*Transactions of the 17th International Conference on Structural Mechanics in Reactor Technology (*SMiRT 17)
Prague, Czech Republic, August 17 –22, 2003

Paper # K13-4

State-of-the-Art on the Development and Application of Seismic Vibration Control Techniques and Some Innovative Strengthening Methods for Civil and Industrial Structures

Alessandro Martelli [1)]

[1)] Chairman, *ASSISi*, GLIS and Assisi Seminar; Coordinator, TG5 of the EAEE; Head, Section on "Prevention and Mitigation of Natural Risks" of the Technical-Scientific Unit "Protection and Development of the Environment and Territory, Environmental Technologies", ENEA, Bologna, Italy; martelli@bologna.enea.it

KEY WORDS: seismic vibrations, passive control, seismic isolation, passive energy dissipation, shock transmitters, shape memory alloys, semi-active control, seismology, seismic input, research and development, application, bridges, viaducts, buildings, cultural heritage, industrial plants, nuclear plants, chemical plants.

ABSTRACT

Nowadays, most modern techniques for the control of seismic vibrations – namely seismic isolation (SI), passive energy dissipation (ED), provisional hydraulic coupling (HC) by means of shock transmitters and systems formed by shape memory alloy (SMA) devices and other smart materials – are considered to be already fully mature technologies of providing a mitigation of seismic damage for civil structures and equipment and have proven to be reliable and cost-effective for bridges and viaducts, civil buildings, cultural heritage and critical facilities. There are already approximately 3,000 applications of such techniques in various countries, which concern not only new constructions but also several retrofits of existing, frequently important, structures, including cultural heritage.

The design and behavioral experience concerning the large civil buildings and bridges and viaducts provided with SI, ED and HC systems (for which the applications of such modern anti-seismic techniques are the most numerous) is extremely important for widely extending their use to other extremely important application fields, like the cultural heritage, ordinary apartment buildings and industrial facilities, including high risk facilities (not only nuclear plants, but also some chemical plants). In fact, the applications in these fields are not very numerous, yet, although some of them are quite important and several new projects are in a rather advanced development stage.

This paper summarizes the key issues in the development and application of the aforesaid techniques, based on the state-of-the-art assessed at the 7th International Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibrations of Structures held at Assisi in October 2001, complemented by some more recent information.

INTRODUCTION

At the 6th International Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures held at Cheju (Korea) in 1999 [1], it was internationally agreed that most passive control techniques of earthquake-induced vibrations (EPC techniques) – namely not only base and floor seismic isolation (SI), but also passive energy dissipation (ED) and provisional hydraulic coupling (HC) by means of shock transmitters (STs) – were already fully mature technologies of providing a mitigation of seismic damage for civil structures and equipment and had proven to be reliable and cost-effective for many structures such as bridges and viaducts, civil buildings, cultural heritage and critical facilities. With regard to ED, several types of devices had already been developed and optimized, like the viscous, elastic-plastic, visco-elastic and electro-inductive devices. In addition, systems using shape memory alloys (SMAs) and other smart materials were also already being developed.

Nowadays, there are already approximately 3,000 applications of SI, ED and HC in various countries; they concern not only new constructions, but also several retrofits of existing important structures, including cultural heritage. The adoption of these techniques was judged necessary at first especially after the Loma Prieta (1989), Northridge (1994) and Kobe (1995) earthquakes and more recently, after those which struck Italy in 1997-98, then Greece, Taiwan, Turkey, Central America and India. It is worthwhile stressing that the EPC techniques are of great interest not only for highly seismic countries, but also for areas characterized by low or moderate seismicity [1].

The design and behavioral experience concerning the large civil buildings and bridges and viaducts provided with SI, ED and HC devices (for which the applications of such EPC systems are the most numerous) is extremely important for widely extending the use of these techniques to other extremely important application fields, like the cultural heritage, ordinary apartment buildings and industrial facilities, including high risk facilities (e.g. not only nuclear plants, but also some chemical plants). In fact, the applications in these fields are not very numerous yet, although some of them, to high risk facilities and cultural heritage, are quite important and several new projects are in progress. The only remarkable still remaining problems for the EPC techniques which were identified at the Cheju Seminar concerned the design rules for structures provided with the EPC systems [1]. In fact, although design rules or guidelines were already available in most countries, they were still different in the different countries, frequently still penalized the use of the EPC systems with respect to the conventional design and their application still required heavy approval processes in some countries.

The state-of-the-art on the development and application of the EPC techniques was updated at the 7th International Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures, held at Assisi on October 2 to 5, 2001 under the auspices of the European Commission (EC) [2]. Similar to the two previous events held in Italy (at Capri in 1993 and Taormina in 1997), this Seminar was organized by GLIS (Italian Working Group on Seismic Isolation), with the cooperation of ENEA (Italian Agency for New Technology, Energy and the Environment), ANPA (Italian National Agency for the Protection of the Environment, now APAT – Italian Agency for the Protection of the Environment and Territory) and several further Italian, foreign and international Institutions, associations and companies. Task Group 5 on Seismic Isolation of Structures (TG5) of the European Association for Earthquake Engineering (EAEE) joined GLIS as main organizer of the Assisi Seminar. In spite of the tragic events of September 11, 2001, the Seminar was attended by 237 experts from 25 countries, the EC and the International Atomic Energy Agency (IAEA), namely considerably more than those (less than 140) who had participated in the previous events [2, 3]. This allowed for fully achieving the Seminar purposes, strengthening and even extending international collaborations and disseminating information to designers, public officials and public opinion. The next sections summarize the main results and conclusions of the Assisi Seminar [3], by also providing some more recent information.

APPLICATION OF THE EPC TECHNIQUES

It was confirmed at the Assisi Seminar that both SI and ED are now fully accepted techniques in the scientific community all over the world: there are no more doubts that a suitable system of one of these kinds can always be identified for each type of structure, both to be erected or to be retrofitted, and that this system will be able to considerably improve the structure seismic safety, by also protecting the non-structural members and other valuable contents, thus ensuring the structure operability after the earthquake.

The present availability of design rules or guidelines for structures provided with EPC systems in several countries is now more helping in convincing designers and builders to adopt these techniques. However, such guidelines and the approval process for the structures under consideration still remain rather different in the different countries; the result is that in some countries, like for instance Japan, the P.R. China and (after the codes modifications following the 1999 earthquake) Taiwan, the number of structures provided with EPC techniques is still or is now rapidly increasing, while in others, for instance in the USA and Italy the number of new applications is more limited (Figures 1-6).

Among others, the differences concerning design rules lead to rather different costs of the structures provided with the EPC systems. For instance, in the P.R. China the use of such systems leads to cheaper constructions, which allowed this country to increase the number of building applications of SI from 160 in August 1999 to 458 at the end of 2002, to largely adopt SI for ordinary apartment buildings, to design new important high-rise buildings with ED devices and also, to retrofit existing buildings using the Tuned-Mass-Damper (TMD) system by adding one or two stories at the top of them. The same occurred in Armenia, as well. On the contrary, construction costs remain larger in the USA for structures provided with the EPC systems with respect to the conventionally founded ones. Thus, attention is being devoted there to the development of cheaper isolators, for instance with fiber reinforcement, which reduces the weight (and consequently, costs) and makes it possible to manufacture rectangular isolators in form of long strips: the latter will allow for retrofitting buildings with structural walls without any more need for adding wall beams (as necessary to carry the wall from isolator to isolator, if their shape is that used at present, round or square).

Anyway, in all developed seismic countries, as well as in Armenia (although it is still a developing country), the number of applications of the EPC techniques significantly increased in the three years (2000-2002) following the Cheju Seminar, for many types of structures, namely, not only for bridges, viaducts and important strategic and public buildings, but also for ordinary apartment buildings. In Japan only, according to very recent information, there are already approximately 1,600 isolated buildings (939 in March 2001).

Bridges and Viaducts

As regards bridges and viaducts, the number of applications of the EPC systems to both new constructions and retrofits considerably increased in all countries, including, for instance:

- Chile, where a significant bridge rehabilitation program has been carried out;

- Italy, where several freeway bridges in the South are being retrofitted using the EPC systems and some new bridges and viaducts provided with them have and are being erected, which has consolidated the leadership of this country with regard to both the number (over 150) and importance of applications of the EPC systems to bridges and viaducts;
- countries with moderate seismicity like Korea, where there are already 20 applications;
- the P.R. China, where the first 9 isolated bridges were constructed prior to the Assisi Seminar;
- Syria, where several hundreds of rubber isolators manufactured in Armenia were being installed at the time of the Assisi Seminar;
- Taiwan, where an extensive use of the EPC systems (partly manufactured in Italy) began shortly before the Assisi Seminar, as a consequence of the 1999 earthquake;
- the USA, where there was a considerable increase of the number of applications, because bridge codes are not so unnecessarily conservative as for buildings;
- Venezuela, where a large number of ED devices manufactured in Italy was under installation, at the time of the Assisi Seminar, in the Caracas-Tuy Medio Railway.

To be reminded is also the excellent behavior, in the 1999 earthquakes, of a viaduct of the Istanbul-Ankara freeway, located near Bolu and provided with elastic-plastic devices manufactured in Italy, which did not collapse, although it was subjected to seismic motions largely exceeding the design value [1].

Strategic and Public Buildings

With regard to buildings, in general, not only the engineers, but also architects are beginning to understand the great potential of the EPC techniques and especially SI, namely that they leave the architect much freer in the definition of the structure architectural features and that, should the adoption of these techniques be already considered at the time of the architectural design, there are great advantages also for the construction costs.

Among the numerous new applications to strategic buildings, the first to be stressed are those to *emergency management centers* and *hospitals,* for which full integrity in an earthquake and full operability after it are essential requirements. With regard to the emergency management centers, SI has been used in all the new ones erected in California; it is also being adopted in other countries, including Italy, where the first base-isolated emergency management center, to be erected at Foligno (Perugia) and provided with high damping rubber bearings (HDRBs), is in an advanced design stage [3]. As regards hospitals, examples of new seismically isolated ones (both using HDRBs) which were reported at Assisi are the Medical Center of San Carlos de Apoquindo at Santiago (the second isolated building in Chile) and the new hospital under construction at Frosinone, which is the first actual hospital being isolated in Italy (it was preceded by a building used for medical purposes at the Navy Base of Augusta, erected at the beginning of the years '90s).

Then, also the new applications to *schools* and *other large public buildings*, including seismic retrofits of those existing, are quite important, even from the social and psychological points of view. As regards Italy, we remind the recent retrofit, using visco-elastic devices, of the Gentile Fermi school at Fabriano (Ancona), a rare example of rationalist architecture that had been severely damaged by the 1997 Marche and Umbria earthquake, in addition to those of Domiziano Viola and La Vista schools at Potenza, which make use of elastic-plastic devices [3]. We also stress the retrofit of the huge "Rione Traiano" Civic Center at Saccavo, near Naples, erected before the 1980 Campano-Lucano earthquake (when the area was not yet seismically classified), that will lead to the first European application of SI for the rehabilitation of existing buildings: the supporting columns are being cut with a procedure similar to that used in 1991 for retrofitting the Rockwell International building at Seal Beach, near Los Angeles (California), and 500 HDRBs are being inserted.

Ordinary Apartment Buildings

As far as the ordinary apartment buildings are concerned, the number of new applications of the EPC techniques, especially SI, is particularly large in Japan and the P.R. China and (taking into account the limited population) Armenia, but, in the near future, should become not negligible also in Italy, where until recently such techniques had been used in only 5 houses erected in the Southern regions at the beginning of the years '90s: 4 at the Navy Base of Augusta (Siracusa) and 1 at Squillace Marina (Catanzaro). In fact, after the Cheju Seminar, a new base isolated house was completed at Rapolla (Potenza), 3 are near to completion at Città di Castello and especially, the design of a set of 36 more isolated houses (which may become 55 in the near future) is already in progress in Calabria [3].

In addition, the first retrofit of an Italian apartment house at Fabriano (Ancona) using SI (with 56 HDRBs) and sub-foundation by cut of the foundation piles is in progress. The retrofit of this building, which had suffered severe non-structural damage in the 1997 Marche-Umbria earthquake, will be the first in Europe which will make use of sub-foundation with SI [3]. Finally, for the first time, a novel restoration method for masonry buildings ("Active Sewing Method" – CAM) was used in 2001 to seismically improve an apartment building at Sigillo (Perugia) and is now being used for a second application in the Marche Region [3].

It is worthwhile stressing that the increase of the number of applications of the EPC techniques to the *construction or retrofit of ordinary apartment buildings* is extremely important for the assertion of such techniques, because this is the largest potential market. On the other hand, design studies performed in various countries (including Italy) have shown that *retrofit* of apartment houses using SI (in the presence of sufficiently large lateral joints) or ED systems may be economically convenient in many cases, even for small (3-stories) buildings (like that previously mentioned at Fabriano) and in countries where the design rules are still penalizing the use of these techniques.

One important problem to be solved to further and more rapidly increase the number of applications in this field is the continuing lack of adequate *information* to designers, public official and also, the ordinary public. To contribute to solve this information problem, GLIS and ENEA are developing the MUSICA Project (which consists in the production of a series of short films, feature films and motion pictures on the development and application of the EPC techniques [4]), but certainly, this kind of activity must be considerably extended to achieve its purpose.

In addition, financial incentives to adopt the EPC techniques for ordinary apartment houses are necessary. On the other hand, as stressed at the Assisi Seminar, such incentives are really possible, especially as far as insurance premiums and loan interests are concerned, which may be lower for structures equipped with EPC systems or their owners, to account for the lower probability of earthquake damage [2].

Chemical Plants

The number of applications of the EPC techniques luckily slightly increased in two further quite important fields, as well: the high risk plants and components, such as the chemical ones, and cultural heritage. For the first, to be cited are new applications of SI, including retrofits, to Liquefied Natural Gas (LNG) tanks (for instance, in France, Korea and Turkey) and studies both in progress in Italy [5] and which should soon begin in the framework of a new EC-funded Project [6]. However, no application to chemical plants was reported at Assisi for some highly seismic countries like Japan.

As for the ordinary apartment houses, a large extension of applications of the EPC techniques to the high risk plants, especially the chemical ones, is extremely important to better protect human life, because such plants are very frequently located in highly seismic areas and are rather vulnerable to the seismic vibrations (see also the separate paper). The adoption of the EPC systems has the advantage of minimizing the impact of seismic protection on the plant lay-out (and thus, the costs) and improving the overall plant reliability, in addition to seismic safety [5,6]. Due to the large number of such plants existing all over the world, even in highly seismic areas, this is also a very important market for the EPC techniques.

Cultural Heritage

For cultural heritage, new important applications of the EPC techniques followed in Italy those performed at the end of 1999 to the Upper Basilica of St. Francis at Assisi, damaged by the 1997 Marche and Umbria earthquake (where use was made of both innovative STs developed in the framework of the EC-funded REEDS Project and for the first time in the world, of SMA devices, developed in the framework of the EC-funded ISTECH Project and to the Bell Tower of the St. Giorgio Church at Trignano, practically cut into two pieces (which luckily remained superposed) by the 1996 Reggio Emilia and Modena earthquake (this was the pilot application of SMA devices developed in the framework of the ISTECH Project) [3]: these new Italian applications were to the St. Feliciano Cathedral at Foligno and the Church of St. Serafino at Montegranaro (Ascoli Piceno), also damaged by the 1997 Marche and Umbria earthquake (third and forth worldwide applications of SMA devices, completed in 2000 and 2002, respectively) and the Cathedral of “Santa Maria di Collemaggio” at L’Aquila, which had considerably vibrated in the aforesaid earthquake, in spite of its large distance from the epicenter (this was first application of low invasivity elastic-plastic devices to cultural heritage, also completed in 2000).

In addition, new applications and designs in other countries, as well, were reported at Assisi, for instance in Egypt (in collaboration with Italy, towards the seismic retrofit of the Memnon Colossi at Luxor), Korea, Portugal, P.R. China and (to less ancient but still historical buildings, like, for instance, the San Francisco City Hall and Asian Art Museum and the Berkeley Civic Center) in the USA [2].

For the application of the EPC system to cultural heritage, however, there are some problems to solve [2]. The first hard problem is that the EPC systems must be compatible with the conservation requirements (namely, those of low invasivity and full reversibility). Then, ancient structures are frequently not well known and each of them is different from the others. This makes it necessary to develop specific systems for each intervention of restoration. Moreover, the conservation requirements make it necessary to build a *sub-foundation* to allow for the use of SI: however, as shown by the first studies performed in Italy – concerning two churches in Perugia Province, severely damaged by the Marche and Umbria earthquakes of 1997-98 and to be restored by means of SI in the framework of the PROSEESM Project funded by the Italian Ministry for University and Scientific and Technological Research (Santa Lucia at Aggi and St. Giovanni Battista at Apagni) – this is feasible and is the only way to avoid that the same damage reappears in the next earthquake, as already occurred in these churches and other ancient structures in Marche and

Umbria in 1997 for damages repaired after the 1979 Valnerina earthquake [3].

Moreover, to be reminded about cultural heritage, is that SI also allows for on site *reconstruction of ancient buildings* severely damaged by earthquakes, using the original masonry material (as shown, for instance, by the feasibility study in progress at ENEA for the village of Mevale di Visso in the Marche Region, fully destroyed by the 1997-98 earthquakes), and for the *seismic protection of single masterpieces* in existing conventionally constructed museums. About the latter (after the applications made in the past, for instance to precious objects at the Paul Getty Museum at Santa Monica in the USA and more recently in Italy, by means of multi-stage HDRBs, to the Bronzes of Riace at the Museum of Reggio Calabria and a bronze statue of Germanicus Emperor at the Museum of Perugia), it is worthwhile citing the new ongoing applications to precious objects displayed in museums in the P.R. China and Italy. As regards Italy to be cited are the very recent or ongoing applications to:

- the Satyr of Mazzara del Vallo, again isolated by means of multistage HDRBs, to be exhibited at the Montecitorio Palace in Rome,
- the Scylla statue, being isolated by means of a system formed by sliding devices in conjunction with SMA dampers, to be exhibited at the Messina Museum;
- the Neptune fountain, also being isolated at Messina using the aforesaid system;
- to a precious wooden Roman ship excavated at Ercolano, near Naples, being isolated by ENEA at the Ercolano Museum by means of a three-directional (3D) system (for the first time in Europe), which was developed in the framework of the EC-funded SPACE Project.

Extension of the Number of Countries Interested in the EPC Techniques

Finally, with regard to the interest in the EPC techniques, to be stressed is that it is now extending to new countries, like, for instance, Turkey (where the first applications concern the Istanbul airport, LNG tanks and viaducts and a bridge near Bolu on the Istanbul-Ankara freeway), Iran and India. Some other countries are beginning to follow the excellent example of Armenia (where there were already 14 isolated buildings at the end of 2002, which should become 24 in the near future, and where seismic isolators are locally manufactured also for foreign markets, like Syria): this is shown, for instance, by the great interest in the EPC techniques expressed at Assisi by countries like the Czech Republic, Kyrgyz Republic and Romania.

RESEARCH AND DEVELOPMENT

Test Laboratories and On-Site Tests

Large experimental laboratories which are now available in numerous countries for testing the EPC devices using special equipment, as well as small- and large-scale structure mock-ups provided with such devices, by means of shake tables (dynamic method) and/or reaction walls (pseudo-dynamic method). Nowadays, large test equipment (such as, for instance that CALTRANS installed at the University of California at San Diego, USA) are fully operating and allow for testing the full scale EPC devices up to large deformations, thus ensuring their reliable qualification.

Very interesting on-site tests of isolated structures were also reported at Assisi, for instance to:

- an existing bank building at Irkutsk-City in Russia, retrofitted by applying the technology invented in Armenia and using HDRBs manufactured in the P.R. China, which was tested both before and after retrofit;
- the previously mentioned apartment building at Rapolla in the South of Italy, which was subjected to snap-back tests to 180 mm lateral displacement with two different SI systems (HDRBs and HDRBs in conjunction with sliding devices).

These tests were similar to those which had been performed by ISMES, ENEL and ENEA in 1990, by laterally moving to 110 mm then suddenly releasing (through the use of explosive bolts) one of the five 8-stories isolated buildings (25 m high) of the Italian Telephone Company TELECOM-Italia at Ancona (these buildings were the first application of base SI in Italy) [7].

With regard to on-site tests of real buildings, to be stressed is their great importance to convince public officials and public opinion on the large benefits of the EPC techniques.

New Studies on Engineering Aspects Concerning Non-Nuclear Structures

Since most of the work necessary for the development and optimization of the EPC systems was already completed prior to the Cheju Seminar, R&D concerning the engineering aspects is now mainly focusing on the development of active, hybrid and especially, semi-active control (*SAC*) systems of seismic and non-seismic vibrations or new materials such as SMAs for anti-seismic devices.

With regard to SAC, particular attention is being devoted to the *magneto-rheological (MR) fluids*, to make ED of dampers dependent on seismic excitation level (see, for instance, the EC-funded CASCO and SPACE Projects [2]) and other anti-seismic devices with properties dependent on the intensity of a magnetic field (e.g. those studied in the framework of the recently EC-funded VAST-IMAGE Project [8]).

With regard to SMA devices, development is in progress not only in Italy, but also in other countries, like the USA, Spain and Chile, for their possible use as dampers or plugs for rubber isolators, as well. In Chile, where large copper quantities are available, ED devices based on copper-based SMA bars have been developed.

Further ongoing engineering R&D work is aimed at solving the specific issues concerning the three aforesaid types of structures which require (and are suitable for) a wide extension of the application of the EPC techniques, namely [2]:

- *ordinary apartment buildings*, by developing low cost EPC devices and systems, such as, for instance, the damper-cable system developed in the framework of the EC-funded SPIDER Project [2] and isolators with fiber reinforcement, being studied in some countries (for instance in the USA and Iran);
- *chemical plants and components*, by developing EPC systems compatible with the frequently adverse environmental conditions characterizing such structures, need for withstanding fire and chemical attacks and need for limiting displacement to values consistent with those allowed by piping (see, for instance, the Italian ISI and the EC-funded IN-DEPTH Projects [5,6]);
- *cultural heritage*, by developing new EPC systems compatible with the conservation requirements and suitable retrofit techniques (see, for instance, the PROSEESM Project [2]).

In addition to the aforesaid research Projects, the importance of international Networks (such as the new SAMCO Network [2]) was stressed at the Assisi Seminar, since they allow for largely enhancing collaboration by optimizing the exchange of information among several partners.

New Studies on Engineering Aspects Concerning Nuclear Reactors

For the other structure types, to be cited are the studies performed for the nuclear reactors, for which it was confirmed at the Assisi Seminar that SI is very beneficial, both because it enhances reactor safety and because it reduces the construction costs. These benefits are particularly evident for the fast reactors, where components are relatively flexible and thin-walled due to low internal pressure and high thermal stresses. These conclusions were stressed in all lectures on nuclear applications that were presented at the Assisi Seminar, namely in those concerning the studies in progress for SI of:

- the future Indian, Japanese and Russian reactors, with the development of 3D isolators (since also vertical isolation is important for this structure type),
- the International Thermonuclear Experimental Reactor (ITER),
- the Generation 4 Reactors in the USA,
- the Accelerator Driven System (ADS) in Italy,

together with studies in progress for a new type of Floating Power Reactor being studied in Russia.

New Studies on Seismological Aspects

Besides the R&D on the engineering aspects, new seismological studies of great interest for the application of the EPC techniques and in particular, SI, have also been performed. They concern the evaluation of near field earthquakes, site effects and long period waves, which could cause serious problems of isolators' failure or impacts against adjacent structures to the isolated structures, should not they be adequately taken into account in the design, because of the induced large displacement demand.

Furthermore, the need was stressed at the Assisi Seminar for an adequate evaluation of the differential motions among the piers of bridges and viaducts caused by different soil conditions, which shall be adequately taken into account when using all EPC devices in such structures [2].

CONCLUSIONS

The key issues in the development and application of the EPC techniques have been outlined, based on the state-of-the-art assessed at the 2001 Assisi International Seminar and some more recent information. The great success of the Seminar, in spite of the very difficult international situation, was stressed by all participants in its Closing Panel [2,3].

At the end of 2001, the proposal of the American University of Armenia to organize the *8th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures* at Yerevan, the capital of Armenia, in October 2003, was approved, together with that of the Institute of Industrial Science of the University of Tokyo to hold the 9th event in Japan in 2005. As far as the Seminar topics are concerned, even prior to that at Assisi, it had been stressed that two key issues have to be better addressed, namely *design rules* (this was the reason why, as a first step, translation of the design rules or guidelines applicable in the different countries were collected at the Assisi Seminar) and (through a special session) *seismic input* [2,3]. The 8th Seminar will be the first that will be co-organized by the *A*nti-*S*eismic *S*ystems *I*nternational *Soci*ety (*ASSISi*), the foundation of which was decided at Assisi and took place at Budrio, Bologna, on November 21, 2002 [2,4].

REFERENCES

1. Martelli, A., Forni, M., and Koh, H.M., “An Overview on Recent Application of the Innovative Anti-Seismic Techniques and Needs for Further R&D Activity”, *Proceedings of the 2000 ASME-Pressure Vessel and Piping Conference,* Seattle, Washington, USA, 2000, PVP-Vol. 402-1, pp. 157-172.
2. Martelli, A., Forni, M., Arato, G.-B., and Parducci, A., eds., *Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures – Proceedings of the 7th International Seminar – Assisi, Italy*, October 2-5, 2001. ENEA and University of Perugia for GLIS and EAEE-TG5, Bologna, Italy, 2002.
3. Martelli, A, and Forni, M., “Key Issues in the Development and Application of Passive Seismic Vibration Control Techniques”, *Proceedings of the 3rd World Congress on Structural Control*, Como, Italy, 2002.
4. Martelli, A., Arato, and G.-B., Bellani, E., “«Advanced tested technology for earthquakes» and «The Shapes of Memory»: a Short Film and a Motion-Picture Developed in the Framework of the MUSICA Project”, *Proceedings of the 17th SMiRT Conference,* Prague, Czech Republic, 2003.
5. Martelli, A., Muzzarelli, M., Forni, M., Poggianti, A., and Spadoni, B, “Valutazione dell’applicabilità dell’Isolamento Sismico alla protezione sismica di Impianti Industriali (ISI) (Evaluation of the Applicability of Seismic Isolation to the Seismic Protection of Industrial Plants). *Proceedings of the VGR 2002 Conference – Risk Evaluation and Management in Civil and Industrial Sites, Annual Seminar of the National Group for the Defense from Chemical, Industrial and Ecological Risks,* Pisa, Italy. 2002 (in Italian).
6. ENEL.Hydro, ENEA, FIP Industriale et al., *IN-DEPTH – Development of Innovative Devices for Seismic Protection of Petrochemical Facilities*, EC-funded Project, 2002.
7 Martelli, A., and Forni, M., “Seismic Isolation of Civil Buildings in Europe”, *Progress in Structural Engineering and Materials*, London: Construction Research Communications Ltd. 1998; 1 (3): 286-294.
8 Maurer Söhne, ENEA, ENEL.Hydro et al., *VAST-IMAGE – Development of variable stiffness seismic isolators and vibration mitigation dampers based on magnetically controlled elastomer,* EC-funded Project, 2002.

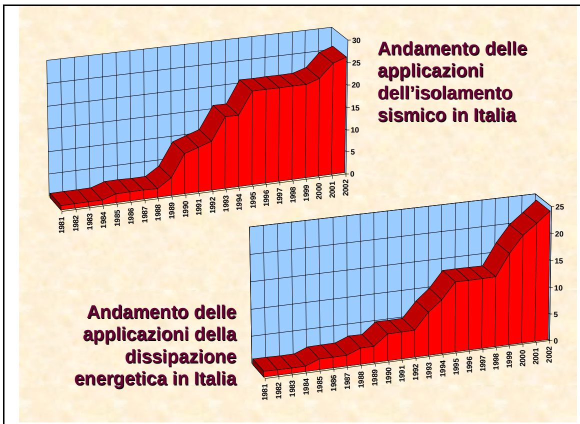


Figure 1: Number of building applications of SI (upper diagram) and energy dissipation (lower diagram) in Italy.

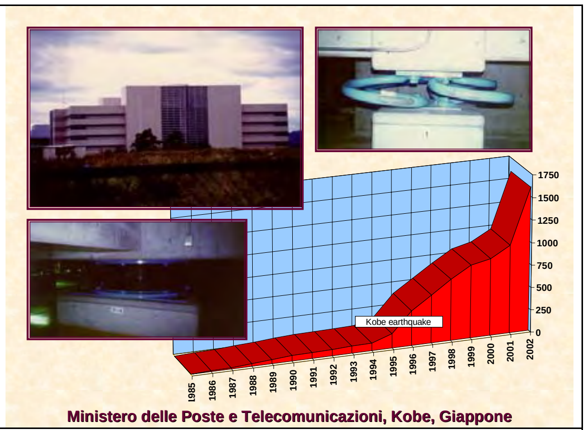


Figure 2: Number of building applications of SI in Japan and a view of the Ministry of Post and Telecommunications at Sanda City.

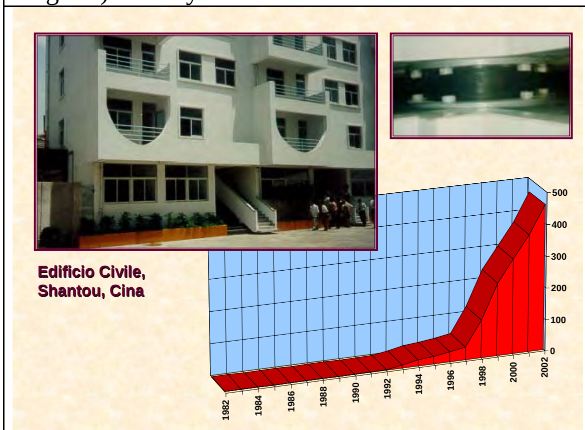
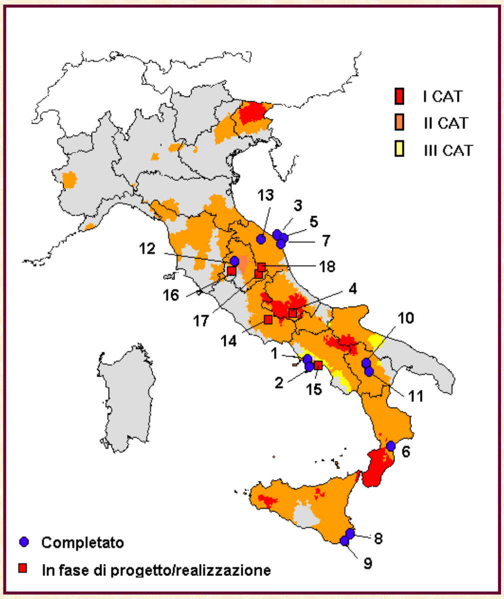


Figure 3: Number of building applications of SI in the P.R. China and view of a building at Shantou, which was seismically isolated in 1994.

Figure 4: Number of building applications of SI in the USA and views of the San Francisco City Hall and Asian Art Museum retrofitted with SI.



Distribuzione degli edifici isolati

Classificazione sismica attualmente in vigore

App	Località / Edificio / Anno	Edifici (N° totale)
1	Napoli, Caserma dei Vigili del Fuoco, 1981	1
2	Napoli, Nuova Caserma dei Vigili del Fuoco, 1985	1 (2)
3	Ancona, Centro Civico, 1989	1 (3)
4	Avezzano, Edificio Texas Instruments, 1989	1 (4)
5	Ancona, Centro Regionale TELECOM, 1990	5 (9)
6	Squillace, Appartamenti, 1992	1 (10)
7	Ancona, Centro Medico della Marina, 1992	1 (11)
8	Augusta, Ospedale della Marina, 1993	1 (12)
9	Augusta, Appartamenti, 1993	4 (16)
10	Potenza, Università della Basilicata, 1995	5 (21)
11	Rapolla, Appartamenti, 2000	1 (22)
12	Città di Castello, Edifici IERP, 2001	3 (25)
13	Fabriano, Appartamenti (retrofit), 2002	1 (26)
14	Frosinone, Ospedale	3 (29)
15	Soccavo, Centro Civico (retrofit)	1 (30)
16	Foligno, Centro della Protezione Civile	13 (43)
17	Nocera Umbra Chiesa (retrofit)	1 (44)
18	Apagni, Chiesa (retrofit)	1 (45)

Figure 4: The seismically isolated buildings in Italy (completed or under construction or retrofit), their location and the present seismic classification of the Italian territory (December 2002).

Andamento delle applicazioni dell'isolamento sismico nel mondo

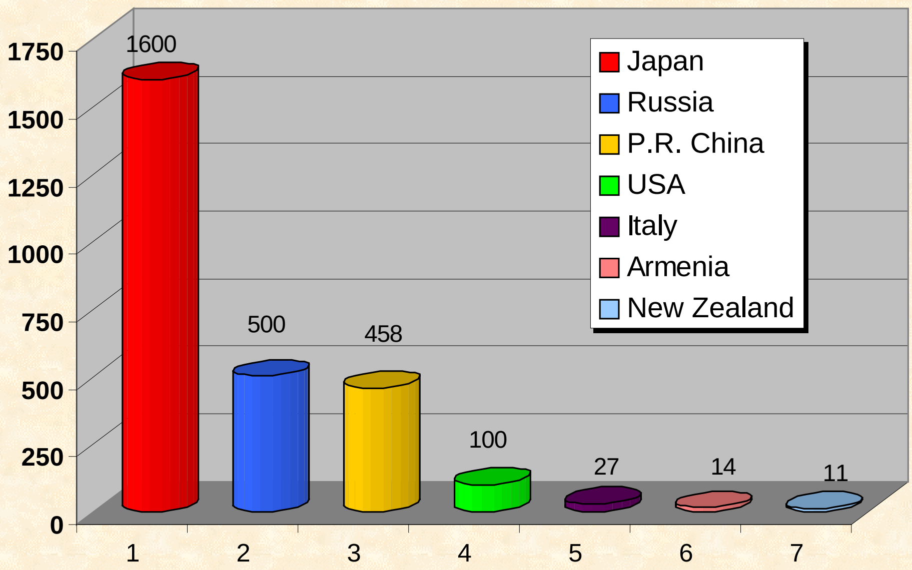


Figure 6: Numbers of seismically isolated buildings in the various countries (December 2002).