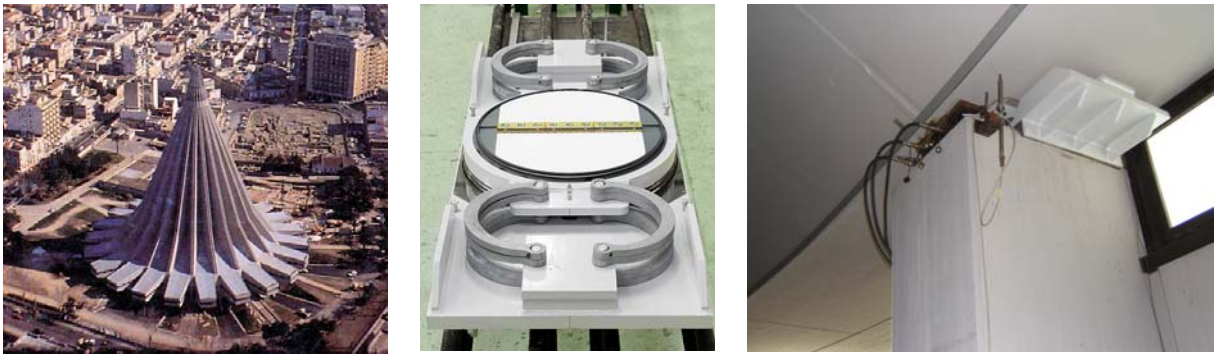


Figure 21: Seismic retrofit of the *Madonna delle Lacrime Santuary* at Syracuse (containing up to 11·000 people), performed in 2007 by uplifting the 22,000 t dome (left) and by inserting isolators with elastic-plastic damping elements (at the centre and right).

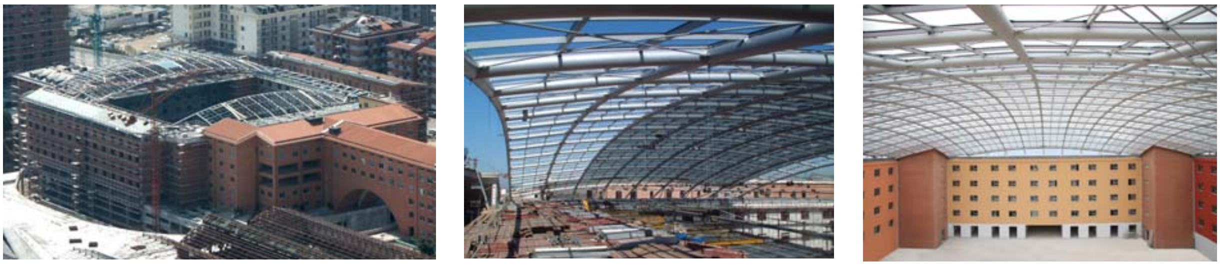


Figure 22: New ceiling of the *Crowne Plaza Hotel* in Caserta, set up by the GLIS board member and *ASSISi* member G.C. Giuliani of Milan in 2006 by constraining it by means of SDs to 3 of the 4 buildings to which it is connected.

Figure 23: One of the 3 tanks of *Polimeri Europa* located in Priolo Gargallo (Augusta, Syracuse, seismic zone 2*), which were seismically retrofitted using U.S. FPS devices in the years 2005-2008 and one of the isolators during and after its installation.

In the years 2005-2008, three chemical tanks of the company *Polimeri Europa* of the Italian ENI Group were also retrofitted in Sicily by means of U.S. CSS devices, namely by the so called Friction Pendulum System (FPS), after cutting the supporting columns (Figure 23) [11, 13]. This is the only application of SI to chemical plants and components so far existing in Italy. Prior to the 2009 *Abruzzo* earthquake, it was also the only application of Curved Surface Slider (CSS) isolators to Italian structures (a similar intervention, using 3 HDRBs and 8 SDs, had been designed by ENEA, APAT – now ISPRA – and the University of Rome “La Sapienza” for a sphere tank of Enichem, located in the same site [1, 2], but was never performed, although it had been demonstrated to be very effective).

Figure 24: External and internal damages suffered by the *San Giovanni Battista Church* in Apagni (Perugia) during the 1997-98 *Marche & Umbria* earthquake.

Figure 25: The *Santa Croce della Ficarella Church* in Case Basse (Perugia) put in safe conditions after the 1997-98 *Marche & Umbria* earthquake (left) and subsequent conventional restoration works (at the centre and right), which should have been followed by the construction of a sub-foundation and insertion there of a SI system formed by 8 HDRBs with 600 mm diameters and 294 mm height (maximum design displacement = 256 mm).

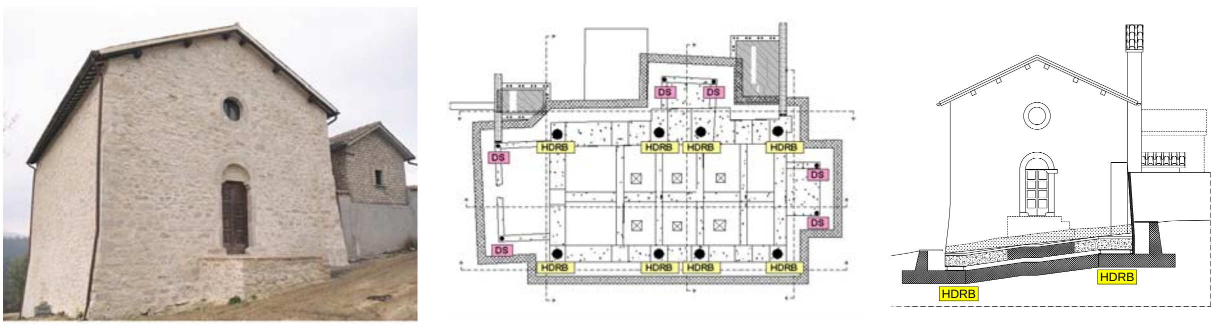


Figure 26: The *San Giovanni Battista Church* of Figure 24 after the new conventional restoration (left); horizontal section of the church with location of the 8 HDRBs and 6 SDs foreseen by the retrofit design with SI (at the centre); vertical section, where the sub-foundation curb is shown.

In addition, the use of SI in a sub-foundation was planned by ENEA and others for two small old churches, decorated by valuable paintings (of Giotto school) which had been severely damaged by the 1997-98 *Marche & Umbria* earthquake: the *San Giovanni Battista Church* in Apagni, near Sellano (Figure 24), and the *Santa Croce della Ficarella Church* in Case Basse, near Nocera Umbra (Figure 25), which are both located in the Umbrian Perugia Province [1, 2, 14, 15]. They had already suffered similar damages during the 1979 *Valnerina* earthquake, after which they had been conventionally restored: this stresses the limits of the conventional restoration. Both churches were conventionally retrofitted again and the SI design was developed by the partners of the PROSEESM National Project, which included ENEA (see Figures 26 and 27 for the *San Giovanni Battista Church*) [1, 2]. Such designs were approved by the Regional Technical-Scientific Committee which was entrusted for the examination of the reconstruction designs, but were never funded later!

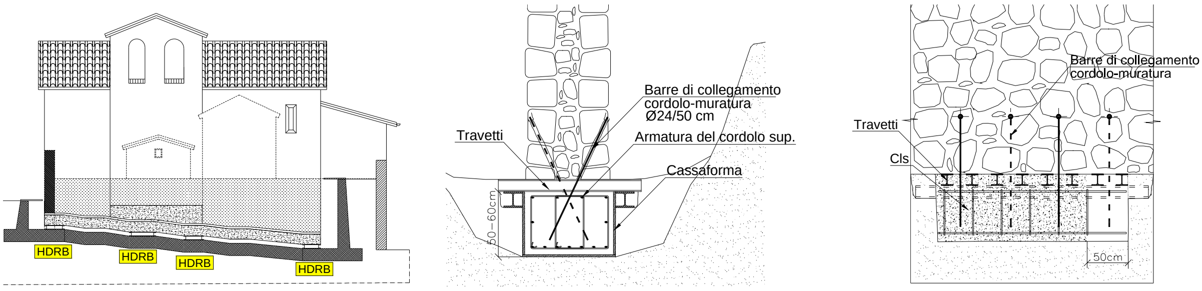


Figure 27: Details of the retrofit with SI in a sub-foundation designed by ENEA for the *San Giovanni Battista Church* of Figures 24 and 26.

Figure 28: Mevale di Visso as reconstructed with conventional techniques after the damages suffered during the 1979 *Valnerina* earthquake (left) and again heavily damaged after the 1997-98 *Marche & Umbria* event (at the centre and right)

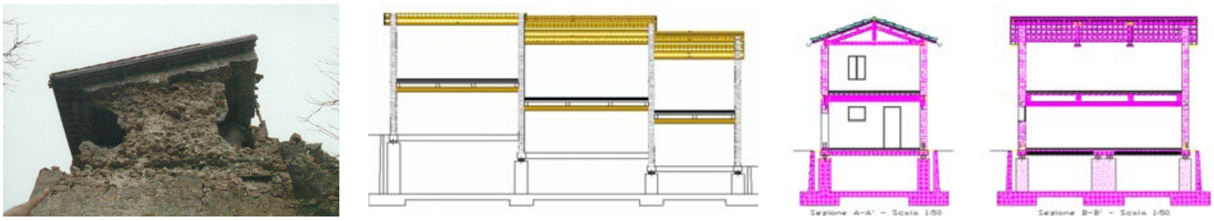
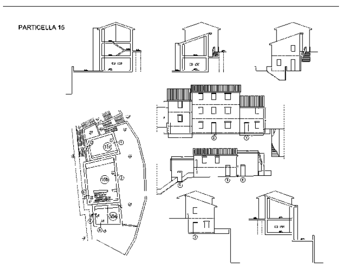


Figure 29: Damage suffered by a house in Mevale di Visso during the 1997-98 *Marche & Umbria* event (left) and vertical sections of isolated houses proposed in the reconstruction designs of ENEA and other partners (at the centre and right).



	TT	IS	CA
	361.881,35	**394.962,59**	**357.675,70**
TT	_	33.081,24	-4.205,65
	_	**9,14%**	**-1,16%**
IS	-33.081,24	_	-37.286,89
	-8,38%	_	**-9,44%**
CA	4.205,65	37.286,89	_
	1,18%	**10,42%**	_

Figure 30: Design selected for the first application of SI in the reconstruction of portions of Mevale di Visso and related cost differences among the various retrofit methods (TT = fixed-base masonry; IS = seismically isolated masonry buildings; CA = fixed base r.c. structure).

Another project that was developed by ENEA and other partners and was technically approved by the Marche Technical-Scientific Committee for a first application after the 1997-98 *Marche & Umbria* earthquake (but, again, never funded until now) concerned the reconstruction of portions of the ancient village of Mevale di Visso (on the Apennines in the Marche Macerata Province), with the original materials and construction methods, but on seismically isolated r.c. slabs [1, 2, 14, 15]. This village (Figures 28 and 29) was severely damaged by several earthquakes during its history, including the aforesaid *Valnerina* and *Marche & Umbria* events. The latter caused the partial collapse of several buildings. The reconstruction designs of ENEA and other partners (Figures 29 and 30) showed that the use of SI requires an additional cost of only 5-9% with respect to the case of simple reconstruction of the masonry buildings without any reinforcement and of 3-11% with respect to that of reconstruction using r.c., namely with respect to two solutions that, in any case, are inappropriate or not permitted in Italy: in the first case due to insufficient seismic protection, in the second because it would be in contrast with the conservation requirements which apply for cultural heritage in Italy.

Figure 31: *Bronzes of Riace*, which were isolated in the Reggio Calabria Museum (seismic zone 1) in the years '90s (left); its present 3-stage HDRBs system (at the centre), which should be soon replaced by an improved SI system; *Dancing Satyr* in the Mazara del Vallo Museum, again protected by a 3-stage HDRBs system (right).

Figure 32: The original statue of *Scylla*, in the Museum of Messina, in seismic zone 1 (left); monument including copies of the statues of *Scylla and Neptune* in Messina (at the centre); the SI system developed for protecting the originals of both aforesaid statues in the Museum of Messina (right).

Finally, it is worthwhile citing that SI has also already been used in Italy to protect some unique masterpieces. In particular [1, 2, 14, 15]:

- the *Bronzes of Riace* in the Museum of Reggio Calabria, the bronze statue of *Germanicus Emperor* at the National Museum of Perugia and that of the *Dancing Satyr* of Mazara del Vallo (Figure 31) have been seismically isolated by means of 3-stage HDRBs systems (an unique isolators stage would cause geometrical instability of the isolators, because their diameter shall be small for such light bronze statues);

- the original marble statues of *Scylla* and *Neptune* in the Museum of Messina have been supported by a SI system formed by SDs and Shape Memory Alloy Devices (SMADs), the latter acting both as dampers and as re-centring elements (Figure 32);
- steel sphere isolators were used to protect display cases in the Assisi Museum;
- four 3D isolators, developed in the framework of the SPACE Project, funded by the European Commission, were installed in the Ercolano Museum to protect a wooden Roman ship, very vulnerable to seismic vibrations even in the vertical direction, which was excavated in that area, after having been buried by materials erupted by Vesuvius in 79 AD for a long time (each of these isolators is formed by 3 steel spheres rolling between steel plane surfaces with a re-centring rubber cylinder for the horizontal excitations and by a spring and a viscous damper for the vertical one, see Figure 33).

Figure 33: Roman ship excavated near Ercolano (Naples) and exhibited in the local museum, which is located in seismic zone 2 (left); one of the four 3D isolators manufactured to protect it (at the centre); shake table tests of its SI system (right).

Figure 34: The dwelling building of Via Borgo dei Tigli 6-8-10 in L'Aquila (Pianola area), before the 2009 *Abruzzo* earthquake (its construction had been just completed before this event).

4.5 Further retrofits planned after the 2009 *Abruzzo* earthquake

As mentioned, the very significant extension of the applications of SI begun after the 2009 *Abruzzo* earthquake concerns this and other Italian regions. Such applications include numerous retrofits. With regard to those in L'Aquila, to be stressed are those:

- beginning for numerous dwelling buildings damaged by the earthquake, partly based on the experience achieved for the retrofit of the previously mentioned Fabri-

ano house, damaged by the 1997-98 *Marche & Umbria* quake (Figures 34 and 35);
- which should soon begin for some public buildings (e.g. for the town court, the upper storeys of which will be demolished, then reconstructed after the insertion of a SI system at the top of the first floor);
- planned for some monumental buildings, to be partly performed within a collaboration agreement signed between ENEA and L'Aquila municipality in 2010.

Figure 35: Damage caused by the 2009 *Abruzzo* earthquake to the building of Figure 34; its retrofit by means of HDRBs and SDs has been planned, based on a design of the already mentioned GLIS and *ASSISi* member G. Mancinelli of Fabriano, with safety certification of A. Martelli.

Figure 36: The monumental building *Palazzo Margherita* in L'Aquila before the 2009 *Abruzzo* earthquake (left) and put in safe conditions because of the damages suffered during this event (at the centre); its internal courtyard after the earthquake (right).

The latter will concern *Palazzo Margherita* (Figure 36), the historical *De Amicis* primary school (Figure 37) and other buildings. For these the SI system will be inserted in a sub-foundation, in order not to cut any structural elements, including the existing foundations (according to the conservation requirements to be respected in Italy for cultural heritage). Among others, a new method patented by ENEA and the Polytechnic of Torino will be used (Figure 37): it consists in inserting large tubes below the building, laterally to it, and placing the isolators between the upper and the lower semi-spherical halves of such tubes (the upper ones will be the base of the superstructure, the lower ones will form the surface of the new foundation).

Retrofits of existing buildings, even not damaged by the 2009 *Abruzzo* earthquake or other seismic events, have already been planned in other Abruzzo towns or other Italian regions, as well. With regard to Abruzzo, to be cited are some monumental buildings (including at least one school) to be retrofitted in Sulmona, which is also an earthquake prone town, not distant from L'Aquila: where possible, SI in a sub-foundation will be used. To select the intervention types and to control their adequate execution, a collaboration agreement between ENEA and the Sulmona municipality is under preparation. The support of GLIS experts to ENEA is also being considered in this agreement.

Figure 37: The *De Amicis* primary school in L'Aquila, damaged by the 2009 *Abruzzo* earthquake (left); sketch of the new sub-foundation technique patented by ENEA and the Polytechnic of Torino in 2010 (right).

Figure 38: Front view of the *Romita High School* for scientific studies in Campobasso, when it was still in use, namely before the 2009 *Abruzzo* earthquake (left); block "C" of the school (at the centre); horizontal section of the school, showing the different blocks (right).

Figure 39: The *Romita High School* in July 2010, after the demolition of blocks "A" and "B" (left); two HDRBs and a SD installed in the underground technical floor of the new block "B" of the school, during its reconstruction (at the centre); state of the reconstruction of the new block "B" in October 2010, before casting of the upper deck, at the side of the original block "C" (right).

With regard to building retrofits with SI planned in other Italian regions, an interesting case to be cited is that of the *Romita High School* for scientific studies in Campobasso (Figure 38), which hosted about 1,300 students, when it was in use [1, 2, 9, 10]. It consists of various blocks, erected in different years. When it was built, Campobasso was not seismically classified (while now it belongs to seismic zone 2), thus, no seismic design was performed for the school. In addition, the results of investigations performed by a team of experts (including ENEA ones) after the 2002 *Molise & Puglia* earthquake showed that blocks “A” and “B” (Figure 38) were particularly unsafe, even statically, due to very bad quality of the construction materials, and that block “C” was in better but not fully satisfactory conditions.

Based on these results, ENEA immediately advised the school owner (Campobasso Province) to demolish and reconstruct, with SI, at least blocks “A” and “B”. In spite of this, the fear that demolition would have given rise to questions of the population, very difficult to answer, on the static and seismic safety of the other schools of the town, led the owner to decide to first reinforce the unsafe blocks (to make them statically safe) and only later, when possible, to retrofit them with SI or ED. However, such retrofits had not been performed, yet, when the 2009 *Abruzzo* earthquake occurred.

This affair, commented by the first author of this paper during a conversation with a journalist, was reported by his newspaper a few days after the latter event: this led to bitter controversies in Campabasso (with a general strike of the students of the town). Thus, at the end of April 2009, at last, the Campobasso Province accepted the ENEA suggestion to demolish block “A” and “B”, immediately reconstruct block “B” with SI and do the same for block “A”, with the same technique, as soon as the necessary funding would have become available.

As shown by Figure 39, blocks “A” and “B” were both demolished (in July 2010) and reconstruction of block “B” (for which safety will be certified by the first author of this paper) is now in advanced progress (the upper deck was completed in 2010). On the contrary, no funds were found, yet, to reconstruct block “A” too (however, reinforcement rods have been placed in block “A” so as to easily connect them to those of block “B” when it will be built). With regard to block “C”, it is noted that it has been suggested not to demolish it (due to the better construction materials), but to retrofit it by inserting RBs at the top of the pillars of the first floor (Figure 38).

Finally, with regard to the seismic protection of single Italian masterpieces, it is noted that Japanese steel sphere recirculation devices have been used in Italy to isolated the *Worrier of Capestrano* during the 2009 G8 meeting in L’Aquila and that U.S. rolling devices will go on supporting statues that will be returned by the *J. Paul Getty Museum* of Santa Monica (California, USA) to Sicily (Figure 40) [10, 15].

(a) (b) (c) (d)

Figure 40: The statue of the *Worrier of Capestrano* (a) exhibited during the G8 Summit of L’Aquila in 2009 (b), protected by a Japanese SI table, which makes use of steel sphere recirculation isolators; one of the 9 statues which have already been isolated at the *J. Paul Getty House* in Santa Monica (California, USA) and their “wheel” rolling SI system (c & d).

5 LEGISLATIVE MEASURES ALREADY ADOPTED BY THE ITALIAN GOVERNMENT TO PROMOTE THE USE OF ANTI-SEISMIC SYSTEMS

The Italian Government, besides making the use of the new seismic code at last obligatory (during Summer 2009, in the framework of the law for the reconstruction in Abruzzo), already decided some legislative measures to favour the extension of the adoption of the anti-seismic systems and devices (especially of SI), for both erecting new buildings and retrofitting existing ones [9]. These measures were largely based on proposals of GLIS and, in particular, of the first author of this paper. For instance, economic incentives for those adopting such technologies were decided by the Regional Government of Sicily in 2010 and are under discussion at national level and in other regions.

With regard to the seismic protection of schools, it is worthwhile reporting a translation of the whole text of an "agenda" (consistent with a "declaration" of UNESCO-IPRED-ITU [16] and based on a proposal of the first author of this paper [17]) which was submitted by the President of the 8th Commission on Environment, Territory and Public Works of the Italian Chamber of Deputies [18] in the framework of the vote of the 2009 Financial Law and was immediately accepted by the Italian Government [19]:

"The Chamber of Deputies, considering that:

- paragraph 229 of article 2 of the bill under examination contains measures aimed at guaranteeing the safety of schools and, in this framework, in order to ensure the maximum quickness for the completion of the interventions necessary to put the school buildings in safe conditions and to seismically retrofit them, prescribes, in particular, that, within thirty days from the date of enforcement of the financial law itself, the interventions which can be immediately undertaken shall be the first to be identified;
- it shall be stressed in such a framework that, among all construction types, the school buildings, together with hospitals, should be the most protected from earthquakes, which are the events characterized by the highest risk in Italy;
- for such buildings the objective shall be the full safety of the students and the other occupants;
- to this aim, besides preventing the collapse of school buildings in the case of earthquakes (which is the requirement foreseen by the seismic codes, including the new Technical Norms for Constructions), it is also indispensable to guarantee their full integrity, with no damage even to the non-structural elements and the objects contained;
- furthermore, the level of the seismic vibrations transmitted by the ground to the buildings shall be minimized, to prevent panic;
- the aforesaid objectives cannot be achieved by the conventional anti-seismic design, which is based on the «robustness» of structures, while they can be fully achieved thanks to base seismic isolation and can be achieved to a large extent by inserting energy dissipation systems inside the structures themselves;
- more than half of the school buildings existing in our country result to be inadequate to withstand the earthquakes to which they may be subjected;
- for many of such buildings retrofits able to guarantee a sufficient seismic safety are very difficult or too costly, either because they are monumental buildings (thus also subjected to the conservation requirements), or because they are rather old;
- in the first case it would be desirable to assign the buildings to a different use and move the school functions to other structures, possibly of new construction; in the second the best solution would be demolition and subsequent *ex novo* reconstruction;
- for the new school buildings there are no obstacles of technical nature against their construction with seismic base isolation (in Italy 5 new isolated schools have already been completed and further 12 are under construction); in favour of this tech-

nological solution there are, besides the largely higher safety level with respect to a conventionally founded construction, the overall economic balance too (which takes into account not only the construction costs, but also those of demolition and repair, removal and storage of the debris, displacement of the school activities) and the evident environmental and energetic benefits;

- with regard to the sole construction costs, it is worthwhile noting that, in Italy, the school buildings have a limited number of storeys and usually do not need for an underground storey; thus, although the new Italian seismic code allows for lightening the superstructure and foundations of seismically isolated buildings, for school buildings with base isolation some additional construction costs due to the use of such a protection (isolators, an additional storey above them, etc.) have to be foreseen sometimes;
- for interventions on existing school buildings, seismic isolation may be used only if the room necessary for the «rigid body» motion which characterizes the building part supported by the isolators exists or can be created around the building; the related costs may be even significantly lower than those characterizing a conventional retrofit, because it is possible to avoid stripping the structure, strengthening pillars and beam-pillar nodes and inserting shear walls;
- when seismic isolation is not applicable, it is usually possible to seismically improve the buildings by inserting dampers inside them; in this case the cost of dampers is usually largely balanced by the possibility of avoiding stiffening of the structure;
- in Italy the most famous seismically isolated building is the new Francesco Jovine or «Angels of San Giuliano», school; such a school was the first, among those protected by seismic isolation, to be completed in Italy, in September 2008; the isolation system was designed by a team of experts co-ordinated by ENEA and the structure was subjected to inspections during construction and safety certification of an expert of the Agency; ENEA also contributed to the design of the seismic isolation system and/or certified or will certify the safety of further new schools, in Marzabotto (Bologna), Campobasso, Vado (Bologna) e Mulazzo (Massa); to be cited are also the design and safety certification of 4 further new seismically isolated schools in Tuscany, performed in the framework of the Collaboration Agreement on «Applications of seismic isolation and other modern anti-seismic technologies to constructions and buildings, in particular for educational use» signed by Tuscany Region, ENEA and GLIS in 2004;
- previously other existing schools had been seismically improved by means of energy dissipation systems, first of all at Potenza and its province, then in the Marche Region too: among the latter it is worth citing the Gentile Fermi school in Fabriano, of rationalist architecture, which, due to the damages suffered during the 1997-98 Marche and Umbria earthquake, was seismically improved by means of visco-elastic dampers developed in the framework of the EU-funded project REEDS promoted by ENEA;
- ENEA, in the framework of school building, may profitably contribute in its specific competence fields, among which:
  - the development of new anti-seismic devices and, by means of its experimental equipment, tests on such devices and mock-ups of structures protected by them;
  - the definition of seismic input, also by means of on-site seismic tests, and

analysis of local seismic response and seismic micro-zoning, with definition of site-specific spectra and/or acceleration time-histories;
- the evaluation of the seismic vulnerability of existing buildings, also by means of experimental tests on the materials and structures, with the identification of the most suitable techniques for the seismic retrofit of the structures;
- specialist consultancy in support to the structural design, with particular reference to the sizing and verification of the modern seismic protection systems, for both new buildings and retrofits of existing buildings;
- specialist consultancy in support to the installation of the anti-seismic devices;
- inspections during construction and final safety certification of the buildings;
- seismic monitoring of the structures,

commits the Government,

in the framework of the realization of the provisions of paragraph 229 of article 2 of the bill under examination, to evaluate the opportunity of involving ENEA and, in the affirmative, to draw up specific agreements, as to define interventions for the seismic safety of schools which are not only highly effective, but are also both the most advanced with regard to the construction technologies to be adopted and as advantageous as possible as far as costs, safety and functionality are concerned."

6 CONCLUSIONS AND REMARKS ON THE CORRECT USE OF SEISMIC ISOLATION

The overview reported in Sections 2 and 3 of this paper has stressed the large effects of earthquake experience and seismic design code features on the extent of the use of the AS systems, in particular of the SI technique, in the various countries [9-11]. With regards to the code features, it is noted that, in countries like, for instance, Japan, the USA and Chile, SI is considered as a safety measure additional to the conventional design; consequently, the use of SI obviously always introduces additional construction costs. In spite of this, this technique is being widely adopted by the Japanese, because of their high level of perception of the seismic risk and due to the fact that violent earthquakes are very frequent in Japan.

The aforesaid level of perception is much lower in other countries: this is the reason why, in order to limit or even balance the additional construction cost entailed by the use of SI (and, thus, promote a significant application of such a technique), the seismic codes of other countries (including Italy, the P.R. China, Armenia, etc.) allow for somewhat lowering the seismic forces acting on the superstructure and (consequently) foundations when SI is used.

It is worthwhile stressing, however, that, in the latter countries, a real safety will be ensured to the isolated structures <u>if and only if</u> great care is paid to [10, 11]:

- the selection of the SI devices (taking into account the amplitude of vertical and low frequency vibrations), their qualification, production quality, installation, protection, maintenance and verification that their design features remain unchanged during the entire useful life of the structure;
- some further construction details (structural gaps, their protections, interface elements – like gas and other safety-related pipes, cables, stairs and lifts –, etc.).

Otherwise, the isolators, instead of largely enhancing the seismic protection (as they do, if the aforesaid conditions are satisfied), will make the structure <u>less earthquake resistant</u> with respect to a conventionally founded one and, thus, will expose both human life and the entire SI technology to a great risk [10, 11].

Finally [6], a common key requirement for the optimal performance of all the AS systems and devices (but especially of the isolators) is the realistic and reliable definition of seismic input, which cannot rely upon the oversimplified routine probabilistic methods, mainly when dealing with displacements definition (on which the design of isolated structures is based): thus, because of the ongoing rapid extension of the use of the AS systems and devices, the need for a considerable improvement of the *Probabilistic Seismic Hazard Assessment* (PSHA) approach, which is at present that in use in several countries (including Italy), is very urgent now, by complementing it through the development and application of deterministic models [20]. This particularly applies to the P.R. China and Italy, to ensure safe reconstruction after the 2008 *Wenchuan* and 2009 *Abruzzo* earthquakes, because in the areas struck by both events a wide use of SI is in progress.

All the aforesaid items were discussed at the already mentioned 8th Commission on Environment, Territory and Public Works of the Italian Chamber of Deputies in February 2011, by also interviewing some experts (including the first author of this paper, as ENEA representative). The aim of the Commission is to agree on a resolution which shall stress again the benefits of SI, clarify the conditions for its correct use and recommend modifications of the current national and European design rules applicable to the seismically isolated buildings, based on the presently available knowledge and technological developments. This resolution should integrate those proposed by the president of the commission, who belongs to a governmental party [21], and by an expert member of an opposition party [21] (these two texts, written with the collaboration of the first author of this paper, have very similar contents and contain the same recommendations). The aforesaid recommendations (where particular attention is given to building retrofits) should be drafted by CSLLPP with the collaboration of ENEA (a specific agreement to this purpose should be soon signed between the two institutions).

REFERENCES

[1] M. Dolce, A. Martelli, G. Panza, *Proteggersi dal terremoto: le moderne tecnologie e metodologie e la nuova normativa sismica, 2nd edition, ISBN 88-87731-28-4*. 21mo Secolo, Milan, Italy, 2005.

[2] M. Dolce, A. Martelli, G. Panza, *Moderni metodi di protezione dagli effetti dei terremoti, Special edition for the Italian Civil Defence Department, A. Martelli ed., ISBN 88-87731-30-6*. 21mo Secolo, Milan, Italy, 2006.

[3] A. Martelli, U. Sannino, A. Parducci, F. Braga, *Moderni sistemi e tecnologie antisismici. Una guida per il progettista, ISBN 978-88-87731-37-8*. 21mo Secolo, Milan, Italy, 2008.

[4] U. Sannino, H. Sandi, A. Martelli, I. Vlad, *Modern systems for mitigation of seismic action – Proceedings of the symposium held at Bucharest, Romania, on October 31, 2008, ISBN 978-973-720-223-9*. AGIR Publishing House, Bucharest, Romania, 2009.

[5] A. Martelli, M. Forni, Recenti applicazioni dei sistemi di isolamento sismico in Italia. *Ingegneria Sismica*, Anno XXVII, **1**, 63-73, 2010.

[6] A. Martelli, On the need for a reliable seismic input assessment for optimized design and retrofit of seismically isolated civil and industrial structures, equipment and cultural heritage. *Pure and Applied Geophysics*, DOI 10.1007/s00024-010-0120-2, 2010.

[7] A. Martelli, Protezione degli edifici dal terremoto mediante moderne tecnologie – Parte 2. *L'Edilizia – Structural*, **162**, 60-70, 2010 (in Italian).

[8] A. Martelli, M. Forni, Recent progress of application of seismic isolation in Italy. Invited lecture, *Engineering Mechanics Institute (EMI) 2010*, Los Angeles, California,

USA, August 8-11, 2010; *Technical Program and Book of Abstracts*, USC Viterbi School of Engineering, 142, 2010.

[9] A. Martelli, M. Forni, Seismic isolation and other anti-seismic systems: recent applications in Italy and worldwide. *Seismic Isolation And Protection Systems (SIAPS),* ***1****, N. 1*, 75-123, DOI 10.2140/siaps.2010.1.75, Mathematical Sciences Publishers (MSP), Berkeley, California, USA, 2010.

[10] A. Martelli, M. Forni, Recent worldwide application of seismic isolation and energy dissipation and conditions for their correct use. Invited lecture, *Structural Engineering World Congress (SEWC)*, Cernobbio, Como, Italy, April 4-6, 2011.

[11] A. Martelli, M. Forni, Seismic isolation and other passive anti-seismic systems: worldwide application and conditions for their correct use. Invited lecture, *Minisymposium MS09 on Active, Semi-Active and Passive Vibration Control, EURODYN2011 – 8th International Conference on Structural Dynamics*, Leuven, Belgium, July 4-6, 2011.

[12] N. Kani, *Recent trends of seismically isolated structures in Japan*. Japan Society for Seismic Isolation (JSSI), Tokyo, Japan, 2011.

[13] N. Scibilia, Tecniche di riduzione del rischio sismico – Isolamento di serbatoi. *Meeting on Moderne Tecniche di Protezione Sismica*, Palermo, Italy, October 16, 2010.

[14] A. Martelli, Development and application of innovative anti-seismic systems for the seismic protection of cultural heritage. Key-note lecture, F.M. Mazzolani ed. *Protection of Historical Buildings – PROHITECH 2009, ISBN 13:978-0-415-55803-7,* **1**, 43-52, CRC Press – Taylor and Francis Group, Leiden, The Netherlands, 2009.

[15] A. Martelli, Development and application of innovative anti-seismic systems for the seismic protection of cultural heritage. Invited lecture, *Proceedings of the International Conference on the Protection of Cultural Heritage from Earthquake Damage*, Palermo, Italy, October 13-15, 2010.

[16] UNESCO-IPRED-ITU, *Declaration of participants in the UNESCO-IPRED-ITU Workshop, Istanbul, 7 July 2009*. UNESCO, Paris, France, 2009.

[17] A. Martelli, Sicurezza sismica delle scuole: possibili contributi dell’ENEA. *Il Portale dell'Ingegneria Sismica*, www.ingegneriasismica.net/Tematiche/5CS/5CStecnologieM/5CStecnologieM_martelli06/5CStecnologieM_martelli06.htm.

[18] A. Alessandri, L. Rainieri, M. Lanzarin, Ordine del giorno n. 9/2936-A/50. *Atti parlamentari, XVI Legislatura – Allegato A ai Resoconti – Seduta N. 259*, 51-53, Rome, Italy, December 16, 2009

[19] Camera dei Deputati, *Atti Parlamentari, XVI Legislatura – Allegato A ai Resoconti – Seduta del 16 Dicembre 2009 – N. 259*. VII-VIII, Rome, Italy, December 16, 2009.

[20] G. Panza *et al.*, eds., Advanced seismic hazard assessment. *Pageoph Topical Volume, ISBN 978-3-0348-0039-6 & ISBN 978-3-0348-0091-4*, 2011.

[21] A. Alessandri, G. Dussin, M. Lanzarin, R. Togni, Risoluzione in commissione n. 7/00409 in materia di isolamento sismico delle costruzioni civili e industriali. *Atti Camera dei Deputati*, Rome, Italy, October 14, 2010.

[22] G. Benamati, T. Ginoble, Risoluzione in commissione n. 7/00414 in materia di isolamento sismico delle costruzioni civili e industriali. *Atti Camera dei Deputati*, Rome, Italy, October 14, 2010.