The Journal of the Anti-Seismic Systems International Society (ASSISi)

Seismic Isolation and Protection Systems

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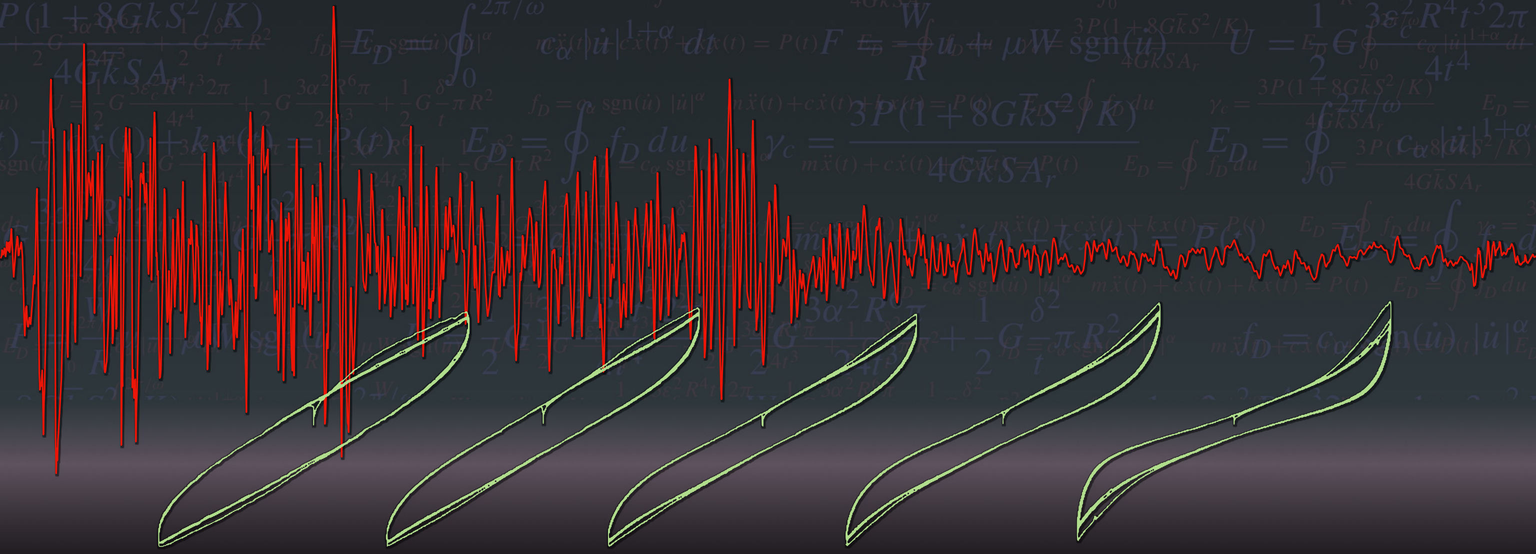

vol 1, no 1 2010

mathematical sciences publishers

mathematical sciences publishers + Anti-Seismic Systems International Society
SEISMIC ISOLATION AND PROTECTION SYSTEMS 1:1 (2010)

SEISMIC ISOLATION AND OTHER ANTISEISMIC SYSTEMS RECENT APPLICATIONS IN ITALY AND WORLDWIDE

ALESSANDRO MARTELLI AND MASSIMO FORNI

Over 10,000 structures have been protected in the world by antiseismic systems and devices, namely by seismic isolation and energy dissipation systems, shape memory alloy devices and shock transmitter units. Such structures are located mostly in Japan, but they are more or less numerous in over 30 other countries as well — for example, in the Peoples' Republic of China, the Russian Federation, the United States, Italy and even countries with very a limited population like Armenia and New Zealand. The number of such systems and devices is increasing everywhere, although the extent of their use is strongly influenced by earthquake experience and the features of the design rules used. Applications have been developed for both new and existing structures of all kinds: bridges and viaducts, civil and industrial buildings, cultural heritage and industrial components and installations, including some high risk plants. The use of such systems in a civil context already includes not only strategic structures (civil defense centers, hospitals, etc.) and public ones (schools, churches, commercial centers, hotels, airports, etc.), but also residential buildings and even many small private houses. This paper provides an overview on the dissemination of such applications worldwide, based on the most recent information available to the authors. Particular attention is paid to Italy, in the context of specific seismic events — for example, the Molise and Puglia event (October 31, 2002) and that of Abruzzo (April 6, 2009) — and the lessons learned from them. Information is also provided on the features of the Abruzzo event, the development of national seismic design rules (which became obligatory only after that event) and some very recent decisions on the part of the Italian government which promote the use of seismic isolation and energy dissipation to enhance the safety level of structures, especially schools. The paper focuses mainly on seismically isolated buildings, but some information is also provided on the use of other antiseismic systems, devices, and applications to structures other than buildings.

Keywords: passive control, seismic isolation, energy dissipation, SMADs, STUs, new constructions, retrofit, schools, hospitals, dwellings, residential buildings, cultural heritage, industrial installations and components, high risk plants.

1. Introduction

Since the end of the 1980s, great efforts have been devoted by ENEA[1], the Italian GLIS Association[2], the EU/WEC Territorial section of *ASSISi*[3] and EAEE-TG5[4] to the development and application of seismic vibration passive control (SVPC) systems and devices, namely to seismic isolation (SI) and energy dissipation (ED) systems, shape memory alloy devices (SMADS) and shock transmitter units (STUs). This activity was performed in the context of extensive collaborations with the Italian Civil Defense Department (*Dipartimento della Protezione Civile* or DPC) and further national, regional and local institutions [Dolce et al. 2006; Martelli et al. 2008; 2009a; 2009b; 2010a, Sannino et al. 2009; Martelli and Forni 2009a]. Such collaborations also include support to the DPC for emergency and post-emergency management, as well as rebuilding, in the case of earthquakes. In particular, this support was provided after the 2002 Molise and Puglia earthquake and has been ensured in Abruzzo since the event of April 6, 2009.

Recent information on the development and implementation of the SVPC systems and devices was provided in some successful conferences that were organized or coorganized by GLIS, ENEA, *ASSISi*, its EU/WEC Territorial Section and EAEE-TG5. The proceedings of such conferences were published by [Erdik et al. 2007; 2008; Martelli et al. 2008; Santini and Moraci 2008; Sannino et al. 2009; Phocas et al. 2009; Mazzolani 2009; JSSI 2009; Zhou et al. 2009]. Numerous GLIS members and ENEA researchers actively participated in special sessions dealing with the previously cited topics in these conferences and other important recent events that were more generally devoted to seismic engineering and seismology [Martelli 2008a; 2008b; 2009a; 2009b; 2009c; 2009d; 2009e; 2009f; Martelli and Forni 2008a; 2008b; 2009a; 2009b]; part of these sessions were organized by the first author of this paper [Martelli et al. 2008; Santini and Moraci 2008; Katayama et al. 2008; Sannino et al. 2009; Phocas et al. 2009; Mazzolani 2009].

As witnessed by the proceedings of all these conferences, at present there are over 10,000 structures in the world that are protected by SVPC systems and devices. These structures are located mostly in Japan, but they are more or less numerous in about 30 other countries as well (see Figure 1, left), including China, Russia, the United States and Italy, which follow Japan for the number of applications (however, as pointed out in [JSSI 2009], should the number be normalized to that of the residents in each country, Armenia and New Zealand would be those immediately following Japan). Everywhere, the number of such structures is on the rise, although the extent of the use of the SVPC systems and devices is strongly influenced by earthquake experience and the features of the design rules used. Applications address both new and existing structures of all types: bridges and viaducts, civil and industrial buildings, cultural heritage (monumental buildings, museums, ceilings of archaeological excavations, museum display

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[1] ENEA changed its full name from *Ente per le nuove Tecnologie, l'Energia e l'Ambiente* (Italian Agency for New Technologies, Energy and the Environment) to *Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile* (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) in September 2009.

[2] The full name of GLIS is *GLIS – Isolamento ed altre Strategie di Progettazione Antisismica* (namely GLIS — Isolation and Other Anti-Seismic Design Strategies).

[3] The EU/WEC Territorial Section of *ASSISi* is the Territorial Section for the European Union and Other Western European Countries of the *A*nti-*S*eismic *S*ystems *I*nternational *S*oc*i*ety. GLIS has been a corporate member of *ASSISi* since the foundation of the latter in 2002.

[4] EAEE-TG5 is Task Group 5 on Seismic Isolation of Structures of the European Association for Earthquake Engineering.

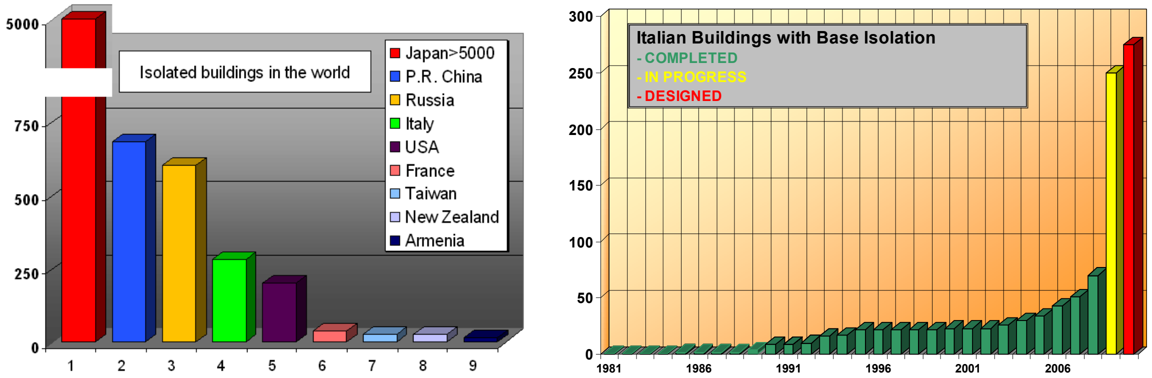

Figure 1. Left: overall number of building applications of SI in the most active countries. Right: overall number of building applications of SI in Italy over the years.

cases and unique masterpieces) and industrial components and installations. The latter include some high risk plants like nuclear reactors, other nuclear facilities and liquefied natural gas (LNG) storage tanks. Applications to civil construction encompass not only strategic ones, such as civil defense centers, hospitals, airports, bridges and viaducts, and public ones such as schools, churches, commercial centers, and hotels, but also many residential buildings and even some private houses.

This paper includes parts of [Martelli and Forni 2009c] and [Martelli 2010a]; more precisely, it summarizes the recent progress in the use of the SVPC systems and devices, mainly based on the information made available at the International Workshop Celebrating the 15 Years Anniversary of JSSI (Tokyo, Japan, September 2009; see [JSSI 2009]) and at the 11th World Conference on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures (Guangzhou, China, November 2009; see [Zhou et al. 2009]). Particular attention is devoted to applications in Italy (see Figure 1, right), other countries where the use of the SVPC systems is less known and, in general, to isolated buildings, but information is also provided on the use of other SVPC systems in the context of structures other than buildings. With regard to Italy, some remarks are also reported on the seismic risk in this country, on the 6.3 magnitude earthquake that struck the Abruzzo region (in particular, the town of L'Aquila and several surrounding villages) on April 6, 2009, and on the lessons learned from seismic events. Information is also provided on the features of the new national seismic code and some very recent decisions of the Italian government promoting the use of such systems and devices, to increase the seismic safety of schools and other structures. More details on the adoption of the antiseismic systems and devices in Italy and worldwide may be found in [Dolce et al. 2005; 2006; Martelli et al. 2008; Sannino et al. 2009], in a recent DVD [Zhou et al. 2009], as well as (for Italy) in the article [Martelli and Forni 2010].

2. Japan

Japan, thanks to the availability of an adequate specific code since 2000 and the free adoption of SI since 2001, is more and more consolidating its worldwide leadership on the use of the SVPC systems and devices, with over 5,000 buildings or houses protected by SI (Figure 1) and about 3,000 more provided with ED systems [Zhou et al. 2009]. This country, where the first application of base SI dates back to

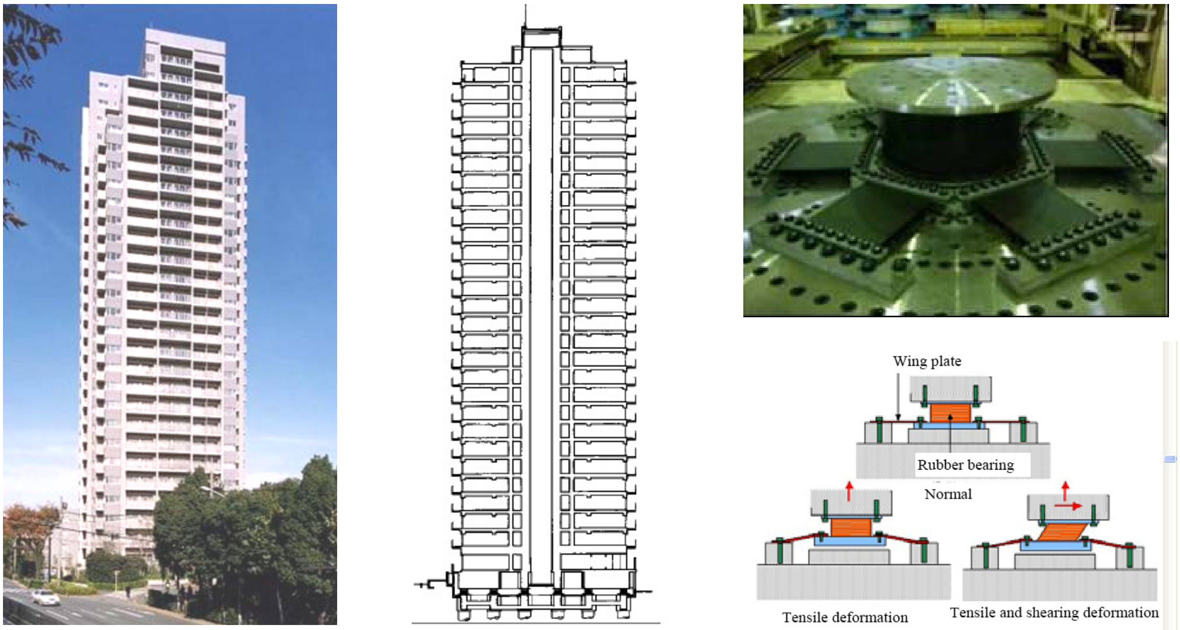

Figure 2. Left and middle: The first Japanese application of SI to high-rises is a 87.4 m high building that was seismically isolated in Tokyo in 2000 by means of 30 low-damping rubber bearings (LDRBs) and 99 elastic-plastic dampers (EPDs), with a period $T = 4\,\mathrm{s}$. Right: sketch of its LDRBs, provided with an anti-uplift system.

1985, is continuing the extensive adoption of the SVPC systems initiated after the excellent behavior of two isolated buildings near Kobe during the 1995 Hyogo–ken Nanbu earthquake (this behavior was later confirmed for all Japanese buildings protected by SI systems that were struck by subsequent events; see, for instance, [Martelli 2009c].

The Japanese have confirmed the trend, initiated some years ago, of isolating even high-rise buildings (Figure 2) and sets of buildings (Figure 3) supported by a common isolated reinforced concrete (r.c.) structure, called an *artificial ground*, a solution that allows large savings in construction costs (see also Figure 4). Moreover, an ever-increasing number of even very small private houses have been protected by SI (Figures 4 and 5). The isolated high-rise buildings are over 120 and include many condominiums, while the isolated houses are already about 3,000.

About 1,000 Japanese buildings and 2,000 private houses have also been protected by various kinds of dampers: for instance, the applications of the buckling-restrained braces (BRBs) were already over 250 in 2003. The ED systems too behaved very well during various earthquakes. Moreover, approximately 40 Japanese buildings were seismically controlled by tuned mass dampers (TMDs), of active or hybrid types, in June 2007, and so-called *active damping bridges* (ADBs) were installed between pairs of adjacent high-rise buildings to reduce the seismic response of both (Figure 7).

The use of the SVPC systems and devices also recently increased in Japan for the protection of cultural heritage (Figures 8 and 9) and for that of bridges and viaducts. For the latter it began rather later than for buildings; it is being largely based on the use of high damping rubber bearings (HDRBs) and lead rubber

Figure 3. Left: Applause Building in Osaka, with a hybrid control system moving an heliport structure at the top. Right: sketch of the complex of 21 six- to fourteen-storey buildings erected on a unique “artificial ground” isolated at Sagamihara (Tokyo area) with 48 lead rubber bearings (LRBs), 103 sliding devices (SDs) and 83 ball bearings.

Figure 4. Lateral view of the isolated building complex of Figure 3 and the large garage located below the artificial ground plate, with the isolators protected from fire (the SI system lowers the period of the 111,600 t superstructure to $T = 6.7$ s, with a design displacement of 800 mm).

Figure 5. Japanese private houses protected by 2 SDs and 4 HDRBs.

Figure 6. A Japanese private house protected by an SI system formed by steel sphere recirculation isolators, viscous dampers (VDs) and recentering devices.

Figure 7. Left: "green mass damper", used as the TMD of a 45 m tall building of the Keyaki-zaka residential complex, in Tokyo. The garden base is 1 m thick, weights 3,650 t, or 8% of the building mass, and is supported by 46 rubber bearings (RBs) and 22 visco-elastic dampers (VEDs). Right: ADB between Japanese high-rise buildings.

Figure 8. Retrofits with SI in a subfoundation of the National Western Art Museum, designed by Le Corbusier (above), and of the “Gates of Hell” in Tokyo (right column), performed in 1999.

bearings (LRBs) and considerably extended especially after the 1995 Hygo–ken Nanbu earthquake (by becoming obligatory for overpasses in Kobe).

Finally, as to the industrial plants, besides detailed studies for the SI (even with three-dimensional systems) of various kinds of nuclear reactors, the construction of the Nuclear Fuel Related Facility, supported by 32 low damping rubber bearings (LDRBs) and LRBs, was completed (Figure 9). Application

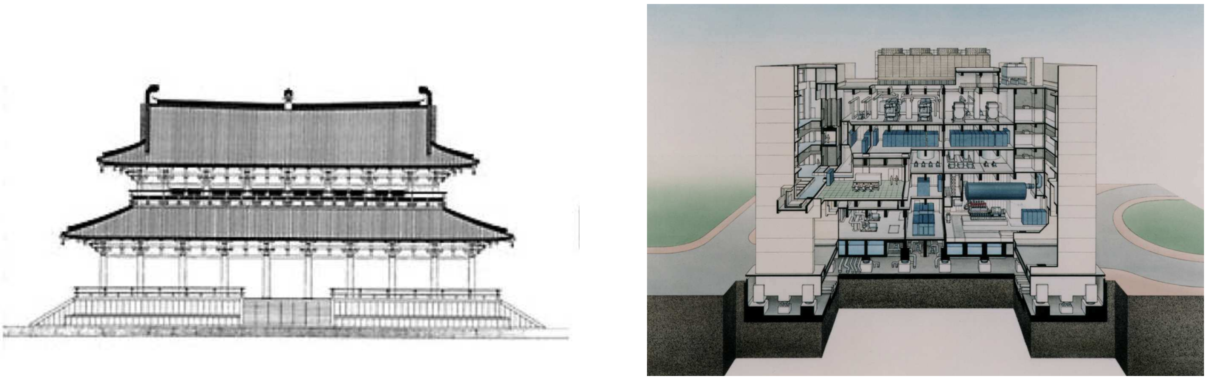

Figure 9. Left: example of retrofit of cultural heritage in Japan, begun for the Daigokuden at Nara in 2001. Right: the Nuclear Fuel Related Facility, the first nuclear structure to be isolated in Japan.

Figure 10. First seismically isolated Japanese factory for the production of semiconductors (height = 24.23 m, total area $\approx$ 27,000 m^2).

of SI to large industrial factories also began in 2006; the first was a semiconductor plant, built on LRBs and VDs (Figure 10). At least two other similar factories are also already in use.

3. People's Republic of China

In China very ancient monasteries, temples and bridges, protected by means of rough sliding SI systems, are still standing, which withstood numerous earthquakes, including very violent events, up to 8.2 magnitude [Dolce et al. 2005; 2006]; however, the application of modern SI systems began only in 1991. In any case, initially the SI systems, then the ED ones too have rapidly got a footing since that year, so that the isolated buildings were already 490 in June 2005, by leading China to the third place at worldwide level for the number of applications, only slightly after the Russian Federation. Many of these applications were to residential buildings and no less than 270 to the masonry ones [Dolce et al. 2006].

At the end of 2006 the number of the Chinese isolated buildings had increased to more than 550 and included even rather tall constructions (Figure 11); furthermore, SI had already been applied to 5 further

Figure 11. The tallest seismically isolated Chinese building (19 storeys), erected at Taiyuan City, in Northern China (left), and a Chinese high-rise building protected by VDs (center and right).

large span structures and 20 road and railway bridges or viaducts, 30 buildings were already protected by ED devices (Figure 11) and 5 buildings and 6 bridges by hybrid or semiactive seismic vibration control systems. SI had also already been used, for the first time in China, to protect LNG tanks [Erdik et al. 2008].

In 2007 China passed Russia [Erdik et al. 2008]: in fact, Chinese isolated buildings reached 610 in May 2007 (against the approximately 600 in Russia; see Section 4) and those protected by ED systems reached 45. The former included the Isolation House Building on Subway Hub, completed near the center of Beijing in 2006; it consists of 50 seven- to nine-storey buildings, all separately isolated above a single huge two-storey isolated structure containing all services and infrastructures, including railways and subways. The objective of this application had been to optimize the use of a wide and valuable central area, which was previously occupied only by railway junctions and the subway, by also minimizing the consequent vibrations and noise: SI enabled a 25% savings in construction costs, making it possible, within the same budget, to increase the height of the 50 buildings by an average of three storeys.

In the same period, the Chinese started applying three-dimensional SI systems to civil buildings (Figure 12) and isolators or SMADs to cultural heritage (Figure 13). In October 2008, isolated Chinese buildings numbered about 650.

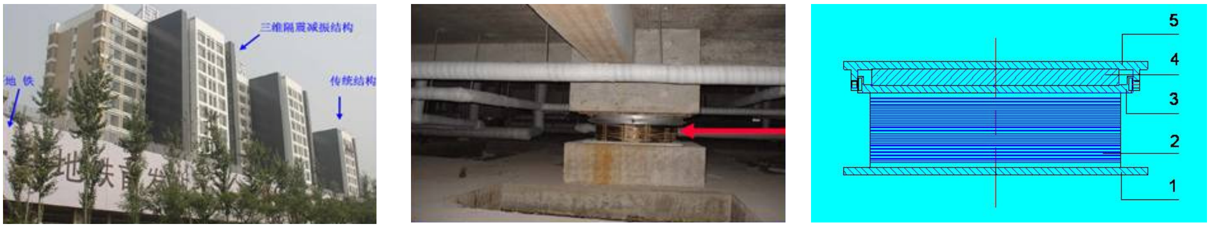

Figure 12. Left: new Chinese buildings protected at Guangzhou by 3D RBs from both horizontal seismic vibrations and vertical traffic vibrations. Center: one of the 3D RBs. Right: its sketch (4 = vertical element). Similar applications exist in Beijing.

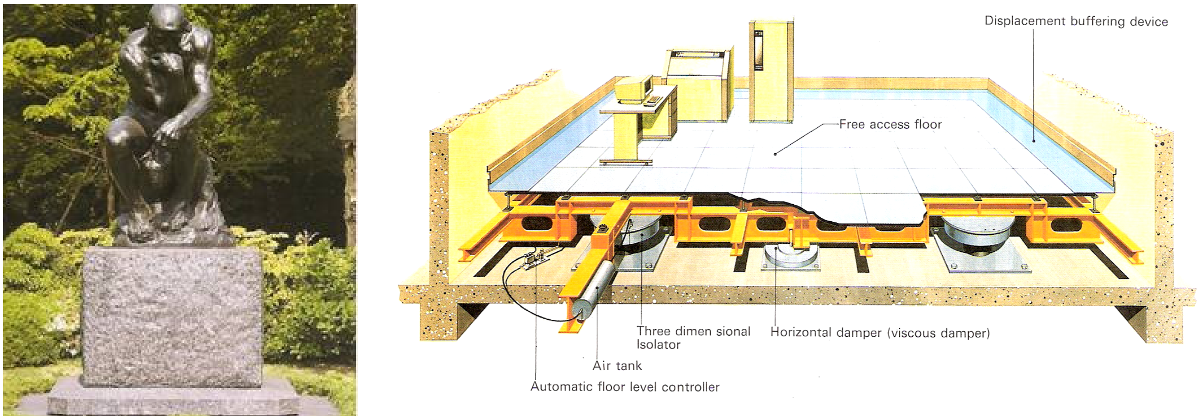

Figure 13. Left: example of an SI-protected of Chinese masterpiece. Right: SI table for the protection of vulnerable equipment or art objects.

In November 2009, a further significant extension of the applications of the SVPC systems in China was reported: the number of isolated buildings erected each year doubled there after the Wenchuan earthquake of May 12, 2008, increasing from 50 to 100 per year [Zhou et al. 2009]. This rapid increase in the number of building applications of SI was due, one the one hand, to the excellent behavior of two r.c. isolated buildings (Figure 14) and a six-storey masonry one during that earthquake — although its violence had been greatly underestimated, by a factor of 10 for the peak ground acceleration! — and, on the other, the fact that the Chinese code (which still requires the submission of the projects the isolated buildings to the approval of a special commission) permits to reduce the seismic loads acting on the superstructure and foundations of such buildings.

Figure 14. Top left: heavy damage was inflicted on this conventionally founded r.c. building by the 2008 Wenchuan earthquake; the building had been designed to withstand events of intensity $I_{\mathrm{MMS}} = 7$. Top right and bottom: this isolated building remained free of structural and nonstructural external and internal damage after the same earthquake.

To date, SI systems have been installed in China in 32 bridges and 690 buildings, while 83 buildings have been protected by ED devices such as EPDs, VDs or VEDs, 16 by TMDs or other type dampers and 5 by semiactive or hybrid systems. The latter have also been installed in 8 bridges. SI is applied not only at the building base or at the top of the lowest floor, but also on more elevated floors (for risings or for erecting highly vertically asymmetric constructions), or at the building top (to sustain, in the case of retrofit, one or more new floors acting as a TMD), or also on structures that join adjacent buildings having different vibrational behaviors.

New applications include sets of buildings on artificial ground (Figure 15), base and roof SI of stadiums (Figure 16) and the protection of valuable objects, such as electronic equipment and artwork, by means of SI tables (Figure 13).

Figure 15. Set of buildings of the Headquarters of China Earthquake Administration during their construction in Beijing on a seismically isolated “artificial ground” slab in 2008 (first Chinese application of this kind).

Figure 16. Left: Chinese stadium (23,000 m^2) protected by RBs and VDs, for which SI reduced the seismic response by a factor of 4.2. Right: and roof SI of the News Centre and Restaurant of Shanghai F1 Autodrome.

4. Russian Federation

The Russian Federation is now third in the number of isolated buildings, with over 600 applications [Zhou et al. 2009]. The use of modern SI systems, formed by rubber bearings (RBs), frequently in conjunction with steel-PTFE Sliding Devices (SDs) and/or dampers (similar to those adopted in the other countries), is going on replacing that of the previous so-called low cost isolators (reversed mushroom-shaped r.c. elements), which had been installed since the 1970s. After the retrofits of some important historical buildings [Dolce et al. 2005; 2006; Sannino et al. 2009], new Russian applications include even high-rise buildings, in particular in Sochi, where the 2014 Olympic games will take place (Figure 17). For some of these, Italian HDRBs have been used.

Figure 17. Top: new Sea Plaza Hotel at Sochi (27 storeys, in addition to 2 underground ones; height ≈ 93 m; total living area = 40,000 m^2), protected by 102 HDRBs. Bottom: new r.c. commercial center, with cinema, underground parking and offices, again at Sochi (21 storeys, in addition to the ground and 2 underground floors; height ≈ 100 m; total living area = 50,000 m^2), protected by 200 LRBs.

5. United States

The United States rank second, after Japan, in the overall number of applications of the SVPC systems and devices [JSSI 2009]. In this country, however, such applications are progressing satisfactorily only for bridges and viaducts and for buildings protected by ED systems. They include both new constructions and retrofits. More precisely, HDRBs, LRBs and, more recently ED devices and STUs have been installed in about 1,000 US bridges and viaducts, in several states (Figure 18), while dampers of various types protect over 1,000 buildings: VDs and friction dampers (FDs) protected approximately 40 and, respectively, 12 buildings in 2001 and BRBs 39 further buildings in 2003 [Dolce et al. 2005; 2006].

By contrast, the number of new applications of SI to buildings remains limited (recently 3 or 4 per year), in spite of the excellent behavior of some important US isolated buildings during the 1994 Northridge earthquake [Dolce et al. 2005; 2006] and the long experience of application of this technique to such structures (since 1985). This is a consequence of very penalizing design codes for isolated buildings. According to recent information, US seismically isolated buildings number between 100 and 200, though they are generally important ones, including monumental buildings (Figures 20–23). About half of them are retrofits.

Figure 18. Left: Carquinez Bridge, California, retrofitted by means of Italian STUs. Right: Marquam Bridge, Oregon, retrofitted by means of Italian RBs and EPDs.

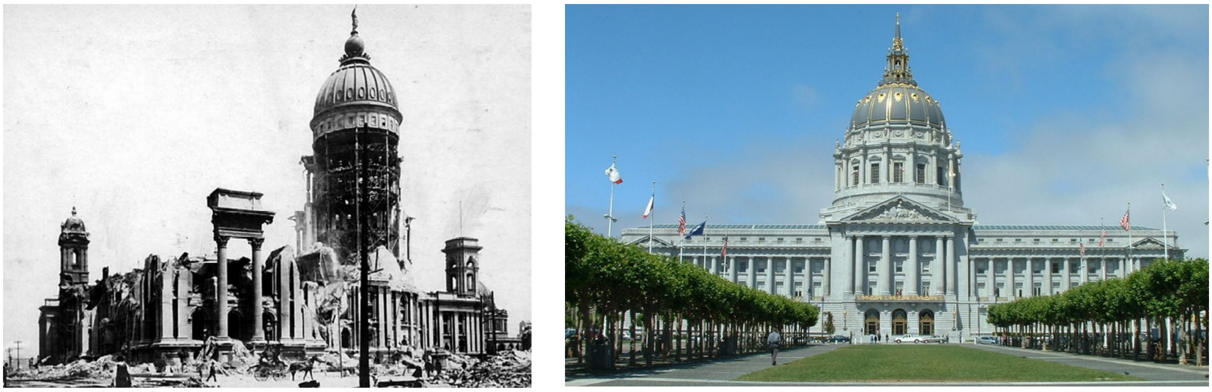

Figure 19. San Francisco City Hall, destroyed by the 1906 earthquake (left), rebuilt in 1912, damaged by the 1989 Loma Prieta earthquake and retrofitted in 2000 using 530 LRBs and 62 SDs (retrofit cost = 105 MUS$, with savings of 11 MUS$ thanks to SI).

Figure 20. Left: construction of the 911 Emergency Communications Center in San Francisco, designed to withstand earthquakes to magnitude $M = 8.3$. Right: view of one of its RBs and the fail-safe system (late 1990s).

Figure 21. Asian Art Museum in San Francisco, during its seismic retrofit (with cut of the foundations and insertion of HDRBs) performed according to the design of the Italian architect Gae Aulenti (late 1990s).

Figure 22. Retrofit with HDRBs of the Berkeley Civic Centre (California).

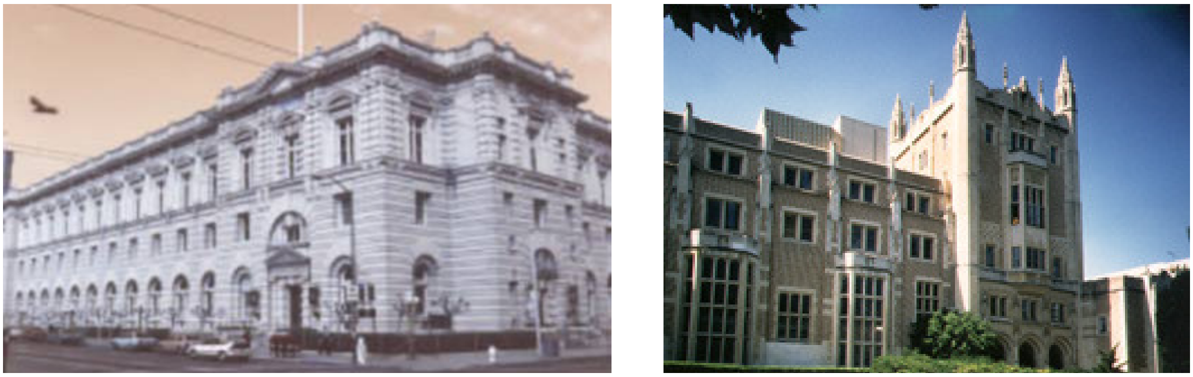

Figure 23. Further US building retrofits with SI. Left: San Francisco Court of Appeal, retrofitted with FPS. Right: Kerckhoff Hall at the University of California, Los Angeles (total living area = 8,300 m^2, 6 storeys).

Buildings in the US have been isolated using HDRBs, LRBs (in some cases in conjunction with LDRBs, SDs, VDs and other ED devices) and, more recently, the friction pendulum system (FPS), too. With regard to the design earthquake levels adopted in California, it is noted that they correspond to very large magnitudes M (for example, $M = 8.3$ for the new 911 Emergency Communications Center in San Francisco in the 1990s — see Figure 20 — and $M = 8.0$ for the retrofit of the San Francisco City Hall with 530 LRBs and 62 SDs in 2000 (see Figure 19). This imposes the use of SI as the only possibility for these applications, in spite of its high cost in the US.

6. Italy

Seismic risk in Italy. Despite a significantly lower seismic hazard than, say, Japan, China, or California, Italy is characterized by the highest seismic risk in the European Union and by one of the highest in the industrialized countries; see [Dolce et al. 2005; 2006; Martelli 2009b; 2010a] and Table 1. In fact, the vulnerability of Italian constructions is such that more than half of them (including 75,000 strategic and public buildings) are incapable of bearing the seismic actions to which they may be subjected.

This situation is due to several factors. Italy is home to a good fraction of the world's cultural heritage. There has been, in the last few decades, significant progress in seismology and seismic engineering, and consequently also changes in seismic codes and in the seismic classification of the country's regions.

Event of magnitude M = 7.0		
	dead	wounded
Southern Apennines	5,000–11,000	$\geqslant$ 15,000
World (average)	6,500	20,500
Japan	50	250

Event of magnitude M = 7.5		
	dead	wounded
Calabria	15,000–32,000	$\geqslant$ 37,000
World (average)	18,500	75,000
Japan	400	2,000

Table 1. Number of victims expected in high seismic hazard areas of Italy, as well as (for an equal population) in Japan and (on average) worldwide [Dolce et al. 2005; 2006].

Italian region or area	Year	Violence
Abruzzo (L'Aquila area)	1639	severe
Abruzzo (L'Aquila area)	1703	severe
Messina and Reggio Calabria	1908	very severe
Abruzzo (Avezzano)	1915	very severe
Friuli (2 main shocks, within 6 months)	1976	severe
Irpinia (Campano–Lucano earthquake)	1980	severe
Marche and Umbria (2 main shocks in the first day)	1997–98	moderate/severe
Molise and Puglia (2 main shocks, in the first and second day)	2002	moderate
Abruzzo (L'Aquila area)	2009	severe

Table 2. Violence of earthquakes in Abruzzo and of the most recent Italian events.

Equally importantly, traditionally there has been a certain lack of awareness, at both the institutional and individual levels, that severe earthquakes occur in Italy too, though less frequently than in other countries. Paradoxically, Italy's problem has been that severe earthquakes are not sufficiently frequent in this country and that, in any case, their return periods are much longer than the duration of its governments (see Table 2). In the past, the consequence was that, when a severe earthquake occurred, the government in office at that time strictly limited its action to emergency management, without investing any resources in prevention, and that seismic risk was soon forgotten even in the struck areas. It has been estimated that the overall cost of this lack of prevention policies has already been almost three times larger than the overall amount of money which would have been necessary to adequately seismically upgrade all the existing Italian constructions (apart from the thousands of avoidable victims).

Lessons learned from the San Giuliano di Puglia tragedy in 2002. With regard to the evolution of knowledge on the seismic hazard in Italy [Dolce et al. 2005; 2006; Erdik et al. 2007; 2008; Martelli et al. 2007; 2008; Sannino et al. 2009], it is noted that 70% of the Italian territory is now defined as seismic, while this percentage was estimated to be only 45% prior to 1998 and 25% prior to 1980 (seismic classification began in Italy after the 1908 Messina and Reggio Calabria earthquake, but, down to the middle of the 1970s, Italian areas were classified as seismic only after having been struck by an earthquake). In addition, although the present seismic hazard map was already known and had already been proposed by the Italian seismologists in 1998, it became official only in 2003, after the collapse of Francesco Jovine Primary School at San Giuliano di Puglia during the 2002 Molise and Puglia earthquake (Figure 24). This collapse killed 27 children, including all the youngest (those born in 1996), and it has been officially recognized that the earthquake itself was not to blame: the deaths were mainly caused by poor construction, worsened by the shoddy addition of another storey.

This seismic reclassification was enforced by an ordinance of the Italian Prime Minister (*Ordinanza del Presidente del Consiglio dei Ministri*), published in May 2003 (OPCM 3274/2003), just because of the inertia shown by the normally responsible national and local institutions (Ministry of Constructions and regional governments). Thanks to this ordinance a new seismic code was also enforced (although not yet obligatorily), which was fully different from the previous (very old and inadequate) one: while the latter was prescriptive, the new one was based on performance, consistently with Eurocodes.

Figure 24. Collapse of the Francesco Jovine primary school in San Giuliano di Puglia (Campobasso) during the 2002 Molise and Puglia earthquake, and search for survivors amid the debris.

In addition, the new Italian seismic code freed and even simplified the use of SI, ED and other modern SVPC systems and devices. In fact, it canceled the previously existing need for submitting the designs of structures protected by such systems and devices to the approval of the High Council of Public Works of the Ministry of Constructions and allowed to partly take into account the decrease of the seismic forces acting on the superstructure caused by SI, when designing the superstructure itself and the foundations. With regard to the need for submitting the aforesaid designs to the approval of the High Council of Public Works, it is worth stressing that, due to the very complicated, time-consuming and uncertain approval process, such a need, instead of correctly being a check of the adequacy of the new technologies, had hindered their development and extensive application, although they aim at saving human life and minimizing damage. Finally, OPCM 3274/2003 prescribed that the seismic safety of all strategic and public structures should have been checked by the responsible national or regional institutions within five years.

The enforcement of OPCM 3274/2003 (which was later improved by two subsequent OPCMs, then by decrees of the Ministry of Constructions in 2005 and 2008 and, finally by the new Technical Norms for Constructions) can be considered as the birth of a real prevention policy in Italy. In particular, thanks to this ordinance, the use of the SVPC systems and devices soon significantly increased in Italy (Figure 1, right), especially for the protection of schools (as a consequence of the San Giuliano di Puglia tragedy): SI of the new Francesco Jovine at San Giuliano di Puglia, which was opened to activity in September 2008, was followed by that of further 16 schools (4 of these were completed in 2009, see below).

Lessons not yet learned prior to the Abruzzo earthquake of April 6, 2009. The change of attitude towards the prevention of seismic risk caused by the San Giuliano di Puglia tragedy was, however, only partial. The consolidated general convincement that earthquakes are not a major problem in Italy was not fully canceled. For instance, only half of the new Italian hospitals designed after OPCM 3274/2003 included SI, although this kind of protection is now indispensable to ensure their full integrity and operability after an earthquake. In addition, since the use of the new code was not obligatory, many (not only designers, but, unfortunately, also some institutions owning public buildings) accelerated the completion of the designs of even strategic and public buildings and/or of the related approval processes just to make sure that they were allowed to use the old, less stringent, code, which implied lower construction costs.

Moreover, the prescribed verifications of seismic safety of the existing strategic and public constructions went much slower than planned; even now it is far from being completed and no interventions have been undertaken, yet, in several cases, even when the problems detected are not limited to the seismic safety, but also concern the static one. Such unexpected, very worrying, situations were numerous, especially in Southern Italy, even for r.c. buildings (see, for instance, Figure 39). Finally, the obligatory use of the new seismic code was deferred year by year, thus also causing a lot of confusion: even in February 2009 it had been postponed from the end of June 2009 to that of June 2010 and only thanks to the polemics following the Abruzzo earthquake this further extension was canceled during Summer 2009 (also thanks to a resolution of the Commission on Environment, Territory and Public Works of the Italian Chamber of Deputies drafted with the collaboration of the first author of this paper).

Remarks on the Abruzzo earthquake of April 6, 2009. The earthquake which struck the L'Aquila town and 48 further municipalities in Abruzzo on April 6, 2009 (Figure 25), had a magnitude $M_w = 6.3$ and an epicentral depth of 9 km. It occurred at 3:33 local time at about 5 km south east from L'Aquila (seismic zone 1, according to the 2003 seismic reclassification of the Italian territory). It caused 298 dead, 1,600 wounded and 36,000 homeless people. Costs of 8.5 billion Euro have been estimated as necessary for the reconstruction. Here are the values of peak ground acceleration (PGA) predicted in this area for various return periods T_R, according to the Italian seismic classification, which is based on probabilistic seismic hazard assessment (PSHA):

T_R :	475 yr	975 yr	2475 yr
PGA :	0.261 g	0.334 g	0.452 g

Thanks to seismic monitoring systems which had been installed in the area, a large amount of data was made available by this event: in fact, there were 55 recordings of DPC and 114 of the Italian Institute for Geophysics and Volcanology (*Istituto Nazionale di Geofisica e Vulcanologia* or INGV), at epicentral

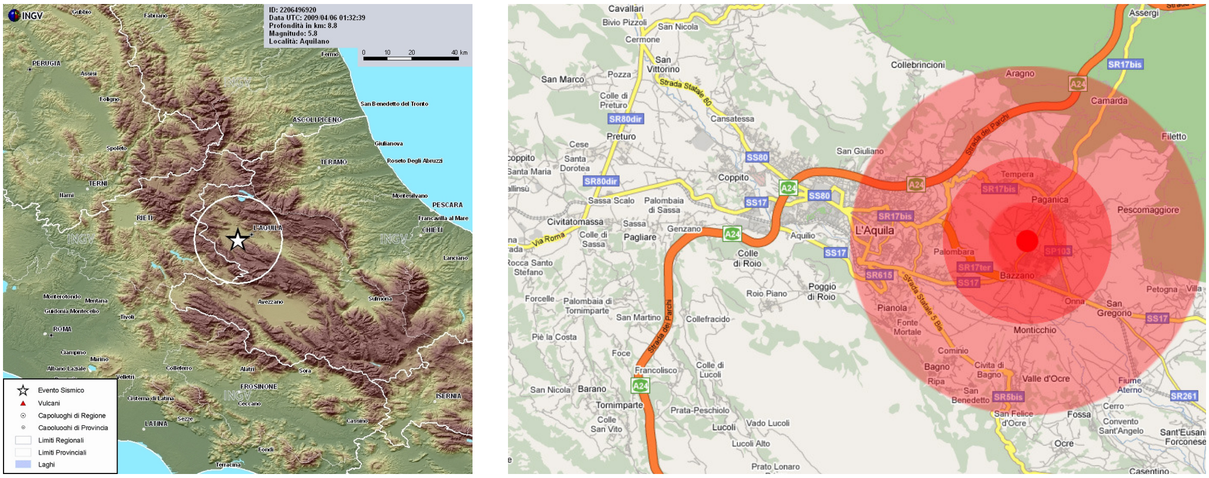

Figure 25. Epicenter of the Abruzzo earthquake of April 6, 2009, and area struck by this earthquake.

distances varying from 4.3 km to 280 km. These recordings form the largest amount of seismological data ever obtained in Italy. The following results of these measurements will be mentioned:

- a PGA value larger than 1 g was measured in one station;
- a residual maximum vertical displacement of 15 cm was detected close to the fault (zero distance);
- amplification of the seismic motion at 0.6 Hz was also detected in the epicentral zone (namely at zero distance from the fault and less than 10 km from the epicenter);
- the attenuation laws which are available in the literature underestimated the PGA values at small epicentral distances and overestimate those at large distances;
- the measurements in the epicentral zone were strongly influenced by source effects;
- the recordings of the main shock showed a clear directivity effect towards south-east;
- most recordings in the epicentral zone showed PGA $> 0.3\,g$ and in one spot (del Moro station, close to Pettino) even $> 1\,g$;
- the response spectra ordinates were particularly large especially in the range 2–10 Hz (0.1–0.5 s), which contains the natural frequencies of most buildings of the region;
- the duration of the most energetic part of the acceleration records was only 2–5 s (in one station almost 60% of the energy was released in the first 3 s); this led to a strong impulse at high frequency, even for the vertical earthquake component, which struck buildings with a moderate number of cycles but of large amplitude;
- very large local amplifications were measured, which stresses the presence of rather poor soils.

Thus, most structures that were not ductile nor built according to reasonable engineering requirements, the nonreinforced masonry buildings (including cultural heritage monuments) and a significant part of the other buildings which were characterized by limited ductility and insufficient seismic resistance (due to poor designs or construction problems) were unable to withstand the earthquake (Figures 26–30).

Figure 26. L'Aquila (April 2009): aerial views of some parts of the town where buildings collapsed or were heavily damaged.

Figure 27. L'Aquila (April 2009): collapse of the Prefettura building (provincial headquarters of the national government) and the Santa Maria Paganica Church (right).

Figure 28. The Cathedral of Santa Maria di Collemaggio, a rare example of Abruzzo Romanesque style, prior to the earthquake, and the collapse of the roof of its baroque (not yet retrofitted) part. The façade, which had been protected by some EPDs installed on the roof some years earlier (see Figure 45), survived the earthquake; however, a steel scaffold, previously erected for an already planned retrofit, certainly helped.

Figure 29. L'Aquila (April 2009): pillars in the San Salvatore Hospital, heavily damaged due to very inadequate steel reinforcement and poor concrete quality (no inert materials are visible in the upper part of the pillar).

Figure 30. L'Aquila (April 2009): partly collapsed and heavily damaged private buildings. Note in particular the heavily damaged beam-column joints (top row).

Bridges were also damaged. At the L'Aquila Museum and elsewhere, a number of artistic masterpieces were destroyed or heavily damaged (Figure 31).

As far as cultural heritage is concerned, over 1,000 ancient monumental buildings were heavily damaged or collapsed in part, largely due to earlier incorrect or incomplete retrofits (see Figure 27, right, and

Figure 31. L'Aquila (April 2009): collapse of statues at the Museum.

Figure 32. L'Aquila (April 2009): headquarters of ANAS (the Italian agency for road construction and maintenance), which suffered mainly nonstructural damage (with the exception of two pillars, which, however, are reparable — see right. Retrofit by means of SI was possible and was suggested for this building.

Figure 28). The collapse of numerous r.c. buildings, such as the Student House, or the heavy damage they incurred (including some further public or strategic buildings) was due to very inadequate reinforcement and poor concrete quality (see Figure 27, left, and Figures 29 and 30). The importance of maintenance was evident: similar equally old buildings suffered only limited or even zero damage if they had been adequately maintained, while they were heavily damaged when maintenance had been neglected.

Luckily, several buildings suffered mainly nonstructural damage and/or minor structural one: many of them may be retrofitted by means of SI (see, for instance, Figure 32) or ED systems. To this end, the experience achieved through the retrofit of a three-storey house at Fabriano (Ancona) after the 1997–98 Marche and Umbria earthquake will be very useful: this house (Figure 33) had suffered severe nonstructural damage in the earthquake and was retrofitted by subfoundation and insertion of HDRBs in the new

Figure 33. Three-storey r.c. private house in Fabriano (Ancona), in seismic zone 2, damaged by the 1997–98 Marche and Umbria earthquake. It is the first EU application of SI in a subfoundation, the retrofit of which was completed with 56 HDRBs of three sizes in 2006, with safety certification by A. Martelli.

underground floor. For the reasons mentioned in [Dolce et al. 2005; 2006], the cost of this retrofit allowed for saving 20% of construction costs with respect to a conventional reinforcement. Obviously, SI will also be used to rebuild collapsed buildings or those being so damaged that they must be demolished.

Lessons learned from the Abruzzo earthquake of April 6, 2009. Obviously, the not yet obligatory use of the new seismic code was not to blame for the damage and collapses occurred during the 2009 Abruzzo earthquake. However, the latter were caused by the same reasons for which some builders (thanks to the support of a senator) had tried to postpone the beginning of the obligatory use of the code: again the belief that earthquakes are not a major problem in Italy. In fact, part of the damage to ancient buildings — which could be greatly reduced though not fully avoided — as well as the collapse and damage to many other structures were caused, as mentioned, by bad construction (poor concrete and absent, inadequate or insufficient steel reinforcement, especially for stirrups), not consistent with any code (even the oldest), and by lack of adequate maintenance.

Hopefully, after the Abruzzo earthquake, both Italian institutions and public opinion are now fully convinced that seismic prevention is indispensable and that the related policy will be strengthened and accelerated; in particular, that the presently best available techniques (such as SI and ED) should be extensively used for the reconstruction and retrofits in Abruzzo and that this should be done not only for strategic and public buildings, but also for residential ones. The additional construction costs (if any) are quite limited and safety is much higher. This will strongly reduce casualties and damage during the next shocks, which, by the way (according to history and also to some recent seismological studies), might unfortunately occur in Abruzzo rather soon. In addition, such a prevention policy should be extended to the entire Italian territory, because, if the earthquake of April 6, 2009 had taken place elsewhere in Italy, the consequences would not have been significantly different.

With regard to the seismic protection of existing structures, although the work to be done and money to be spent are enormous (because nearly nothing was done in the past), the efforts should be much increased. Several old buildings should be demolished and rebuilt with safe features, instead of being all considered as cultural heritage, as done to date in Italy after a 50 years life. (Not all constructions are comparable to the Coliseum!) The interventions should be scheduled based on priorities, namely beginning from the most risky structures in the areas characterized by the highest seismic hazard. The latter should be assessed by means of not only the currently used PSHA, but also of the deterministic approach, which should be considered (as it is, in the author's opinion) as complementary and already proved to be quite reliable [Dolce et al. 2005; 2006; Sannino et al. 2009; Martelli 2010b].

Reliable seismic engineering technologies and seismological methodologies exist: thus, there is no more excuse not to widely use them. However, in applying modern technologies like SI, great care must be paid to the selection of the devices, their installation and their protection from external causes of damage and some further construction details, as well as to an adequate maintenance [Martelli 2009f]. In particular, in order to ensure real safety of the isolated structure, correctly qualified, checked and protected devices should be installed and adequate inspection and maintenance should be performed during the entire structure life to ensure that the SI features remain unchanged. Otherwise, these devices, instead of enhancing protection in an earthquake (as SI does, if properly applied), will expose both human life and the entire SI technology to a great risk: in fact, since the Italian seismic code (contrary to the Japanese and US ones) allows for "lightening" both the superstructure and foundations when an SI system is installed, the inadequate performance of the latter would make an isolated building less safe than a conventionally founded one [Martelli 2009f; 2009g].

Application of SVPC systems and devices in Italy. As mentioned in [Dolce et al. 2005; 2006; Martelli et al. 2007; Martelli and Forni 2009b], the first applications of SVPC systems in Italy go back to 1975 for bridges and viaducts and to 1981 for buildings — thus predating those in Japan and the US by four years (compare Figure 1, right). These early applications involved the Somplago viaduct of the Udine–Tarviso freeway and a suspended steel-structure fire-command building in Naples. Thanks to its SI system (formed by sliding devices on the piles and rubber springs between the deck and the abutments), the Somplago viaduct survived without any damage the second main shock of the 1976 Friuli earthquake (when one of the decks had already been installed), unlike most other structures similarly located in the epicentral area; for the Naples building, which had been conventionally designed before the 1980 Campano–Lucano earthquake (when the site was not yet seismically classified), the insertion of neoprene bearings (NBs) at the top (to isolate the suspended structure) and, inside, that of floor dampers and STUs, allowed for not fully modifying the original design, in spite of the classification of the Naples area in seismic category 3 only after the earthquake in question.

The excellent behavior of the Somplago viaduct, in the years of construction of the Italian freeway system, caused an immediate rapid extension of the application of SVPC systems to the new Italian bridges and viaducts. Those protected by such systems were already 150 at the beginning of the years 1990s: this ensured the worldwide leadership to Italy for the number and importance of the applications in this field.

As to buildings, the extension of applications was slower in the first years, but the trend had become very promising, in this field too, at the beginning of the 1990s (Figure 1, right), after the erection of the Telecom Italia Centre of Marche Region in Ancona on 297 HDRBs and the impressive on-site tests performed on one of its five buildings. (Their safety was later certified by the first author of this paper, as mentioned, for instance, in [Dolce et al. 2005; 2006].)

On the contrary, the use of the SVPC systems and devices became very limited after such an application (Figure 1, right): in fact, the Italian Ministry of Constructions, by recognizing that no specific rules for structures provided with said systems and devices were included in the Italian seismic code in force at that time, on the one hand decided that all designs of such structures had to be submitted for approval to the already mentioned special commission of the Ministry, but, on the other hand, did not make any specific design guidelines available until the end of 1998. Moreover, such design guidelines, when they were published, resulted to be inadequate and the approval process remained uncertain, very complicated and time consuming.

Thus, in spite of its long tradition, Italy was only fifth, at least for the number of seismically isolated buildings in use, prior to the 2009 Abruzzo earthquake, with over 70 isolated buildings already opened to activity and about 30 further applications of this kind in advanced progress [Sannino et al. 2009]. Some tenths of Italian buildings had also already been protected by ED systems or SMADs (19 at the end of 2007) or STUs (28 at the same date). Moreover, there were already over 250 bridges and viaducts provided with SVPC devices and important applications of such devices, completed or planned, to worldwide known cultural heritage (Upper Basilica of St. Francis at Assisi, damaged by the 1997–98 Marche and Umbria earthquake; the Bronzes of Riace and other structures and masterpieces, such as those shown in Figures 28 and 45–48). (Italian SVPC devices had been installed in several constructions in other countries too [Dolce et al. 2005; 2006; Martelli 2009b].)

In recent years, however, there has been a large increase of the number of applications completed and, especially, of those in progress or under design (Figure 1, right, and Figures 34–44). This change

Figure 34. Sketch of the new isolated Del Mare Hospital, during its construction in Naples, nowadays in seismic zone 2, and view of some of its 327 HDRBs. Several new Italian hospitals being or to be erected in seismic areas now include the use of SI.

Figure 35. The Emergency and Management Operative Center of the new Civil Defense Center of Central Italy in Foligno (Perugia) was designed by the GLIS board and *ASSISi* member A. Parducci of e-Campus University. Their safety will soon be certified by A. Martelli. The photo on the left shows in the foreground the main building, which is being erected on ten HDRBs of 1 m diameter, two of which are seen on the right, with provisional protective covers. Also seen on the left is the adjacent service building, isolated by HDRBs and SDs. The Foligno Center will include at least seven isolated buildings, three of which have already been completed. Its site was reclassified from seismic category 2 to seismic zone 1 in 2003, but no design changes of the structures and foundations were necessary, thanks to SI. An increase in the diameters of isolators was sufficient, as demonstrated by a study performed by ENEA.

Figure 36. The new Francesco Jovine primary school and Le Tre Torri Professional and University Centre, erected in San Giuliano di Puglia (seismic zone 2 since 2003) on a single seismically isolated slab, and its SI system (61 HDRBs and 12 SDs) during construction. The isolators were donated by the Italian ALGA, FIP Industriale and TIS manufacturing companies. The SI design is by a team of experts coordinated by the GLIS and *ASSISi* member P. Clemente of ENEA, with tests done by the University of Basilicata. Safety was certified by A. Martelli and GLIS member C. Pasquale in September 2008.

Figure 37. The first new school building of Mulazzo (Massa Carrara), protected by LRBs and SDs (right) and the new primary and secondary school of Gallicano (Lucca), protected by HDRBs and completed in September 2009. They are two of the 5 schools rebuilt or being rebuilt with SI in Tuscany, in seismic zones 2. Safety of the Mulazzo school will be certified by A. Martelli, that of the Gallicano was certified by A. Parducci.

was due at first to the new Italian seismic code, enforced in May 2003, which (as mentioned) freed and simplified the adoption of the SVPC systems, then, very recently, to the Abruzzo earthquake [Martelli and Forni 2009a].

Figure 38. The new school in Marzabotto (Bologna), in seismic zone 3, erected on HDRBs and SDs. Its safety was certified by A. Martelli in September 2010.

Figure 39. Romita High School for scientific studies of Campobasso (hosting about 1,300 students), in seismic zone 2, which was at last partly demolished and is now being rebuilt with SI, due to its very poor concrete quality (as demonstrated by an ENEA study performed after the 2002 Molise and Puglia earthquake). Safety of the new seismically isolated buildings will be certified by A. Martelli.

As already mentioned, the enforcement of the new Italian seismic code was largely a consequence of the collapse of the Francesco Jovine school during the 2002 Molise and Puglia earthquake. This school was recently rebuilt: the new Francesco Jovine, opened to activity in September 2008 (Figure 36), is the first Italian isolated school and has been judged as the safest Italian school. It is being followed by 16 further applications of this kind (5 have already been completed). Seismic protection of schools by means of SI, in addition to that of hospitals, other strategic structures and cultural heritage (Figure 31 and Figures 45–48), was a “priority 1” objective in Italy even before the Abruzzo earthquake.

After this event, this kind of protection is being further extended and planned for residential buildings too, in the framework of the retrofit/rebuilding program in Abruzzo, which should make a large use of SI and ED systems.

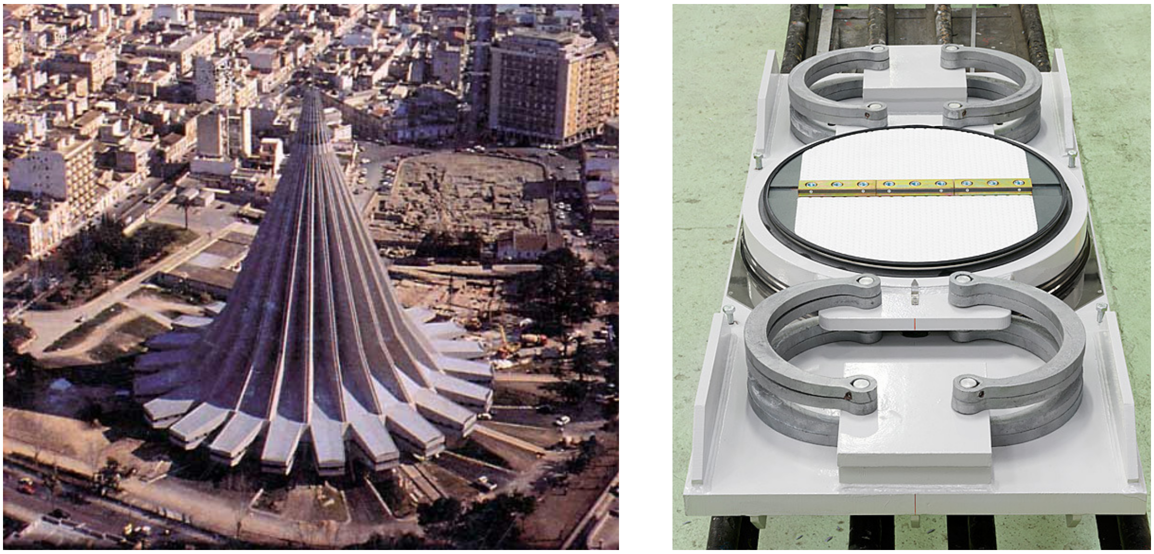

Figure 40. Shrine of the Madonna delle Lacrime in Syracuse (seismic zone 2), designed to fit 11,000: it was retrofitted in 2006 by lifting the dome (22,000 tons) and replacing the previously existing rubber supports by EPDs (right).

Figure 41. Left: Headquarters of the association Fratellanza Popolare – Croce d'Oro in Grassina (Florence), in seismic zone 2, isolated by means of SDs and VDs; it is a L-shaped building to be used for civil defense, designed by the GLIS board and *ASSISi* member S. Sorace of the University of Udine and certified as safe by A. Martelli in 2007. Right: NATO Centre in South Naples, in seismic zone 2 (399 HDRBs and 20 dissipative SDs), during construction in 2007.

In particular, the construction of 184 prefabricated houses of various materials (wood, concrete, steel), each erected on a 21 m × 57 m r.c. platform, 50 cm thick and supported by 40 steel or r.c. columns with curved surface sliding (CSS) devices manufactured in Italy (by ALGA and FIP Industriale) at the top, has been completed: these houses (Figure 44) will host first about 17,000 people who remained homeless after the earthquake and later, in a few years, students.

Figure 42. The four r.c. residential buildings of the new San Samuele Quarter of Cerignola (Foggia), in seismic zone 2, first application of the new Italian seismic code to isolated dwelling buildings, completed with 124 HDRBs (right) in May 2009, with safety certification of A. Martelli.

Figure 43. Left: residential building in San Giuliano di Puglia, isolated by 13 HDRBs and 2 SDs with the collaboration of ENEA, completed in 2007. Right: SI formed by LRBs and SDs of an 8-storey building under construction at Messina, in seismic zone 1; its safety will be certified by A. Martelli.

It is noted, however, that the CSS isolators (besides needing very careful protection from dust and humidity) had never been previously used in Italy. Building applications of similar isolators existed in other countries, like Turkey and Greece, but such devices had been manufactured in Germany (Figures 55 and 59), using a sliding material different from the Italian ones. Thus, a debate was promoted in Italy by the first author of this paper on the need for submitting the Italian CSS isolators to a very detailed experimental verification campaign, including two-directional (2D) simultaneous excitations in the horizontal plane, representing real earthquakes, at the laboratories of the University of California at San Diego, similar to those performed for the German silding isolation pendulum (SIP) devices and,

Figure 44. One of the 184 seismically isolated pre-fabricated houses erected at L'Aquila for homeless residents and CSS devices installed to isolate its supporting slab.

Figure 45. Interior of the Cathedral of Santa Maria di Collemaggio at L'Aquila (see also Figure 28) prior to the 2009 Abruzzo earthquake and view of one of the EPDs which had been installed on the roof at the beginning of the years 2000 to prevent overturning of the façade.

previously, for the American FPS devices, from which the German SIP and Italian CSS isolators derive. This debate is still ongoing (the 2D tests are required neither by the Italian code nor by the European one, although they had been found necessary for both the FPS and the German SIP isolators), but a first positive result has already been achieved: in fact, the CSS isolators of FIP Industriale installed at L'Aquila were submitted to these 2D tests in November 2009, with excellent results.

Legislative measures recently adopted to promote the use of the antiseismic 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 rebuilding in Abruzzo), decided some legislative measures to favor the extension of the adoption of the antiseismic systems and devices (especially of SI). These measures,

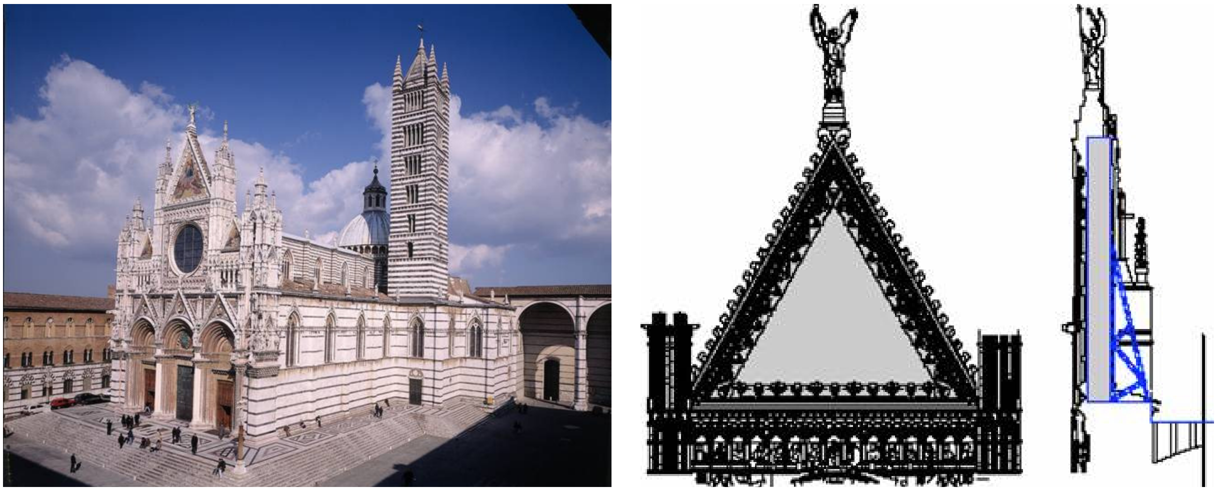

Figure 46. The Orvieto Cathedral. Right: position of the recentering VDs inserted some years ago to prevent overturning of its façade.

Figure 47. The wooden Roman ship excavated at Herculaneum, near Naples, in seismic zone 2, which was recently protected in the local museum by means of 3D isolators formed by three spheres and a re-centering rubber cylinder for the horizontal SI and a spring and a VD for the vertical one.

adopted in December 2009, were largely based on proposals of GLIS and, in particular, of the first author of this paper. For instance, economic incentives have been included in the project of the new so-called "Quality House" national law for those adopting such technologies and even more favorable measures were recently decided by the regional government of Sicily.

With regard to the seismic protection of schools, it is worthwhile reporting a translation of the whole text of an "agenda" (consistent with the declaration [UNESCO-IPRED-ITU 2009], and based on a proposal of Martelli [2010c]), which was submitted by the President of the Commission on Environment, Territory and Public Works of the Chamber of Deputies [Alessandri et al. 2009] in the framework of the

Figure 48. Michelangelo's marble David, displayed at the Galleria dell'Accademia, in Florence: note the worsening of the cracks in its ankles in recent years (right), which make it very vulnerable to both seismic and environmental vibrations. A study to evaluate the feasibility of SI of the masterpiece has been proposed by Prof. Antonio Borri of the University of Perugia and the first author [Dolce et al. 2005; 2006, Martelli 2009a]. Consideration of the losses at the L'Aquila Museum (Figure 31 on page 95) may give pause to the opponents of the development and installation of an adequate seismic protection system for Michelangelo's David.

vote of the 2009 Financial Law on December 16, 2009, and was immediately accepted by the Italian government [Camera dei Deputati 2009, pages VII–VIII]:

> "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 condition 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 present persons;
> - 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 nonstructural 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 antiseismic 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* rebuilding;
- 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 favor of this technological 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 stories 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.) are sometimes to be foreseen;
- 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 coordinated 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 antiseismic 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 antiseismic 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 microzoning, 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 antiseismic 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."

Figure 49. Approaches of the Seo-Hae Granel Bridge in South Korea (overall length 5820 m, height of piles 12–60 m), which were retrofitted by means of 54 Italian VDs ($K = 100\,\text{kN/mm}$) in 2000–2001.

7. South Korea

In South Korea SI has already been applied for several years [Zhou et al. 2009]. Nowadays, it includes about 400 bridges and viaducts, partly with devices manufactured in Italy (Figure 49), as well as 13 large LNG tanks at Inchon and Pyeong–Taek. In October 2008, however, only one building was seismically isolated (in 1999) and only one (a 30-storey residential building) was protected by dampers (VEDs). Anyway, the use of the SVPC systems is now rapidly increasing, especially for ED, which is being more and more used for protecting high-rise buildings and long span bridges. This is a consequence of the magnitude 7.0 Busan–Fukuoka earthquake of 2005 (with epicenter between Korea and Japan) and of the more recent event of January 2007, with a much lower magnitude ($M = 4.8$), but with epicenter in the Korean territory.

8. Taiwan

After the 1999 Chi Chi earthquake and the consequent modifications of the national seismic code (performed in 2002 and 2006), which now permits and even promotes the use of SI and other SVPC systems in Taiwan, the adoption of such systems is increasing more and more in this country and includes both new constructions and retrofits [Zhou et al. 2009]. Frequently, SVPC devices manufactured in Italy have been used. As to the isolated buildings, those completed or under construction (initially mainly hospitals, but, more recently, residential buildings too) were already 29 in May 2007, against the 25 of June 2005; at the same date, the isolated bridges and viaducts were over 20. In addition, there is an even larger number of buildings that are protected by ED systems in Taiwan: these were already 85 in 2005. The isolators used for buildings are HDRBs and LRBs and have been installed either at the base or the top of the first floor. Dampers are of various types, namely BRBs, EPDs, VDs, VEDs, etc.

9. Continental France and Martinique Island

France was one of the first countries that developed and applied the modern SI systems [Erdik et al. 2008]. Its first applications date back to the 1970s, when they amounted to a few nuclear plants and structures and some civil buildings and industrial components. The isolators used were multilayer NBs and, in

Figure 50. An isolated school in the French Martinique island (France), with a view of some NBs and VDs that protect it.

particular, the so-called "GAPEC System". From 1977 to 1989 this system was adopted both to protect new constructions in the continental France and to erect or retrofit some plants and electrical or electronic components in the US and Chile. The applications in France in this period included 11 new residential buildings and (in 1978) the new high school of Lambesc (a town that had been partially destroyed by the 1909 Provence earthquake), besides 4 industrial (partly high risk) components or structures and 3 LNG tanks (in Rognac in 1993). Later, VDs were also developed in France and were applied to bridges, viaducts and some buildings and chemical plants too, both in this country and abroad (e.g., together with Italian SDs, to the building of Figure 41.

As to the French applications of SI performed in the nuclear field in the 1970s, it is worthwhile reminding those to the Pressurized Water Reactors (PWRs) of Cruas and spent nuclear fuel storage pools of La Hague, carried out to allow for the use of standardized plant designs in these sites too, which are characterized by seismic intensities larger than those considered in such designs (for the same reason SI was also used to protect the Koeberg PWR, in South Africa, which was built by the French industry). Based on this experience and the subsequent remarkable developments of SI techniques, the French already decided to isolate both the Jules Horowitz Reactor (for which construction is in progress) and the ITER plant for the controlled fusion, both located at the Cadarache Research Center (PGA = 0.33 g).

With regard to civil buildings, on the contrary, the most important French building applications of SI are now in progress in its Martinique island. This has a relatively small area, thus, the whole territory will shake in an earthquake. Buildings and houses are very vulnerable there (similar to the neighboring Guadeloupe). There is no hope for the inhabitants to benefit from safe zones. Moreover, the insular situation complicates the arrival of helps, taking into account that two thirds of the airport landing strip are liquefiable. The most recently isolated buildings that were built in the island make use of French devices, namely NBs (the "GAPEC System" until 2001) in parallel (at least for the protection of important structures) to VDs (Figures 50 and 51). We note that, some years ago, the Martinique Regional Council decided that all secondary schools, all Council buildings and all other public buildings it funds, even in part, must be seismically isolated, and financial support must be provided to private individuals using SI [Erdik et al. 2008]. By March 2007, SI had already been used to protect four primary or secondary schools (each consisting of several buildings — see Figure 50), two residential buildings and the Earth

Figure 51. Left: a small seismically isolated building in the French Martinique. Right: the New Zealand Parliament at Wellington, a historic building erected in 1921 and retrofitted using LDRs in 1992–93.

Science Centre at Saint-Pierre (which was designed to withstand a PGA of 0.45 g). New applications that were in the design phase included two more secondary schools, one college, four residential buildings, two important public buildings, a museum and a private clinic.

In continental France, by contrast, further application of SI to civil buildings has been hampered by an unfavorable seismic code that has been in force for several years, the moderate seismic hazard of most of its territory and the consequent limited interest of the French public opinion and institutions in seismic risk mitigation.

10. New Zealand

New Zealand, which is characterized by a high seismicity, is one of the countries where the SVPC systems took origin [Zhou et al. 2009]. These are, in particular, the LRBs (which have been applied since 1974 based on researches begun in 1967) and other devices based on the lead technology (e.g. lead dampers). Nowadays, SI is a fully accepted construction technique in this country, to protect both buildings (even the historic ones) and bridges and viaducts. In addition, the New Zealand manufacturing industry is very active in other countries, as well (e.g., in Turkey).

In spite of the country's limited population, 19 buildings, besides several bridges and viaducts, had already been protected by means of SI in June 2005 (Figure 51, right, and Figure 52). In May 2007, the

Figure 52. Wellington, New Zealand: the isolated Te Papa Museum (left) and the Maritime Museum (right), retrofitted with SI in 1993.

construction of the Wellington Regional Hospital (supported by 135 LRBs and 135 SDs) was in progress, and 2 new buildings of the Wanganui District Hospital were being designed. The latter are isolated by 90 RoGliders, a new SI system conceived in New Zealand, combining a SD with a rubber membrane: this system is very suitable for light structures, like the aforesaid buildings [Erdik et al. 2008]. Further new applications that were already planned in 2007 included the Christchurch Hospital (which behaved very well during the quake of September 3, 2010), the New Zealand Supreme Court Building, the retrofit of a Rankine commercial building (performed without any interruption of the activities) and rising of an existing eight-storey building at Wellington, with further 8 stories. At the time being the seismically isolated buildings in New Zealand are over 30, which makes this country third at worldwide level (after Japan and Armenia) for the number of such a kind of applications per residents.

11. Armenia

With regard to Armenia, it is worthwhile stressing again that, after Japan, this country has the largest number of building applications of SI per capita, despite being a small developing country that did not start using SI until several years after most of the countries mentioned earlier [Zhou et al. 2009]. Such applications already number 32, to both r.c. and masonry buildings, including some important retrofits. Retrofits consist of both base SI and the erection of a so-called additional isolated upper floor (AIUF). The related developed and applied techniques allow for not interrupting activities or occupation of the buildings. Moreover, since 2003–2004 even rather tall isolated buildings have been erected at Yerevan, which hosts a large part of the Armenian population (Figure 53 and Figure 54, left).

After the first applications, which made use of LDRBs and HDRBs, the SI devices used at present in Armenia are medium damping rubber bearings (MDRBs), which are steel-laminated neoprene isolators characterized by 8%–10% damping ratios. The MDRBs are manufactured in Armenia and have been also exported (e.g., for applications to bridges and viaducts in Syria). In the aforesaid tall buildings they are arranged in groups of relatively small diameter isolators in each SI position, also in order to minimize torsion effects. Experts of the American University of Armenia have provided important contributions as

Figure 53. Left: the Our Yard multi-functional complex in Yerevan, with 10 to 16 storeys, was isolated in 2006 by means of MDRBs. Right: a group of such bearings.

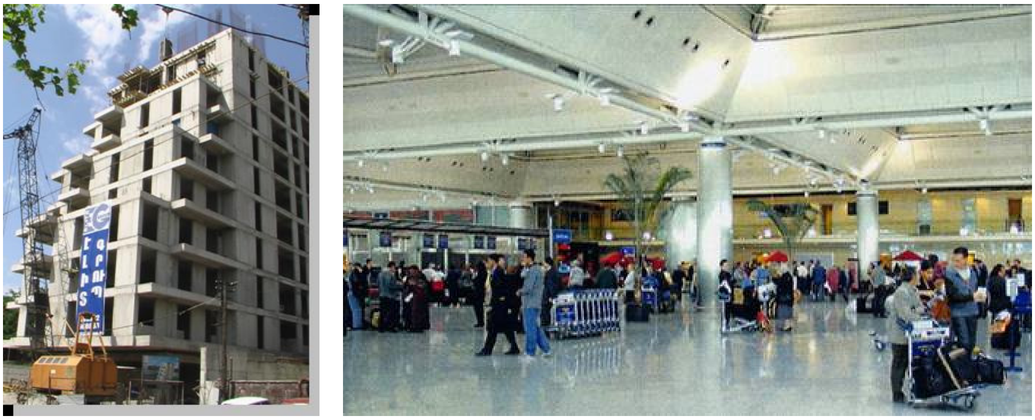

Figure 54. Left: the 15-storey Cascade multifunctional complex, isolated in Yerevan by MDRBs in 2006. Construction of even taller buildings is in progress. Right: the roof of the new Ataturk Airport in Istanbul, isolated by means of 100 FPS devices in 1999.

collaborators with projects in the Russian Federation (including the first of the previously cited retrofits performed in that country), Romania and Nagorno-Karabakh.

12. Turkey

The Turkish applications of the SVPC systems started after the 1999 Kocaeli and Duzce earthquakes, which damaged the now seismically isolated new Ataturk airport in Istanbul (it was being conventionally constructed at that time) — see Figure 54 — while the Bolu viaduct of the Istanbul–Ankara freeway was saved from collapse by EPDs manufactured in Italy [Dolce et al. 2005; 2006]. Thus, the airport was retrofitted by inserting FPS devices below the roof. Further applications of SI were later performed, to both new and existing structures, including, by May 2007, the retrofit of the Antalya international airport terminal, two new hospitals, one hotel, freeway viaducts (including the Bolu viaduct) and two large LNG tanks at Aliaga; see Figure 55 and [Dolce et al. 2005; 2006].

Figure 55. Isolated buildings in Turkey. Left: the T.E.B. Headquarters, a building which was under construction on 87 LRBs and LDRBs in Istanbul in 2006. Right: Söğütözü Congress and Commercial Centre in Ankara, isolated using 105 SIP devices manufactured in Germany in 2007.

Further applications completed in the last two years or in progress include important bridges and viaducts, two further airport structures (one terminal and one hangar), a high school and a mosque. The SI retrofitting of numerous schools and hospitals in Istanbul is foreseen in the framework of an important project [Zhou et al. 2009]. The SI systems initially used in Turkey consisted of FPS devices, while now RBs (partly manufactured in Italy) and SIP devices manufactured in Germany are also being used.

13. Mexico

In May 2007 the Mexican applications of SI were only seven (besides four new projects under development, including the construction of the new Basilica of Guadalajara), while those of ED systems were already 25 [Erdik et al. 2008]. The first, begun in 1974, encompasses two bridges, three civil buildings,

Figure 56. The Legaria Secondary school at Mexico City (first Mexican application of SI, performed in 1974) and one of its rolling SI devices, developed in Mexico.

Figure 57. SI of the printing press of the Mexican Reforma Newspaper (1994) and of the Mural Newspaper building (1998).

one factory for the production of microchips at Mexicali and the printing press of the Reforma Newspaper (Figures 56 and 57). Most of these applications (5) make use of an SI rolling system developed in the country. Those of ED, on the contrary, initiated in 1989 and all to buildings (16 at Mexico City and 9 at Acapulco), were performed with devices manufactured in the USA: the most common (in 16 cases) were the so-called added damping and stiffness (ADAS) EPDs, but VDs too are getting a footing. Fourteen of the aforesaid applications were retrofits of existing buildings.

14. Greece

In Greece, the SVPC systems have already been applied to a limited number of civil structures (only four buildings and some bridges and viaducts had been completed with such systems in 2007), but also to two large LNG tanks, which were isolated at Revithoussa with FPS devices in the 1990s, and a ceiling of archaeological excavations [Erdik et al. 2008]. It is noted that some important Greek civil structures have been protected by isolators or dampers manufactured in Italy [Dolce et al. 2005; 2006] Remarkable examples of application of Italian devices are the ceiling of the new international airport Eleftherios Venizelos, isolated by means of 8 HDRBs and 128 multidirectional RBs with superposed friction plates in 1998, and more recent applications such as those shown by Figure 58. In October 2008 only two Greek buildings were isolated by devices manufactured in countries other than Italy, in this case German SIP devices: both were located in the Onassis Centre in Athens (Figure 59).

Figure 58. Left: the Rion–Antirion bridge in Greece, 12 km in length and protected, together with its approaches, by Italian SVPC devices, including 188 VDs. Right: the International Broadcasting Centre in Athens, isolated in 2003 by means of 292 Italian HDRBs.

15. Cyprus

Cyprus lies on the southern part of the diffuse boundary between the African and Eurasian plate in a relatively active seismic zone; there, the majority of buildings is relatively stiff, with fundamental vibration frequencies that fall within the usually high seismic energy field, rendering them ideal candidates for the application of SI. Nevertheless, in May 2009 its use and, in general, that of SVPC techniques were still

Figure 59. Left: the Onassis Centre in Athens, with the Acropolis Museum, isolated in 2007 by 94 German SIP devices in 2006 (left). Right: the Onassis House of Letters and Fine Arts, during its construction, again with German SIP devices.

limited to a handful of practical applications: a multistorey r.c. building of the Cyprus Sports Organization, which had been protected by steel braces with VDs prior to May 2007; three commercial/industrial buildings with steel rigid frames and frames with eccentric bracing, where HDRBs (Figure 60) or FPS devices were placed on top of the basement columns; a retrofit planned for a multistorey building for the Telecommunications Authority of Cyprus, to be partly supported FPS devices; and three highway bridges, supported either by LRBs or FPS devices [Phocas et al. 2009].

Figure 60. The Shakolas Park Commercial Centre at Nicosia (Cyprus), designed by the Italian GLIS board and *ASSISi* member G. C. Giuliani and his son of Redesco (Milan), formed by two buildings with mixed r.c. and steel structure, with 164 Italian HDRBs installed at top of the basement columns, during construction in 2007.

16. Portugal

In Portugal, the use of the SVPC systems has been so far almost exclusively limited to bridges and viaducts, to which there is already a significant number of applications. In October 2008 [Sannino et al. 2009], the only isolated buildings were the La Luz new hospital and the adjacent residence for old people; they were isolated with 315 HDRBs (Figure 61). The isolators installed in these buildings and the SVPC devices used in a large part of the Portuguese bridges and viaducts were manufactured in Italy.

Figure 61. The new La Luz new hospital in Lisbon, which was base-isolated in 2006, together with a residence for old people, by means of 315 Italian HDRBs.

17. Iran

In Iran the use of SVPC systems recently began in an extensive way, mainly with the application of RBs manufactured in Malaysia to a huge number of residential buildings (several hundreds) at Parand, a new town being constructed near Tehran; however, some problems occurred during construction and only 5 buildings were completed to date [JSSI 2009]. Installation of SVPC devices manufactured in Italy also began (a hotel was retrofitted by means of Italian dampers). In addition, there are some very interesting designs, for instance one for the retrofit of the Iran Bastan Museum at Teheran with SI, developed in the framework of a collaboration between Italy an Iran, which (among others) involves the International Institute of Earthquake Engineering and Seismology of Tehran, *ASSISi* and GLIS members representing the Mediterranean University of Reggio Calabria, ENEA and the Abdus Salam International Centre of Theoretical Physics of Trieste [Erdik et al. 2008].

18. Canada

In Canada the use of ED systems (frequently BRBs) is rather popular [Zhou et al. 2009], but that of SI devices began only recently (Figure 62): the beginning of construction of the first Canadian isolated building was recently reported.

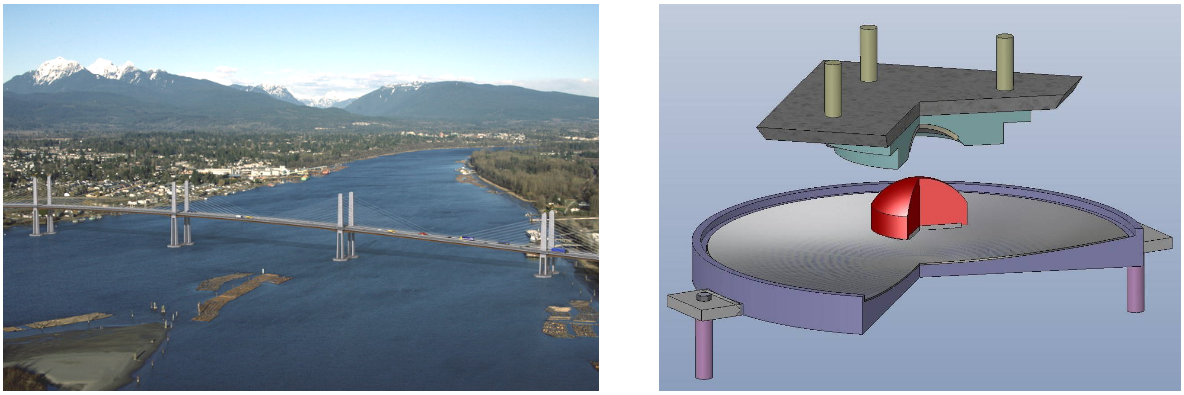

Figure 62. Golden Ear Bridge (Canada), isolated in 2007 by means of Italian CSS devices.

Figure 63. The new building of the Hospital Militar de Santiago (80,000 m^2), in the community of La Reina, under construction in 2006. It is equipped with 114 HDRBs and 50 LRBs.

19. Chile

Chile, where the first isolated building (the Communidad Andalucia residential building) dates back to 1992 [Dolce et al. 2005; 2006], is particularly active in the development of new antiseismic systems, but new application of SI to buildings is hampered by very penalizing design rules, consistent with US ones [Erdik et al. 2008]: the only new isolated building under construction in 2006 was a large hospital in Santiago (Figure 63), completed in 2009. Notably, the buildings just mentioned behaved very well during the quake of February 27, 2010.

20. Venezuela

In Venezuela a considerable number of railway bridges and viaducts have been protected by dampers manufactured in Italy; see Figure 64 and [Sannino et al. 2009].

Figure 64. The The Caracas – Tuy Medio railway in Venezuela (26 isostatic span viaducts, overall length = 7,775 m, 217 spans), protected by over 1,500 isolators manufactured in Italy in 1999–2003.

21. Indonesia

In Indonesia there are already at least two isolated constructions: a demonstration residential building erected on HDRBs in 1994, in the framework of an UNIDO-funded project [Dolce et al. 2005; 2006], and the Medan City Hall, later protected by Italian isolators [Sannino et al. 2009].

22. Macedonia

In Macedonia Italian HDRBs were used to isolate the new Test Laboratory Building of the Skopje University some years ago. Furthermore (see [Erdik et al. 2008] and Figure 65, left), the poorly steel-laminated and very degraded LDRBs of Johan Heinrich Pestalozzi Primary School at Skopje (which was the first modern application of SI) were replaced by locally manufactured HDRBs in 2007: the previous bearings had been installed to protect the aforesaid school when it was erected in the 1960s, after the violent Skopje earthquake of 1963.

Figure 65. Left: the isolated Pestalozzi school at Skopje (Macedonia), built in the 1960s. Top right: a very degraded original low damping rubber bearing (LDRB). Bottom right: a new HDRB, next to original LDRBs yet to be replaced.

23. Romania

In Romania the use of SI began only recently (Figure 66, left), with Italian and Armenian projects (see end of Section 11). Romania is expected to invest heavily in SI, due to the large energy content at low frequencies which characterizes earthquakes in a considerable part of its territory [Sannino et al. 2009].

24. Other countries

The authors are aware of at least one isolated building each in Algeria, Argentina, Israel, India and Switzerland, and a certain number of isolated bridges and viaducts in further countries such as Bangladesh.

Figure 66. Left: retrofit design with SI of the Victor Slavescu monumental building in Bucharest, Romania, erected in 1905 (55.2 m × 20.87 m; height = 22.5 m). Right: residential building for university students at Mendoza, Argentina, isolated by means of four 3D German GERB isolators.

The building in Argentina, erected at Mendoza close to an active fault, has been protected by German 3D isolators (Figure 66, right).

25. Conclusions

SI and the other SVPC technologies have been already widely used in over 30 countries and their application is increasing more and more, for both new constructions and retrofits, for all kinds of structures. The features of the design rules used, as well as earthquake experience, have plaid a key role on the success of the aforesaid technologies. Japan is largely the leading country for the number of applications of both SI and ED systems. It is now followed by China, Russia, the US and Italy. Iran might soon get the second place for the number of isolated buildings, if the huge project consisting in the SI of hundreds of new residential buildings at Parand (a new town under construction near Tehran) will be completed as planned.

Italy (where the contributions provided by ENEA have been of fundamental importance) is the leading country at European level, with regard to both SI and ED of buildings, bridges and viaducts. In addition, it is the worldwide leading country for the use of SVPC systems (in particular SMADs and STUs) to cultural heritage. Its applications are being significantly extended after the 2009 Abruzzo earthquake. Italian SVPC devices have been installed in several other countries too.

SI is now worldwide recognized as particularly beneficial for the protection of strategic constructions like civil defense centers and hospitals (by ensuring their full integrity and operability after the earthquake) and for schools and other highly populated public buildings (also because the large values of the superstructure vibration periods minimize panic). Some codes (e.g., those adopted in Italy, China, Armenia, etc.) allow for taking advantage of the reduction of seismic forces operated by SI: their use makes SI attractive for the residential buildings too, because the additional construction costs due to the use of this technique (if any) are very limited.

In order to really strongly enhance the seismic protection of our communities, an extensive application of the antiseismic systems is necessary [JSSI 2009]: to achieve this objective, legislative measures and economic incentives, such as the first ones that were recently decided in Italy, may considerably contribute, especially in the countries where the perception of seismic risk is not yet sufficient.

Hopefully, the use of SVPC systems (in particular SI) will strongly increase for the protection of cultural heritage and high risk plants, as well. For the first, the problem is the compatibility with the conservation requirements. With regard to the latter, SI has a great potential not only for nuclear structures, but also for chemical components like LNG tanks, for which, to date, only very few applications exist (in South Korea, China, Turkey, France, Greece and, soon, Mexico: in fact, detailed studies have shown that SI is indispensable for such components in highly seismic areas [Dolce et al. 2005; 2006; Martelli 2009a].

However, it should be kept in mind that the use of SI in countries like Italy, where designers are allowed by code to decrease the seismic forces when adopting this technology, requires very careful selection, design, installation, protection and maintenance *during the entire life* of the isolated structure: otherwise, safety could be lower than for if conventional techniques were used.

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Received 22 Mar 2010. Accepted 30 Sep 2010.

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SEISMIC ISOLATION AND PROTECTIVE SYSTEMS

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SIAPS (ISSN 2150–7902) is published in electronic form only. The subscription price for 2010 is US $150/year. Subscriptions, requests for back issues, and changes of address should be sent to Mathematical Sciences Publishers, Department of Mathematics, University of California, Berkeley, CA 94720–3840.

SIAPS peer-review and production is managed by EditFLOW™ from Mathematical Sciences Publishers.

PUBLISHED BY
mathematical sciences publishers
http://www.mathscipub.org
A NON-PROFIT CORPORATION
Typeset in LaTeX

SEISMIC ISOLATION AND PROTECTION SYSTEMS vol 1, no 1, 2010