13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2180

PROGRESS ON THE DEVELOPMENT AND APPLICATION OF SEISMIC VIBRATIONS CONTROL TECHNIQUES IN ITALY

Alessandro MARTELLI[1] and Massimo FORNI[2]

SUMMARY

The state-of-the-art of application of the seismic vibration control (SVC) techniques in Italy is summarized, by stressing recent progress. Some remarks on the related R&D and information and training projects are also reported. The excellent perspectives for a rapid extension of application of the SVC techniques are stressed. They are a consequence of the recent availability of both the new Italian seismic code (which allows for the free use of seismic isolation and energy dissipation and simplifies such a use) and the seismic reclassification of the Italian territory (which considerably increases the percentage of that considered as seismic, suggests minimum seismic design requirements for the entire country and requires the verification of the seismic safety of all strategic buildings within five years). In addition, the new policy of the Ministry of Infrastructures and Transportations to support the use of the modern anti-seismic techniques, in the framework of the "Quarters' Contracts – 2" Program, should considerable help. Finally, it is noted that a wide use of the SVC techniques has been planned for the reconstruction in Molise after the earthquake of October 31, 2002, especially at San Giuliano di Puglia, which was strongly damaged by the aforesaid earthquake and where ENEA and GLIS have been particularly active.

INTRODUCTION

In recent years considerable progress has been made in Italy on the application, R&D and development of design rules for the seismic vibrations control (SVC) techniques of civil and industrial structures, namely for seismic isolation (SI), energy dissipation (ED) and coupling systems formed by shock transmitters (STs) or shape memory alloy (SMA) devices. Activities are going on taking advantage of the national collaborations established in the framework of the Italian Working Group on Seismic Isolation (GLIS) and those with partners of other countries of the European Union (EU), represented in Task Group 5 on Seismic Isolation of Structures (TG5) of the European Association for Earthquake Engineering (EAEE).
Such collaborations and those established with several non-EU partners allowed for the foundation, on November 21, 2002, of the *A*nti-*S*eismic *S*ystems *I*nternational *S*ociety (*ASSISi*). *ASSISi* has already approximately 70 members, representing 27 countries. Its first official event was the 8th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, which took place at

[1] Chairman, GLIS, President, *ASSISi*, and Coordinator, TG5-EAEE; ENEA, Bologna, and Faculty of Architecture of the University of Ferrara, Italy
[2] Technical Secretary, GLIS, and Founding Member, *ASSISi*; ENEA, Bologna, Italy

Yerevan, the capital of Armenia, on October 5-10, 2003 [1].
With regard to the seismic design rules, it is worthwhile stressing that a new code is now available in Italy as a consequence of the large echo provoked by the 27 children killed by the collapse of the elementary school of San Giuliano di Puglia (a village with approximately 1200 residents), with the extinction of an entire class (those born in 1996), during the Molise earthquake of October 31, 2003 (in spite of its not very large magnitude). In fact, a special commission entrusted by the Presidency of the Italian Ministries' Council at the end of 2003 developed such a code within an unusually very short time: it is dated March 20, 2003 and was issued on May 8, together with the general criteria for the seismic reclassification of the Italian territory [2]**.** Besides being at last consistent with Eurocode-8, the new code also includes the free use of SI and ED and simplifies such an use. Thus, it is now no more necessary in Italy to apply for the approval of the projects using such systems by the High Council of Public Works of the Ministry of Infrastructures and Transports (former Ministry of Construction), which was previously a real obstacle, due to very complicated and time consuming bureaucratic procedures. In addition, the new code requires that the seismic safety of all existing strategic and public buildings is carefully checked within five years.
As regards R&D, numerous activities have been performed within both national projects (such as, for instance, in Italy, ALGADECS, ISI and, as far as seismic protection of cultural heritage is concerned, PROSEESM and others) and projects and networks funded by the European Commission (EC) (such as, for instance, SPIDER, SPACE, SAMCO, VAST-IMAGE and INDEPTH). The main features of some of these projects, which were partly recently completed and are partly still in progress, are briefly summarized in the following Section. More details on these and other ongoing projects were provided at the Yerevan Seminar [1,3] and have been reported at this conference in separate papers. Similarly, a separate paper presented at this conference deals with the MUSICA Project of ENEA and GLIS on information and training on the SVC technologies.
As far as the new applications of such techniques are concerned, this paper stresses those, which are in progress in the EU for the first time, for the retrofit of existing Italian buildings by means of SI. Furthermore, in addition to other new ongoing applications (e.g. that to the new Emergency Management Center at Foligno, Umbria), this paper reports some information on the reconstruction of San Giuliano di Puglia and the seismic rehabilitation works of schools planned at Campobasso, because there and in other villages damaged by the earthquake of October 31, 2002 a wide use of the SVC techniques has been planned, for both new and existing buildings.

1. RECENT R&D AND INFORMATION AND TRAINING PROJECTS

1.1 The ALGA-DECS Project

Two important national projects that were recently developed in Italy by ENEA were ALGA-DECS and ISI [3]. Activities for ALGA-DECS began in 2000; they concerned support to the development and qualification of electro-inductive EDs ("Electro-inductive Devices for Structural Control" - DECS) on behalf of the Italian ALGA manufacturing company, in the framework of a four-years research project funded by the Ministry of the University and Scientific and Technological Research. Linear passive DECSs were developed, which join the guarantee of a correct working independently of external factors to manufacturing simplicity. The contribution of ENEA consisted in both the development and validation of numerical models of DECSs and structure mock-ups provided with them, and execution of experimental tests on shaking table of such mock-ups. To this aim MISS ("Model of Isolated Steel Structure"), a steel frame 250 kN weight mock-up, was used. MISS had been designed, manufactured and used for shaking table tests at ENEL.Hydro in the framework of an EC-funded Project aiming at the development of optimized High Damping Rubber Bearings (HDRBs) [3]. Then, it had been suitably modified (by adding rigid braces to allow for the installation of ED devices) and had been successfully used in shaking table tests also at the ENEA-Casaccia laboratories in the framework of the EC-funded REEDS Project, which aimed at the development and optimization of ED devices [3].
Numerical modeling of the single devices and numerical and experimental analyses of the MISS results were performed by ENEA and provided good results. The shaking table tests, carried out at ENEA-

Casaccia laboratories using both natural and synthetic earthquakes, showed that DECSs halve MISS deformations without any increase of acceleration or reaction forces (contrary to rigid conventional braces), due to the excellent ED: their insertion in MISS allowed for the application of a base acceleration 2.5 larger with respect to the conventional solution. This is the best result reached by an ED systems in the experimental campaigns carried out at ENEA [1,3].

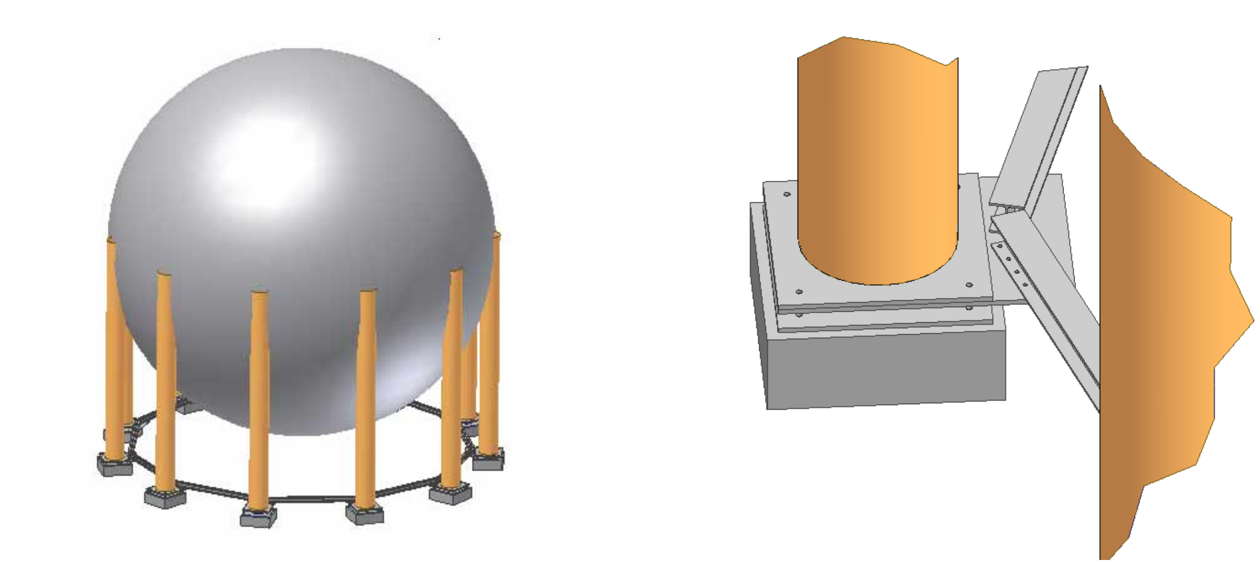

Figure 1: Retrofit with base SI designed for the tank analyzed in the ISI Project.

Table 1: ISI Project: results of calculations on the ISI tank (H = rubber height).

Empty	Full 100%	Full 80%	Sloshing	Seismic Isolation	TRESCA Stress MPa	Displac. mm	Accel. m/sec^2
X				NO	227	26	12.3
X				3 HDRBs + 8 SDs	99	71	1.60
	X			NO	901	107	4.12
	X			11 HDRBs H=100	341	187	1.57
	X			11 HDRBs H=150	346	199	1.14
	X			5 HDRBs +6 SDs	264	232	0.68
	X			3 HDRBs +8 SDs	215	205	0.42
		X		NO	758	90	4.33
		X	X	NO	660	77	5.14
		X		3 HDRBs +8 SDs	183	187	0.46
		X	X	3 HDRBs +8 SDs	161	118	0.52

1.2 The ISI Project

The ISI Project, which was funded by the Italian National Research Council (CNR) and completed in 2002, concerned the evaluation of applicability of SI and ED to the seismic protection of high risk chemical components, in particular Liquefied Natural Gas (LNG) and other tanks. The study was based on an existing spherical storage tank for butanes located in a highly seismic Italian area (Figure 1). The most promising solutions were found that proposed by ENEA, formed by 3 HDRBs (acting as isolators, energy dampers and re-centering devices) and 8 sliding devices (SDs, acting as isolators and dampers), and that proposed by the University of Rome "La Sapienza", formed by 11 elastic-plastic dampers (EPDs) [3]. The SI system proposed by ENEA leads to a reduction of the maximum relative displacements between top and base of the tank supporting columns by a factor 10, namely from approximately 100 mm to approximately 10 mm; it provides a sufficient restoring force and an ED related to the fluid mass inside the tank, but leads to an absolute displacement of about 200 mm during the earthquake (Tables 1 and 2). On the contrary, the SI system formed by 11 EPDs (Tables 1 and 2) entails a lower displacement during the earthquake, but causes a small residual displacement after it (about 40 mm). Both systems offer a strong reduction of the seismic forces transmitted to the structure. At any rate, the benefits of the SI and ED systems being confirmed, they may be used to really retrofit the considered tank. In addition, based on the experience gained in the ISI Project, ENEA decided to considerably extend the studies concerning the seismic protection of chemical plants (see Sect. 1.6). In fact, this is an extremely important field, which is, however, still insufficiently studied, at least in Europe.

Table 2: ISI Project – Comparison of the different solutions on the ISI tank.

	Total Shear Force (kN)		Displacement (mm)	
	Full	Empty	Full	Empty
Fixed Base	14400	3890	90	32
11 HDRBs	2900	1000	243	80
Mixed	1260	470	187	71
11 EPDs	1195	961	144	41

1.3 The SPIDER Project

The objective of the SPIDER Project [4] was to overcome the limits of ED devices through the development of a system based on the in-series coupling of dampers and cables (DCS). The technical key problem concerned the connections between the cables and the structure and between each cable and the related damper. The project, which was concluded in 2002, comprised both tests and numerical analyses. The damper-cable system was validated through the development of prototypes and tests on a full-scale two-story reinforced concrete (r.c.) building mock-up. In parallel, the tests were used to calibrate specifically developed numerical tools. This allowed for the extrapolation of the results to real structures, more complex than a two-story mock-up. The ENEA activities were mainly devoted to the implementation of Finite Element Models (FEMs) of the SVC devices developed within the project itself. [1,3]. Analysis of the experimental results showed DCSs are very efficient: they reduce displacements by a factor 2.5 to 3 and dissipate more than 50% of the total input energy.

With regard to the architectural aspects, those related to the insertion of DCSs were evaluated by ENEA in cooperation with Antonucci Consulting Office based on three very interesting existing civil buildings. Although the application of DCSs can be internal, external and within the walls' plane, the external installation is often preferable because it allows for the operability of the building during the rehabilitation works. However, the architectural features of most buildings may contrast with this kind of technological solution. In these cases, the cables shall be hidden. To this aim, the possibility of using cover panels was analyzed: this second solution also allows for protecting the DCS system and providing thermal insulation to the building. Moreover, the steel frame supporting the panels can also be used as a reaction structure for the static load provided by the cable. In this case, horizontal forces are transmitted by the cables to the structures only during seismic attacks. This solution, which is particularly suitable for old buildings, also allows for a better layout of the cables. In fact, the steel frame can be positioned along the facade of the building in order to eliminate (or, at least, reduce) the number of windows (or doors) crossed by the cables.

1.4 The SPACE Project

The main goal of the SPACE Project [5], which was completed in 2003, was the development of magneto-rheological devices (MRDs) for the semi-active control (SAC) of structures. These are oleo-dynamic (or viscous) devices, the stiffness of which depends on the applied magnetic field. In fact, these devices are filled with a fluid which contains iron particles that change their orientation in presence of a magnetic field. Such an orientation strongly influences the viscosity of the fluid and thus, the stiffness of the device, which can be varied during the earthquake based on a suitable control algorithm depending on the kind of structure. Moreover, two and three-directional (2D and 3D) passive devices for floor SI of critical buildings (control rooms, operational theatres, museums) were developed within the project. It is worthwhile noting that floor isolation (FI), in spite of its apparent affinity with the well known base seismic isolation (SI), is actually a difficult task which implies the solution of hard technical problems. In fact, the design displacement of an isolated floor is the same as that of the whole building, while the isolated mass is only a little part of it. Thus, there are serious instability problems to be overcome for the SI devices. It is worthwhile noting that the 3D isolation devices developed within the project are being used for the protection of an ancient Roman ship, near the museum of Ercolano [1]. Finally, passive and SAC techniques were merged to produce hybrid systems, composed by passive SI bearings and SAC devices. The main features and results of SPACE are reported in a separate paper at this conference [6].

1.5 The VAST-IMAGE Project

Aim of VAST-IMAGE [7], an ongoing EC-funded Project, is the development of a very innovative seismic isolator made of magnetically controlled elastomer (MCE) for the SAC of structures. A MCE is a particular rubber compound filled with iron particles. In presence of a magnetic field, an attractive force is present among the particles, thus the isolator stiffness can be controlled by varying the intensity of the magnetic field. In particular, aim of the project is to reduce the isolator stiffness at low deformations, so as to provide the structures with the same level of protection for any earthquake intensity. In fact, the isolator stiffness is usually significantly larger at low deformations, with a consequent increment of the isolation frequency. Of course, this kind of application is particularly addressed to the protection of the contents of critical buildings, like hospitals, museum, etc., in very seismic areas, which are usually designed to withstand quite large earthquakes and, thus, if protected by passive SI devices, may not adequately behave during much more probable still violent, but rather lower, events. One of the reference structures selected within the project is the hospital of the Italian Navy at Augusta, Sicily. This building is provided with HDRBs and is a very interesting study case to validate a SAC system based on MCE. ENEA is mostly involved in the modeling of the MCE isolator with the aim of providing inputs to the manufacturer, and in the development of the control algorithm [1].

1.6 The INDEPTH Project

The ongoing EC-funded Project INDEPTH [8] aims at developing and applying innovative SI and/or ED devices for critical structures at petrochemical facilities, such as cylindrical/spherical tanks, thereby reducing the seismic risk at such facilities in highly-seismic areas, where a limited number of such applications exists, apart very few in LNG tanks. However, the large displacements experienced by a seismically isolated structure subjected to an earthquake potentially overstress the attached piping. ENEA has been involved in the analysis of the effects of sloshing, in both cylindrical and spherical tanks with the inner liquid at various levels, and in designing the mock-up of spherical tanks to be used in the shaking table tests [1].

1.7 The MUSICA Project

In May 2000, ENEA and other partners (research centers, universities, experimental laboratories, national Institutions, manufacturers, engineering companies and building companies) associated to GLIS jointly undertook the Project MUSICA (“MUltimediale per lo sviluppo di Sistemi Innovativi per Costruzioni Antisismiche”, namely “MUltimidia for the development of Innovative Systems to make Constructions Anti-seismic”). This project consists in the development of a series of films of various durations on manufacturing, R&D and application of the SVC techniques. The aim is to contribute to information and training, on such techniques, of designers, representatives of the national, regional and local Institutions and the regular public, as well, through a better, modern use of media. The expected consequence of this information and training activity is to more incisively contribute to the promotion of the wider application of the SVC techniques. The features of MUSICA are presented in a separate paper at this Conference [9].

2. RECENT APPLICATIONS TO BRIDGES AND VIADUCTS

Applications of the SVC devices to bridges and viaducts began in Italy in the years '70s. In the '90s they were already over 150, which made Italy the worldwide leading country in this field. With regard to recent years [1,3], almost half of the approximately 140 applications to road, freeway and railway bridges and viaducts that have been performed in the EU from 2001 to 2003 concerned Italy. As usual, ED systems and STs have been mainly used for such applications in our country; important examples are those completed in 2002 to:

- the "SS647 Fondovalle Biferno" viaducts in the Campobasso Province (184 EPDs);
- several bridges and viaducts of the Salerno – Reggio Calabria freeway (128 EPDs);
- the "Sospertole" viaduct of the "S.S. 318 Val Fabbrica" road, the bridge over the San Leonardo river of the "S.S. 114 Orientale Sicula" road and the Melilli viaduct of the "S.P. Melilli – Sortino" road (20, 34 and 24 EPDs, respectively);
- a viaduct on the Aquila-Rome freeway, the aforesaid bridge on the San Leonardo river and the aforesaid "Melilli" viaduct, with 2, 50 and 44 fluid dampers (FDs), respectively.

Thanks to the new Italian seismic law, further new applications began in 2003. It is also worthwhile noting that Italian manufacturers considerably extended the application of their devices towards other countries, as well, both in Europe (Albania, Croatia, Czech Republic, Greece, Portugal, Slovenia, Spain, Switzerland) and in other continents (Algeria, Argentina, Bangladesh, Dominican Republic, Guinea, Korea, Taiwan, Venezuela, USA, etc.) [3].

3. RECENT APPLICATIONS TO CIVIL BUILDINGS

To the knowledge of the authors, most recent civil building applications of the SVC techniques in the EU have been performed or designed in Italy. In this country, the total number of completed seismically isolated buildings was 25 at the end of 2003 [3]: they are listed in Table 3 and Figure 2, which also shows their location in a map of the Italian territory that identifies the most seismic areas according to the previously mentioned very recent seismic reclassification. In addition to these, 36 further new building applications of SI were already in quite an advanced development at the end of 2003 (see again Figure 2 and Table 3).

With regard to the building applications of ED systems, those completed were 25 at the end of 2002; however, numerous new applications are in progress or being designed. Finally, as far as the use of SMA devices is concerned, there were 2 further applications to the restoration of Italian monumental buildings in 2002.

The diagrams reporting the total numbers of applications of SI and ED systems in Italy during years are shown by Figures 3 and 4: they stress that, after an initial revival of the interest in such techniques as a consequence of the 1997-98 Marche and Umbria earthquakes and the issue of design guidelines for seismically isolated structures by the Ministry of Constructions at the end of 1998, this interest was again soon damped by the very complicated and time-consuming procedures required by such guidelines to get the approval of the projects by the High Council of Public Works of the Ministry [10].

However, by allowing for the free use of SI and ED systems, the aforesaid recent new Italian seismic law offers new excellent perspectives of a rapid extension of the Italian applications of the SVC systems. This confidence is also a consequence of the seismic reclassification of Italy, which (after the decisions to be taken by law by the Regional Governments) will soon increase the percentage of the territory considered as seismic from the previous 43% to about 70% and suggests minimum seismic design requirement for the entire country. In addition, the new policy of the Ministry of Infrastructures and Transports to support the use of the modern techniques for the prevention of the effects of natural disasters (in particular, earthquakes), in the framework of the so-called "Quarters' Contracts – II" Program for the rehabilitation of degraded residential areas, should considerable help. Even before the activation of the aforesaid Program, the city of Cerignola (which was developing a project in the framework of the previous issue of the Program – "Quarters' Contracts – I") obtained from the Ministry the agreement for the modification of its project so as include SI of the entire concerned residential buildings set (Figure 5) [3]; in addition, several projects being prepared by Italian municipalities in the framework of the "Quarters' Contracts – II" Program are considering the use of SI and / or ED systems (the deadlines for submitting such projects vary from March to April, depending on the Region).

Table 3: Building applications of SI in Italy

Application n°	Place / Building / Year	Number of isolated buildings (and total number)
1	Naples, first New Fire Station building, 1981	1
2	Naples, second New Fire Station building, 1985	1 (2)
3	Ancona, Civic Centre, 1989	1 (3)
4	Avezzano, Texas Instruments building, 1989	1 (4)
5	Ancona, TELECOM Centre, 1990	5 (9)
6	Squillace, Apartment building, 1992	1 (10)
7	Ancona, Italian Navy Training Centre, 1992	1 (11)
8	Augusta, Italian Navy Medical Centre, 1993	1 (12)
9	Augusta, Apartment buildings, 1993	4 (16)
10	Potenza, University of Basilicata, 1995	5 (21)
11	Rapolla, Apartment building, 2000	1 (22)
12	Città di Castello, IERP Apartment buildings, 2003	3 (25)
13	Fabriano, Apartment building (retrofit), in progress	1 (26)
14	Frosinone, Hospital	3 (29)
15	Soccavo, Civic Center (retrofit), in progress	1 (30)
16	Solarino, Apartment buildings (retrofit), in progress	2 (32)
17	Udine, Hospital, in progress	1 (33)
18	Foligno, Civil Defense Centre, in progress	13 (46)
19	Apagni & S. Croce, Churches (retrofits), in progress	2 (48)
20	Mevale, House (reconstruction), decided & designed	1 (49)
21	Cerignola, Aparment buildings, decided & designed	12 (61)

Finally, it is noted that applications in other countries of SVC systems manufactured in Italy are going on also for buildings: recent examples are those performed at the Zurich airport (Switzerland) in 2001 (10 STs) and, in 2003, to the new shelter of Akrotiri antiquities in the Greek Santorini island (92 Lead Rubber Bearings – LRBs – and 2 SDs) and the Taipei Financial Center in Taiwan (8 viscous dampers – VDs).

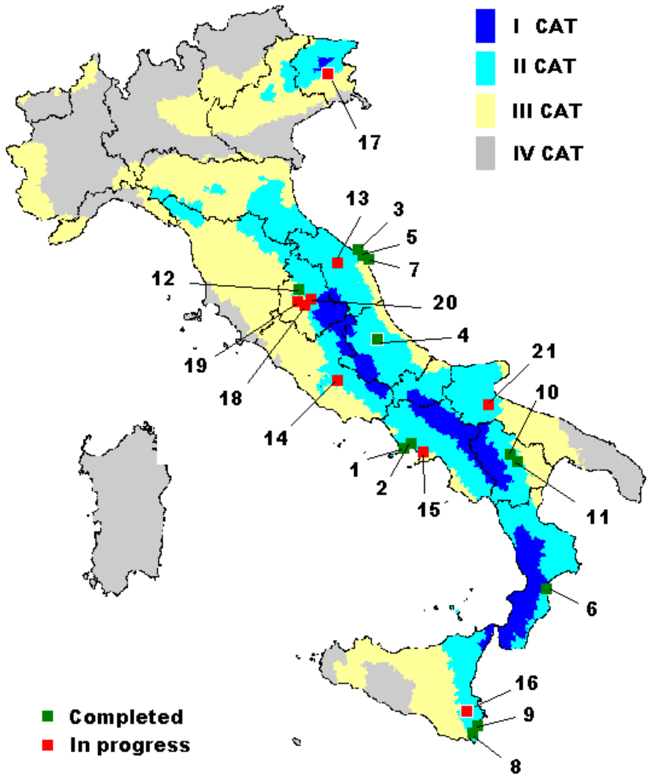

Figure 2: Location of the isolated buildings in Italy (see Table 1) and new seismic classification.

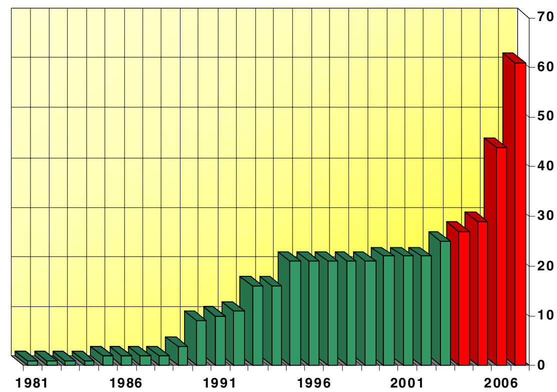

Figure 3: Number of building applications of SI in Italy.

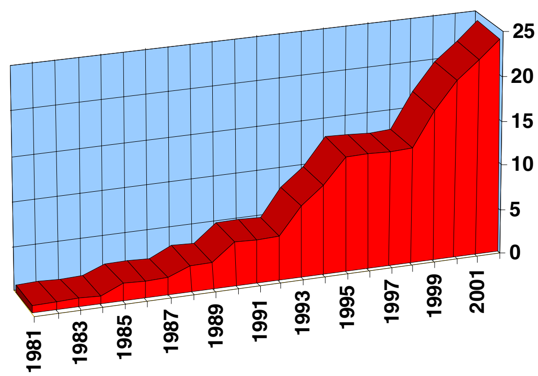

Figure 4: Number of building applications of other SVC systems in Italy.

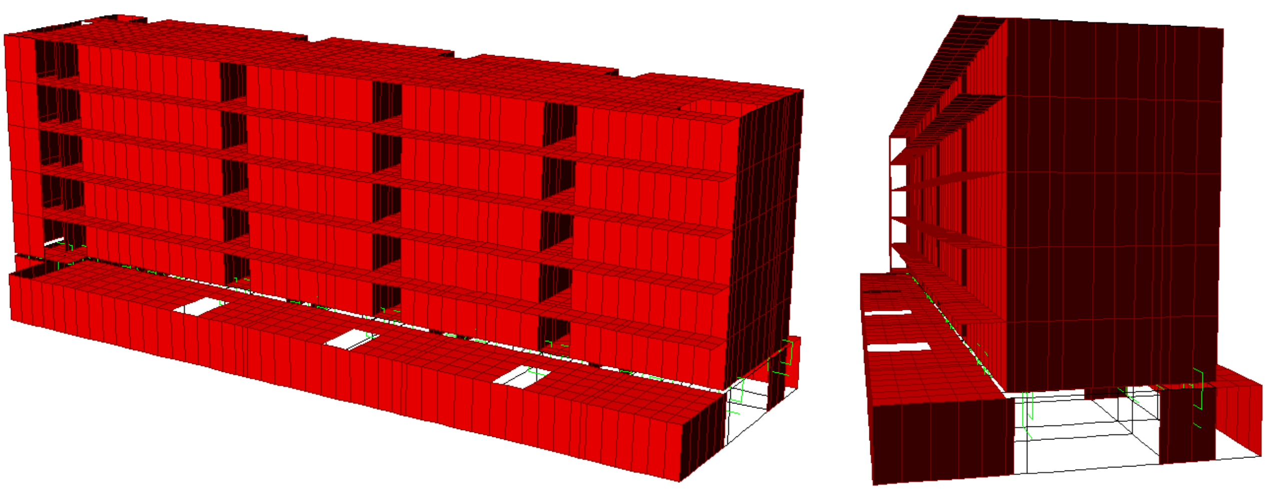

Figure 5: Design of the SI systems of the Cerignola buildings and related structural modifications [10].

3.1 Ongoing applications and projects concerning new buildings

The most important application of SI which was very recently completed in Italy is that to the three residential reinforced concrete (r.c.) buildings of Città di Castello (Perugia) (Figure 6a), containing 34 apartments and some business premises. Their erection had begun in 2001 [11] and made use of HDRBs installed at the top of the first floor (Figure 6b). Based on this positive experience and due to the reasonably limited additional costs caused by SI, some new projects of isolated apartment r.c. and also masonry buildings are already in progress, in both in Umbria and other Italian Regions.

In addition, based on the positive results of the feasibility study performed by ENEA as regards the reconstruction, with the original masonry materials and SI, of the village of Mevale di Visso (which had been fully destroyed by the 1997-98 Marche and Umbria earthquakes [1,3]), these methods should be used for at least one house of this village (but hopefully, more): the final decision will be taken shortly by the Technical-Scientific Committee of Marche Region.

With regard to strategic buildings, to be cited is the erection of a new section of the Gervasutta Hospital at Udine, to be provided with 52 HDRBs, which began in 2003 [3], and the recent completion of the design of part of the 13 buildings of the Emergency Management Center of Foligno [3, 11], which was recently approved by the Umbria Regional authorities taking advantage of the advice of ENEA. (52 HDRBs, 400 mm and 500 mm diameter, were supplied in February 2003 for the Fire Center building).

Finally, as to the applications of ED systems, two examples are the 34 VDs that are being installed in a new church in Rome and the 52 dissipative steel bracings that were supplied in 2003 for retrofitting the Giacomo Leopardi school at Potenza (similar to previous schools in this city [3, 11]).

Figure 6a: Isolated residential buildings at Città di Castello (PG).

Figure 6b: SI system of the residential buildings at Città di Castello.

3.2 Ongoing applications to existing buildings

The first two European applications of SI for the seismic rehabilitation of existing buildings are in advanced progress: that to the Polyfunctional Center “Rione Traiano” at Soccavo (Naples), by cutting the supporting columns (Figure 7), and that to a three-story apartment house at Fabriano (Ancona), through the construction of a sub-foundation (Figures 8a-b). After unfortunately very long approval processes, the projects of both structures were approved by the Ministry of Infrastructures and Transports in 2002.

The Polyfunctional Center “Rione Traiano” at Soccavo [10, 12] has quite a complicated and irregular r.c. structure, which was erected in the years ‘70s and left incomplete due to lack of funds; after the seismic reclassification of the Naples area which followed the 1980 Campano-Lucano earthquake, it resulted not to satisfy the new seismic requirements. Thus, it remained incomplete until recently. However, due to its high value, it was decided by the local authorities in 2000 to seismically improve and complete it. The only possibility to this aim was the adoption of SI. The method used was similar to that selected in the years ‘90s for retrofitting the Rockwell Center at Seal Beach (Los Angeles, USA): more than 600 HDRBs were inserted in the supporting columns and walls and, among other works, the building base was reinforced and a rigid frame was added to allow for the correct transmission of the seismic loads from the ground to the superstructure through the isolators; in parallel, it was possible to complete the building by constructing the non-structural elements (Figure 7).

Figure 7: The Soccavo Polyfunctional Centre retrofitted with a SI made of HDRBs.

Also the Fabriano apartment building [13, 14] has quite an irregular structure (Figure 8a). It is a three-story r.c. house, containing 11 apartments. It suffered considerable damage, mostly of non-structural elements, during the 1997-98 Marche and Umbria earthquakes (Figure 8c).

The reasons of this behavior were the rather large flexibility of the columns (the masonry walls were not capable of tolerating their lateral displacements), torsional effects due to the irregular shape, inadequate foundation system (couples of piles, badly connected or even disconnected), but, especially a large local amplification of the seismic ground motion (several other surrounding buildings had to be demolished and reconstructed). It is worthwhile stressing that the use of SI for retrofitting this house was decided mainly based on economic considerations: in fact, a conventional intervention would have required a considerable stiffening of the structure (including columns) and the reconstruction of all non-structural members (e.g. also including the non-damaged ones) and would not have avoided works on the foundations. In addition, it would have remained unsatisfactory due to torsional effects and the impossibility caused by some openings (windows, doors) to insert some shear walls in the most appropriate positions.

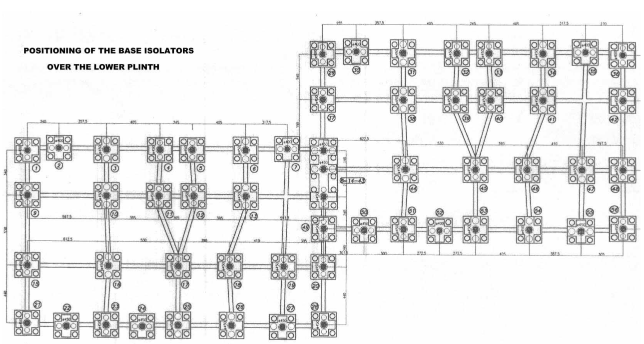

Figure 8a: The Fabriano apartment building and its plan view with the isolators' disposition.

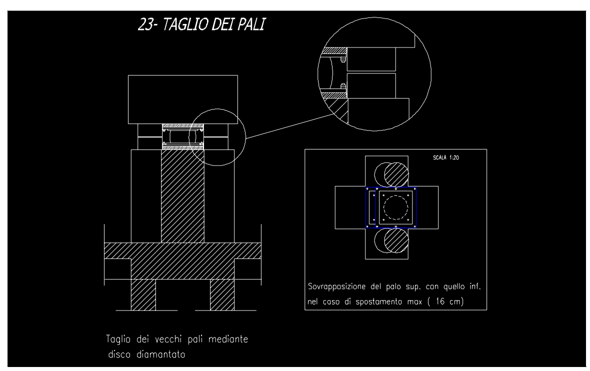

Figure 8b: Sketch of the retrofit intervention on the Fabriano building.

The intervention is similar to that made in the Le Corbusier Museum in Tokyo. It consists in the following main steps (Figure 8b):

- excavation around the house for creation of the lateral gap, with the construction of a suitable ground retaining vertical wall (completed);
- excavation below the house base around the foundation piles (Figure 8d) and improvement of their

connection beams (with the further advantage of adding one floor to the house) (completed);

- execution of a subfoundation, construction of stiff columns involving the existing foundation piles, below and above their part where the isolators had to be inserted (nearly completed);
- insertion of 56 HDRBs above the so-built base columns (between the couples of foundation piles) and of expansion jacks to ensure the adequate transmission of the dead load across the isolators;
- cutting the piles so as to separate the superstructure from the foundations, by leaving a vertical gap between the remaining stumps sufficient as to hinder contact (with adequate margins) during the design seismic movements (thus, these stumps will act as fail-safe system).

The aforesaid two retrofits are being already followed by further applications: the first is to two buildings at Solarino (Siracusa), for which works began in 2003 with the insertion of 24 HDRBs and 26 SDs.

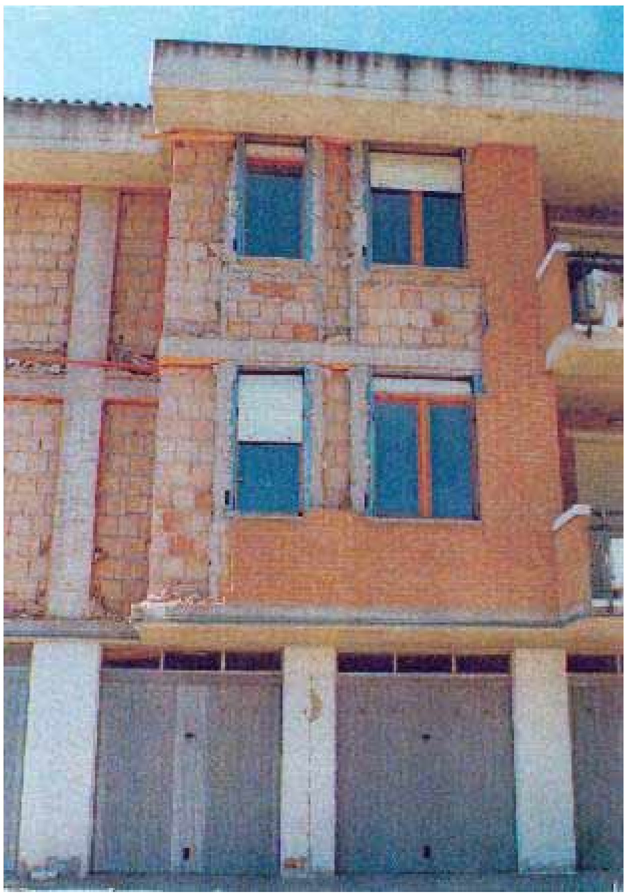

Figure 8c: Damages caused by the 1997 earthquake in the Fabriano apartment building.

Figure 8d: Execution of the new sub-foundation under the Fabriano apartment building.

3.3 Future applications for the reconstruction and rehabilitation in Molise

On October 31 and November 1, 2003 the Lower Molise and some villages of Northern Puglia were struck by two main shocks, with epicenters located at about 5 km from San Giuliano di Puglia (Molise), 5.4 and 5.3 magnitudes and VIII-IX MCS intensity. As already mentioned, the collapse of the elementary school of San Giuliano di Puglia, which was caused by its very bad construction features (including raisings and a heavy r.c. roof supported by masonry walls), killed 27 children (in addition to a teacher). Most buildings located around the school, mainly characterized by construction features similar to those of the school, partially collapsed and suffered very severe damage (Figure 9), which caused two further

victims. The overall damage level of the village (two MCS degrees more than in the surrounding ones) forced the authorities to entirely evacuate it immediately after the first main shock. This damage was caused not only by bad construction, but also by a large local amplification of the seismic motion (1.6, according to subsequent detailed microzoning studies), which led to a peak horizontal acceleration of 0.2 g. It is noted that, although part of Molise (that near and on the Apennines) and Puglia (Gargano Promontory) are characterized by an evident historic seismicity, the area struck by the 2002 events does not turn out to have suffered significant earthquakes in the past.
After a large participation of ENEA (with up to 22 experts, mainly belonging to the Section on Prevention and Mitigation of Natural Risks – PREV – led by the first author of this paper) in the post-earthquake emergency activities in various cities and villages of Molise (San Martino in Pensilis, Campobasso, Guglionesi, Petacciato, etc.) in support to the National Civil Defense Department, a team formed by ENEA-PREV scientists and other GLIS members has been working for the reconstruction of San Giuliano di Puglia since the beginning of 2003, within a cooperation with the authorities of such a village. The activities performed by this team till now concerned their participation in the detailed evaluations of damage, demolitions (of almost 200 buildings), ensuring safe conditions to the buildings to be repaired, actions for allowing residents to safely reenter their non-damaged houses and preparation of the detailed reconstruction plan.

Figure 9: San Giuliano di Puglia, a village in Southern Italy strongly damaged by the 2002 earthquake, after most demolition works.

In agreement with most residents (ENEA also performed a sociological investigation on this and other aspects), the village will be reconstructed mostly where it was (with the exception an area closely surrounding and including that of the collapsed school, for obvious sentimental reasons). The seismic safety will be ensured by adequate construction methods and a possibly large use of the SVC techniques (SI for the new buildings). To this purpose, the reconstruction plan foresees an increase of 15% of the founding to those using the SVC techniques and ENEA signed a new collaboration agreement with the village authorities, which foresees technical support to them for the approval of the designs and the final safety certification of the buildings using the aforesaid techniques. The first phase of the agreements also foresees, among others, some first pilot applications of these techniques, to the construction of new r.c.

buildings with SI, for the retrofit of masonry buildings and for the restoration of historic buildings.
Moreover, further applications of the SVC systems have already been planned in other Molise sites, in particular at Campobasso, where design activities for retrofitting the A. Romita scientific secondary school, a huge very irregular structure with poor seismic resistance, are in progress: this should be a pilot application of the above-mentioned systems, to be hopefully followed by their wide use in the framework of the seismic rehabilitation program of the schools of Campobasso Province.

4. RECENT APPLICATIONS TO CULTURAL HERITAGE

4.1 Retrofit of ancient monumental buildings

As far as the retrofit of monumental buildings is concerned, in 2002 two further applications of SMA devices followed those to the Upper Basilica of St. Francis at Assisi, the Bell Tower of the St. Giorgio Church at Trignano and the St. Feliciano Cathedral at Foligno, which had been completed in the last century [3, 11]: they concerned the restoration of the St. Peter Church at Feletto (Treviso) and that of the St. Serafino Church at Montegranaro (Ascoli Piceno); in the first 6 devices were installed, while in the second, which had been severely damaged by the 1997-98 Marche and Umbria earthquake similar to the Upper Basilica of St. Francis at Assisi and the St. Feliciano Cathedral at Foligno, 2 devices were judged sufficient at the time being (probably two more will be added in the near future).

Figure 10: The Scylla and Nettuno statues, at the Museum of Messina, isolated by means of a system formed by SDs and SMA dampers.

Figure 11: The statue of the Satyr of Mazara del Vallo (recovered close to Pantelleria island), isolated by means of multistage HDRBs.

4.2 Applications to single masterpieces

A few further applications of the SVC systems also concerned single Italian masterpieces. More precisely, after the first applications to the famous Bronzes of Riace at the Museum of Reggio Calabria and the statue of Germanicus Emperor at the Museum of Perugia, both making use of multistage HDRBs, and that in progress, with a three-directional SI system, to the wooden Roman ship excavated at Ercolano [3,15]:

- the Scylla and Neptune statues (Figure 10), at the Museum of Messina were isolated by means of a system formed by SDs and SMA dampers;
- the statue of the Satyr of Mazara del Vallo (Figure 11), recovered close to Pantelleria island and exhibited at the Quirinale Palace in Rome, was isolated by means of multistage HDRBs (three layers of 4 small HDRBS, similar to the aforesaid Bronzes of Riace and the statue of Germanicus Emperor).

CONCLUSIONS

The most recent applications of the modern anti-seismic techniques (SI, ED, etc.) in Italy were outlined, by providing information on the most important ones. The main features and results of some important R&D and information & training projects (recently completed or ongoing) were also briefly summarized.

The excellent perspectives for a rapid extension of the applications to Italian structures of all kinds were stressed. These are a consequence of both:

- the availability (since May 8, 2003) of the new Italian seismic code, which, at last, allows for the free use of SI and ED (namely, without any more requiring the approval of the Ministry of Infrastructures and Transportations) and simplifies it;
- that (since the same day) of new general criteria for the seismic reclassification of the Italian territory, which will increase the percentage of that considered as seismic from the previous 43% to about 70% and suggests minimum seismic design requirement for the entire country.

In addition, the new policy of the Ministry of Constructions to support the use of the modern anti-seismic techniques, in the framework of the so-called “Quarters’ Contracts – II” Program for the rehabilitation of degraded areas, should considerable help.

Some remarks have also been devoted in this paper to the work in progress for the reconstruction of San Giuliano di Puglia, which was strongly damaged by the Molise earthquake of October 31, 2002, and that recently started in other sites of Molise, in particular at Campobasso, since a wide use of the modern anti-seismic techniques is foreseen there, for both the erection of new buildings and retrofit of existing ones. The authors are confident that the ongoing national and international collaborations on the development of the modern anti-seismic techniques will strongly contribute to the definitive worldwide success of such techniques. This applies, in particular, to the collaborations undertaken in the framework of the new *A*nti-*S*eismic *S*ystems *I*nternational *Soci*ety (*ASSISi*), which sees 27 countries already represented through the Founding Members.

REFERENCES

1. Melkumian M. "Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures – Proceedings of the 8th World Seminar Held at Yerevan, Armenia, on October 6-10, 2003", Yerevan, Armenia, 2004.
2. Presidenza del Consiglio dei Ministri (Italian Presidency of Ministries Council), "Ordinance nr. 3274 of March 20, 2003. Ordinary Supplement nr. 72 to the Italian Official Gazette n. 105", May 8, 2003.
3. Martelli A., Forni M., Arato G.-B. "Progress on R&D and Application of Seismic Vibrations Control Techniques for Civil and Industrial Structures in the European Union", Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures – Proceedings of the 8th World Seminar Held at Yerevan, Armenia, on October 6-10, 2003, Yerevan, Armenia, 2004.
4. Bouygues, A2P, ENEA, ISMES, Jarret, University of Udine, VSL. "SPIDER – Strand Prestressing for Internal Damping of Earthquake Response", EC Contract EVG1-CT-1999-00013, Bruxelles, Belgium, 1999.
5. Maurer Söhne, Bilfinger+Berger, ENEA, ENEL, ISMES, TARRC, Thomson-Marconi, University of "Roma Tre", University of Stockholm. "SPACE – Semi-active and PAssive Control of the dynamic behavior of structures subjected to Earthquakes, wind and vibrations", EC Contract EVG1-CT-1999-00016, Bruxelles, Belgium, 1999.
6. Forni M., Antonucci R., Arcadi A., Occhiuzzi A. "A Hybrid Seismic Isolation System Made of Rubber Bearings and Semi-Active Magneto-Rheological Dampers", Proceedings, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, 2004.
7. Maurer Söhne, ENEA, ENEL.Hydro, TARRC, University of Stockholm, University of Ljubljana, IFW, Construcciones Bikani; "VAST-IMAGE: Development of VAriable STiffness seismic Isolators and vibration mitigation dampers based on MAGnetically controlled Elastomer", EC Contract EVG1-CT-2002-00063, Bruxelles, Belgium, 2002.
8. Enel.Hydro, IKI, ENEA, FIP, Principia, MMI, University of Patras, HELPE, IWKA, "INDEPTH; Development of INnovative DEvices for seismic protection of PeTrocHemical facilities", Contract EVG1-CT-2002-00065, Bruxelles, Belgium, 2002.
9. Martelli A., Arato G.-B., Bellani E. "Documentaries on the Development and Application of Seismic Vibrations Control Techniques", Proceedings, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, 2004.
10. Dusi A, Private communication, Cremona, Italy, 2003.
11. Mazzolani F.M., Martelli A., Forni M. "Progress on Application and R&D for Seismic Isolation and Passive Energy Dissipation for Civil and Industrial Structures in the European Union", Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures – Proceedings of the 7th International Seminar, Assisi, Italy, October 2 to 5, 2002, A. Martelli, M. Forni, G.-B. Arato and B. Spadoni, eds., GLIS, Bologna, Italy, 2002, pp. 249-277.
12. Sparacio R., Private communication, Naples, Italy, 2003.
13. Mancinelli G., Private communication, Fabriano, Italy, 2003.
14. Giacchetti R., Private communication, Ancona, Italy, 2003.
15. Indirli M., Clemente P., Carpani B., Martelli A., Spadoni B., Castellano M.G. "Research, Development and Application of Advanced Anti-Seismic Techniques for Cultural Heritage in Italy", Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures – Proceedings of the 8th World Seminar Held at Yerevan, Armenia, on October 6-10, 2003, Yerevan, Armenia, 2004.