RECENT PROGRESS OF APPLICATION OF MODERN ANTI-SEISMIC SYSTEMS IN EUROPE – PART 1: SEISMIC ISOLATION

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ABSTRACT :

As witnessed by the state-of-the-art papers presented at the *10th World Conference on Seismic Isolation, Energy Dissipation and Active Vibrations Control of Structures* (Istanbul, Turkey, May 27-31, 2007) and by more recent information, there are already well over 8,000 structures in the world protected by seismic isolation (SI) and other modern seismic vibration passive control (SVPC) systems. Their number is increasing everywhere more and more. The conclusive influence of earthquake experience and availability and features of the design rules used on the extension of application of the SVPC systems has been confirmed. Fifth at worldwide level for the number of applications (after Japan, the P.R. China, the Russian Federation and the USA) and first in the European Union remains Italy, at least for those of SI to buildings. Italy is now followed by Taiwan, New Zealand, Armenia, Turkey, Mexico, South Korea and Canada. However, important applications also began in other European countries, namely in Greece, Portugal, Cyprus and Macedonia; many of them make use of SVPC devices manufactured in Italy or of Italian designs. Italian devices have also been installed in several other countries. Finally, as regards Europe, applications of the SVPC systems are going on in France: in the mainland for nuclear plants and in the Martinique island for civil buildings. This paper provides details on the use of SI in Italy and the other European countries (including the entire Russian Federation), by stressing the most relevant recent applications, while a separate paper, presented in Session S05-02, deals with that of the other SVPC techniques.

KEYWORDS: Seismic isolation, new constructions, retrofits, civil structures, industrial plants and components, cultural heritage.

1. INTRODUCTION

As witnessed by the proceedings of the *ASSISi 10th World Conference on Seismic Isolation, Energy Dissipation and Active Vibrations Control of Structures* (Istanbul, Turkey, May 27-31, 2007) and by more recent information, at present there are well over 8,000 structures in the world that are protected by means of seismic isolation (SI), energy dissipation (ED) and other modern seismic vibration passive control (SVPC) systems, namely shape memory alloy devices (SMADs) and shock transmitter units (STUs).

Everywhere, the number of such structures is increasing more and more, although the extent of the use of SVPC systems is strongly influenced by earthquake experience and the features of the design rules used. Applications concern both new and existing structures of all types: bridges and viaducts, civil and industrial buildings, industrial components and installations – including some high risk plants, such as nuclear reactors, other nuclear facilities and some Liquefied Natural Gas (LNG) tanks – and cultural heritage (monumental buildings, museums, ceilings of archaeological excavations, museum showcases and single masterpieces). Those to civil buildings already include not only the strategic ones (emergency management centres, hospitals, etc.) and the public ones (schools, churches, commercial centres, hotels, airports, etc.), but also dwelling buildings and even many small private houses (Dolce et al., 2006, Martelli and Forni, 2008, and Martelli et al., 2008).

2. APPLICATION IN THE RUSSIAN FEDERATION

The Russian Federation is now third at worldwide level for the number of applications of the SVPC systems. It is preceded by Japan (which is largely the leading country, with approximately 5,000 isolated buildings, including about 3,000 small private houses, in addition to several isolated bridges and viaducts and hundreds of constructions protected by ED devices), and by the P.R. China (where there were 610 isolated buildings and 45 protected by ED systems, besides numerous isolated bridges and viaducts, in May 2007). In the Russian Federation there were approximately 600 isolated buildings in May 2007 (Martelli and Forni, 2008). There, the use of the not very efficient reversed mushroom-shaped reinforced concrete (r.c.) isolators was replaced by the systems used in other countries some years ago. Recent applications include retrofits of some important historical constructions by means of SI (Figure 1) and the new ones even SI of high-rise buildings (Figures 2 ad 3).

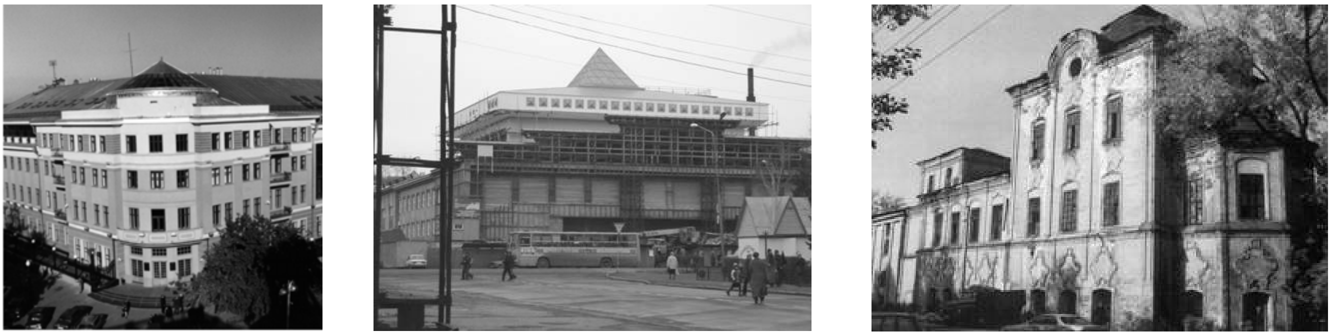

Figure 1 Retrofits with SI in the Russian Federation. (a) Left: *Irkutsk City Central Bank*, retrofitted by means of High Damping Rubber Bearings (HDRBs). (b) At the centre: *National Drama Theatre* at Gorno-Altaisk, retrofitted by means of HDRBs and Visco-Elastic Dampers (VEDs). (c) Right: *Mihailo-Arkhangelskaya Church* at Irtutsk City, retrofitted by means of HDRBs.

Figure 2 The new r.c. *hotel complex* to be erected at a Sochi, Ordzhonikidze Street (27 storeys, in addition to 2 underground ones; height ≈ 93 m; living area = 40,000 m^2), protected by 156 Lead Rubber Bearings (LRBs).

Figure 3 The new r.c. *commercial centre* (with cinemas, underground parking and offices) to be erected at Sochi (21 storeys, in addition to the ground and 2 underground floors; height ≈ 100 m; living area = 50,000 m^2), protected by 200 LRBs.

3. APPLICATION IN ITALY

After the USA, which are at the fourth place for the number of applications of the SVPC systems, with approximately 200 large (new and retrofitted, civil and historical) isolated buildings, 200÷300 isolated bridges or viaducts and several applications of ED systems (Martelli and Forni 2008), fifth and first in the European Union (EU) remains Italy, at least for the number of isolated buildings that are already opened to activity: at least 57 in July 2008 (they were 43 at the end of 2006, see again Martelli and Forni, 2008).

Figure 4 From left to right: (a) cumulative number of Italian building applications of SI during years, based on data of March 2008 (the very limited application from 1995 to 2003 was due to the absence of adequate design rules); (b) *Somplago Viaduct*, first application of SI in Italy, built near the epicentre of the 1976 *Friuli* earthquake in 1975; (c) *Headquarters Building of the New Fire Station at Naples*, built in 1981 with a seismic protection system formed by 24 Neoprene Bearings (NBs) with mechanical dampers at the top and by 80 floor dampers.

Figure 5 From left to right: (a) the 5 buildings of the *Telecom Italia Centre* of Marche Region at Ancona, first large application of base SI in Italy (HDRBs enabled a 7% saving of construction costs, the safety of the buildings was certified by A. Martelli); (b) entrance building of the Centre (its erection with this shape was possible thanks to SI); (c-d) the 8-storey, 25 m high, building of the Centre which was subjected to forced vibration and snap-back tests to 80% of the 140 mm design displacement in 1990.

Figure 6 The new wing of *Gervasutta Hospital* at Udine (first Italian hospital structure to be protected by SI), after its completion and during construction with 56 HDRBs in 2005 (before the enforcement of the new seismic code).

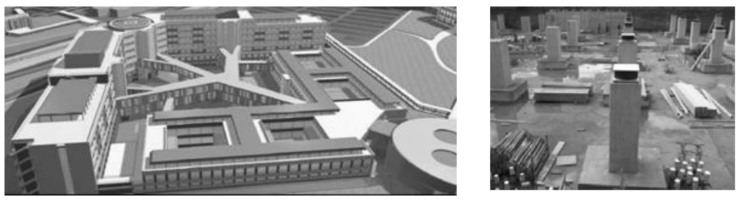

Figure 7 Sketch of the new isolated *Del Mare Hospital*, which was designed after the enforcement of the new seismic code and is under construction at Naples, and view of some of its 327 HDRBs. Most new Italian hospitals being or to be erected in seismic areas now include SI for earthquake protection.

The use of the SVPC systems began in Italy in 1975 for viaducts and in 1981 for buildings (see Figure 4), namely four years before Japan and the USA. However, it remained rather limited several years long after 1990 (Figure 4a): this was due to the lack of design rules to the end of 1998, then because of their inadequacy and the very complicated and time consuming approval process to May 2003.

Figure 8 Form left to right: (a) *Fire Command Building*, completed with 52 HDRBs and 5 Sliding Devices (SDs) in 2005, (b) *Corps of Foresters Building*, completed with 16 HDRBs and 4 SDs in 2006, and (c) sketch of the main *Control Building*, being now erected on 10 HDRBs of 1 m diameter, of the new *Civil Defense Centre of Central Italy* at Foligno (Perugia). The site was reclassified from seismic category 2 to seismic zone 1 in 2003, but there was no need for design changes of the structures, thanks to SI. Four (4) of the 11 isolated buildings have already been completed and 2 are under construction (the safety of the latter will be certified by A. Martelli).

Figure 9 (a-b) Left and centre: the new *Civic Room & Red Cross Headquarters* of Gaggio Montano (Bologna), quite an irregular structure located in seismic zone 3 that was isolated by means of 33 HDRBs and 4 SDs in 2006 (due to the strong structural irregularities, the use of SI did not cause any additional construction costs with respect to a conventional fixed-base design, in spite of the low seismic level). (c) Right: view, in autumn 2007, of the new *School Complex at Bojano* (Campobasso), located in seismic zone 1, which is being isolated by means of 25 LRBs of 700 mm diameter, 16 LRBs of 600 mm diameter, 8 SDs of 1000 mm side and 5 SDs of 890 mm side.

Figure 10 From left to right: (a) the 2 buildings of the new *F. Jovine School* reconstructed at San Giuliano di Puglia (Campobasso, seismic zone 2 since 2003) on an unique isolated slab, after the collapse of the previous primary school during the 2002 *Molise and Puglia* earthquake (it is the second school application of SI in Italy, after that of Morrone sul Sannio in 2005); (b) view of its SI system (61 HDRBs and 12 SDs donated by the Italian manufacturers), during construction in 2006-08 (SI design was offered by a team of experts coordinated by Dr. Clemente of ENEA and tests by the University of Basilicata – safety was certified by A. Martelli and C. Pasquale in September 2008); (c) the first building of the new *School at Mulazzo* (Massa Carrara) (one of the 5 schools being reconstructed with SI in Tuscany, in seismic zone 2), protected by 14 LRBs and 15 SDs (safety will be certified by A. Martelli in 2008); (d) the *Romita High School* at Campobasso (1500 students), to be soon subjected to retrofit and reconstruction of some of its blocks by means of SI (with ENEA collaboration).

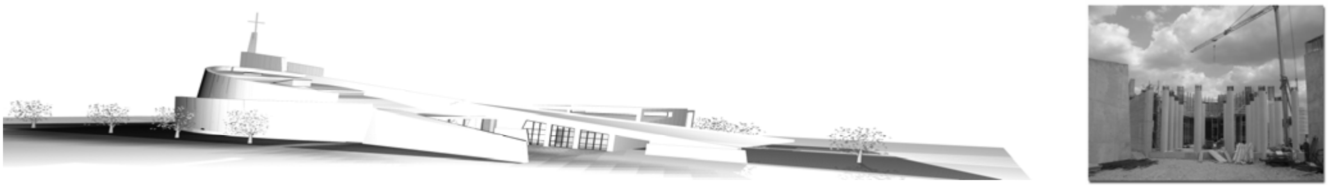

Figure 11 The new *Church of San Francesco d'Assisi in Villa d'Agri*, under construction at Marsico Vetere (Potenza, seismic zone 1). The church roof is being isolated by means of HDRBs and SDs, while the bell tower is being base-isolated by means of "very high damping" rubber bearings (ADRIs) and SDs. This is the first Italian application of SI to new churches, namely structures with rather a large exposure and (frequently) vulnerability.

Figure 12 *Rione Traiano Civic Centre* at Naples, retrofitted by cutting the supporting columns and walls and inserting about 630 HDRBs in 2004. It was the first application of SI in building retrofits that was performed in the EU.

Figure 13 *Headquarters of Fratellanza Popolare – Croce d'Oro* at Grassina (Florence), base-isolated with SDs and Viscous Dampers (VDs) in 2007. Safety was certified by A. Martelli.

Figure 14 *NATO Centre of South Naples* (399 HDRBs and ~20 dissipative SDs), during construction in 2007.

Figure 15 The 4 r.c. dwelling buildings of the new *San Samuele Quarter* at Cerignola (Foggia), in seismic zone 2, first application of the new Italian seismic code to isolated dwelling buildings, recently completed with 124 HDRBs. Their safety was certified by A. Martelli in September 2008.

Figure 16 A r.c. *private house* at Fabriano (Ancona, seismic zone 2), damaged by the 1997-98 *Marche and Umbria* earthquake, first EU application of SI in a sub-foundation, the retrofit of which was completed with 56 HDRBs in 2006. Safety of the house was certified by A. Martelli.

Figure 17 R.c. *private house* isolated using HDRBs at Santa Venerina (Messina) in 2006 (first new Italian isolated private house).

Figure 18 R.c. *private house* isolated at Ragusa by means of HDRBs installed at the top of the lowest floor (as frequently made in Italy), during its construction works in 2006.

Figure 19 *Dwelling building nr. C8R* at San Giuliano di Puglia (Campobasso), isolated by 13 HDRBs and 2 SDs, which was completed in 2007.

Figure 20 The SI system of *dwelling building nr. C20R* at San Giuliano di Puglia, formed by 25 HDRBs and 12 SDs, immediately after installation in March 2008.

Figure 21 *Masonry dwelling building* erected at Corciano (Perugia), in seismic zone 2. SI enabled the construction of one additional floor.

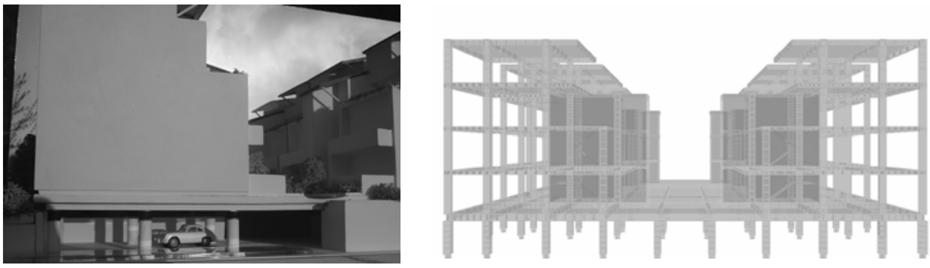

Figure 22 *Group of 6 r.c. dwelling buildings* to be erected on the same artificial ground slab supported by 40 HDRBs and 12 SDs within the demolition & reconstruction project of a very degraded 11-buildings complex at Marigliano (Naples, now seismic zone 2). 60 buildings on 16 slabs, supported 400÷450 HDRBs and 360÷380 SDs, have been planned by a team of GLIS experts.

Figure 23 *Roman ship* excavated near Ercolano (Naples) and displayed of the local museum (seismic zone 2), which was recently seismically isolated by means of 4 three-directional (3D) isolators developed in the framework of the SPACE project, funded by the European Commission (EC). The 3D isolators are formed by 3 steel spheres rolling between two steel plates and by a rubber re-centring cylinder for horizontal SI, with a spring and a VD for vertical SI.

Figure 24 *David of Michelangelo*, for which a SI project has been jointly developed by the University of Perugia, ENEA and ALGA.

Nowadays, however, there is a large increase of the number of applications completed in the last three years and, especially, of those in progress or under design, thanks to the new Italian seismic code, enforced in May 2003 (mostly as a consequence of the tragedy of San Giuliano di Puglia during the 2002 *Molise and Puglia* earthquake

– see also Figure 10a-b), which frees and simplifies the adoption of the SVPC systems. Most new Italian hospitals, civil defence centres and schools are being seismically isolated (Figures 6-10), together with a significant number of dwelling buildings and other constructions (Figures 11, 13-15 and 17-22). Some important retrofits of civil structures have already been completed, even with SI (see, for instance, Figures 12 and 16). SI has also already been adopted for the protection of important masterpieces (e.g. the Bronzes of Riace at the Reggio Calabria Museum) and has been planned even for that of David of Michelangelo in Florence (Figures 23 and 24). Finally, Italy remains among the worldwide leading countries for the use of the SVPC systems in bridges and viaducts.

4. APPLICATION IN OTHER EUROPEAN COUNTRIES

With regard to the number of applications of SI and other SVPC systems in other countries, Italy is now followed by Taiwan (where the use of SVPC systems began after the 1999 *Chi Chi* earthquake, thanks to a new favourable seismic code), France (Figure 25), New Zealand, Armenia (as a consequence of the 1988 *Spitak* earthquake), Turkey (were application began after the 1999 *Kocaeli* and *Duzce* earthquakes), Mexico, South Korea, Chile, Canada and other countries, including some European ones (Martelli and Forni, 2008).

Figure 25 An isolated *school* in the Martinique island (France), protected by means of NBs and VDs, similar to the other isolated buildings of that island.

Figure 26 Left: the reticular ceiling of the *Akrotiri Excavations* in the Greek Santorini island, protected by 92 LRBs and 2 SDs manufactured in Italy in 2003. Right: the *International Broadcasting Centre* at Athens, isolated by means of 292 HDRBs manufactured in Italy in 2003, just before the beginning of the Olympic Games.

Figure 27 The Athens *Onassis Centre* at Athens (Greece), with the *Acropolis Museum* (at the centre), isolated by means of 94 Seismic Isolation Pendulum (SIP) devices manufactured in Germany in 2006, and the *Onassis House of Letters & Fine Arts* (right), during construction with SIP devices in 2007.

The latter are Greece (Figures 26 and 27), Portugal (Figure 28), Spain, Cyprus (Figure 29) and Macedonia (Figure 30). There the SVPC devices have been frequently manufactured in Italy and some designs are due to Italians. Italian devices have also been installed in several other countries, like Taiwan, Turkey, South Korea, Venezuela, Indonesia, the USA, Canada, Iran, etc. Further countries that also began using the SVPC systems for the protection of buildings are Argentina, Israel and India. As to France, after the first applications to nuclear reactors, spent fuel storage pools and other nuclear structures performed in the years 1970s, SI is now being used, in the mainland, for the protection of the *Jules Horowitz Reactor* and has been planned for that the *ITER* plant; furthermore, SI is now obligatory in the Martinique island for schools and other public buildings (Figure 25).

Figure 28 Sketch of the *Shakolas Park Commercial Centre* at Nicosia (Cyprus), designed by the Italian engineers Giuliani (Milan) and consisting of 2 buildings with mixed r.c. and steel structure, which is being isolated by means of 164 HDRBs installed at top of the basement columns.

Figure 29 The new *La Luz Hospital* at Lisbon (Portugal), which was isolated (together with a *Residence for Old People*) in 2006, and view of some of the 315 HDRBs, manufactured in Italy, installed at the buildings base (195 at that of the hospital and 120 at that of the residence for old people). They are the only isolated buildings in Portugal (where, however, several bridges and viaducts have been protected by SVPC systems, many of which manufactured in Italy).

Figure 30 *Pestalozzi school* at Skopje (Macedonia), isolated in the years 1960s, after the 1963 earthquake. Its degraded rubber bearings were replaced by HDRBs in 2008.

5. CONCLUSIONS

Italy (where the contributions provided by ENEA and GLIS have been of fundamental importance) is largely the leading country in Europe as regards the development and application of SI and other SVPC systems. The latter concerns new and existing strategic, public and dwelling buildings, bridges and viaducts and cultural heritage, including some well known masterpieces. SI applications already exist in other European countries too. Many of these make use of Italian devices. The latter have also been installed in several further countries. Hopefully, SI will soon be used in the high risk plants, as well: not only in nuclear structures, but also in chemical components such as LNG tanks, for which, to date, only very few applications exist (in South Korea, P.R. China, Turkey, France and Greece): in fact, detailed studies have shown that SI is indispensable for them in highly seismic areas.

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