Main Features and Conclusions of the 1999 International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures

Alessandro Martelli [1], Massimo Forni [2], Hyun Min Koh [3]

1) Chairman, Working Group on Seismic Isolation (GLIS); ENEA, Bologna, Italy
2) Technical Secretary, GLIS; ENEA, Bologna, Italy
3) Professor and Chairman, Department of Civil Engineering, Seoul National University, Korea

ABSTRACT

Summarised in this paper is the state-of-the-art on seismic protection through innovative anti-seismic techniques, namely seismic isolation (SI), passive energy dissipation (ED) and active control (AC), based on the information collected at the 6th International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures held at Cheju (Korea) in August 1999 and even more recent information which became available to the authors. Reported is information on the most recent applications of such techniques, together with the progress of R&D activities at word-wide level, availability of design rules and the related issues and needs for further activity. With regard to the latter, somewhat more detailed information is reported for European and especially, Italian applications.

INTRODUCTION

Modern society is being more and more characterized by a strong interaction among the large systems by which it is formed: the physical, human and infra-structural systems. Seismic risk results from the interaction among seismic hazard, vulnerability of structures and social-economical effects. In the past, an earthquake mainly caused collapse of buildings and fatalities. Nowadays, a seismic event may also endanger the social-economical stability of large areas, due to the complexity of technologically advanced societies. For instance, the Great Hanshin-Awaji earthquake of 1995, which struck Kobe (where one of the most important ports of the world is located) is the first case in the history of a seismic event that occurred in a highly industrialized urban area, by producing enormous damage to the building, road and in particular, productive systems.

The earthquake which struck Izmit in Turkey on August 17, 1999, caused the fire of the biggest Turkish petrochemical plant, by leading to very difficult fuel supply and heavy pollution. A scenery similar to those mentioned above might take place in many other areas in the world, from California to Italy: in California, for instance, in case of a strong earthquake closer to San Francisco and Silicon Valley, with the respect to the 1989 Loma Prieta event; in Italy, for instance, in case of events like that which struck the now highly industrialized area around Po River in 1117, or that which destroyed South-East Sicily (where a huge number of petro-chemical plants and components is now located) in 1693.

In addition, it is worthwhile mentioning that recent earthquakes showed a fully unexpected violence, like for instance, that which struck again Turkey, with epicenter near Kaynasly (Bolu Mountains), on November 12, 1999. Since ground acceleration was much larger than the design value, this caused severe damage even to some very important modern structures, like a viaduct of the new Istanbul-Ankara freeway, being erected using the most modern anti-seismic technologies, which was extremely close to the epicenter [1]: in fact, the maximum displacement allowed by the horizontal fail-safe system (stoppers) was largely exceeded (another viaduct behaved very well, although it displaced twice the design value, but this was still allowed by the stoppers).

The aforesaid remarks demonstrate, without any doubt, the increased degree of complexity of modern society, and thus, the need for an integrated management of the territory, able to make development and safety compatible. This implies that more and more numerous shall be the structures for which design shall not be limited to prevent their collapse, but shall require the absolute integrity and full operability after the earthquake. The feature of absolute integrity is also indispensable to protect investment, taking into account that the value of contents of more and more buildings is much larger than that of the structural members, as well as to avoid spending the enormous amounts of money during both the emergency phase and reconstruction which were necessary after the recent earthquakes.

For the above-mentioned reasons, a wide extension of the use of innovative anti-seismic techniques, such as seismic isolation (SI) and passive energy dissipation (ED), which aim at ensuring the full integrity and operability of structures, is necessary for both new constructions and retrofit of existing buildings [2]. In fact, SI and ED technologies are now fully mature for such an use, as demonstrated by the results of very numerous research projects and also, by the excellent behavior of seismically isolated buildings in both the Great Hanshin-Awaji earthquake and the Northridge earthquake which struck the Los Angeles area the year before [2]. This conclusion has been confirmed in all the recent Conferences on seismic engineering, in particular at the 6th International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures held at Cheju, Korea in 1999 [3].

RECENT APPLICATIONS

The invited lectures and contributed papers presented at the Cheju Seminar and the extensive discussion both following their presentation and during the Closing Panel, demonstrated that not only SI, but also several ED systems are already fully mature for wide-ranging applications. They also showed that, at last, the benefits of such systems have been well understood in several countries and that they are now being more and more used. The aforesaid benefits had already been very well understood by Japanese after the 1995 Kobe earthquake and to a certain extent, by Californians after those of Loma Prieta (1989) and Northridge (1994). Even before, this had occurred in New Zealand, where there are still new applications of SI to both new and existing ancient constructions, in spite of the limited population; more recently, it also occurred in other countries, like the P.R. China, Russian Federation (especially after the Sakhalin earthquake in 1994) and Italy (after the 1997 earthquake of Umbria and Marche Regions, which severely damaged famous frescos of Cimabue and Giotto in the "San Francesco Basilica Superiore" at Assisi). It is also worthwhile citing again that, according to the information provided at the Cheju Seminar, SI and ED are now considered of great interest also for areas characterized by low or moderate seismicity [3].

Applications in Japan

In Japan the number of buildings provided with innovative anti-seismic systems is still considerably increasing, in spite of the need for still asking for a specific approval for each design including these techniques [3]. The number of licenses began to drastically increase in September 1995, some months after Kobe earthquake (60 new applications) and the annual number reached 207 in 1996, while the overall number during the 10 previous years was 79; such a dramatic increase ended in 1997, when a probably steady progress began (the new licenses were 135 in 1997 and 131 in 1998).

In this country, the use of SI was recently extended from new constructions to retrofit of existing buildings (e.g. Le Courboisier Museum at Tokyo), as well as to many new or existing bridges and viaducts (in some cases, at least in Kobe, becoming compulsory for the latter). SI is having many variations in application objects, application methods of rubber bearings and kinds of devices. The variations include SI of tall buildings of about 100 m height, SI of artificial grounds for multiple buildings, and application of non-rubber type SI devices. SI is finding new applications which include wooden houses, masterpieces in museums, automatic storage systems of warehouses, etc.: for wooden houses, non-rubber type SI systems using ball/rubber bearings or sliding bearings to support the superstructure have been developed and used; for masterpieces in museums, various types of SI have been developed and used for the containing showcases; for automatic storage systems of warehouses, a new type of SI floor has been developed and used. It is also noted that SI is beginning to be used for very important public buildings and facilities, such as, for instance, the new official residence of the Prime Minister.

Applications in the USA

In the USA (especially in California), new constructions of important isolated strategic buildings, including emergency control centers (e.g. those at San Francisco and Long Beach) are going on and retrofit of even large public buildings using SI (e.g. the San Francisco City Hall and San Bernardino Medical Center) is progressing [3]. Most applications make use of rubber bearings, namely High Damping Rubber Bearings (HDRBs) or Lead Rubber Bearings (LRBs).

However, the extent of the aforesaid progress is much less than in Japan. In fact, although the first U.S. seismically isolated building was completed in 1985, in 1999 there were in this country only 25 applications to new constructions and 22 retrofits of existing buildings: this is due to very complex and conservative regulations.

Conversely, SI is now being widely used in the USA for highway bridges, for which it is governed by a simple and not overly conservative code.

Applications in New Zealand

There were 10 isolated buildings in New Zealand in 1999 (in addition to several applications to bridges and viaducts), four of which being retrofits of ancient constructions (those of the Old Bank of New Zealand and Wellington Museums were completed in 1999) [3]. Most applications make use of LRBs, in some cases in conjunction with teflon sliders.

Applications in Other Non-European Countries

As regards other non-European countries, in the P.R. China there were already 160 buildings isolated by means of rubber bearings in 1999 [3]; the total numbers of Chinese isolated buildings and bridges & viaducts reached 230 and 20, respectively, in May 2000 [4]. In Taiwan 10 bridges had been supported by LRBs, in addition to others being erected using viscoelastic devices (VEDs) and elastic-plastic (EP) dampers [3]. It is also worthwhile noting that the number of seismically isolated bridges using LRBs was approaching 30 in Korea in 1999, in spite of its low and moderate seismicity [3]: the main reason is that the use of SI is generally accepted in Korea as an alternative way to reduce the additional construction costs caused by the seismic design requirements recently adopted in this country.

With regard to important new applications of ED systems to bridges and viaducts, to be cited are also those to: (a) three new viaducts of the Istanbul-Ankara freeway in the Bolu Mountains in Turkey (Figure 1), two of which completed and one under construction, which have been provided with multidirectional EP devices (as previously mentioned and explained in [1], two of these viaducts behaved in an excellent way in the earthquake of November 12, 1999); (b) the Bangabundhu Bridge over the Jamuna River in Bangladesh, with hysteretic devices [5, 6]; (c) twenty six important railway viaducts in Venezuela, again with hysteretic devices [5, 6]; (d) five bridges along the North-South Route in Chile, with VEDs [5, 6].

In Chile, the new hospital of the Catholic University has been isolated with HDRBs [5, 6].

Applications in Western Europe

As regards Europe, to the knowledge of the authors, most new applications of the innovative anti-seismic techniques (in progress or under design or planned) concern Italy, where there were already over 30 applications of such techniques in 1998 [2] and such new applications take advantage of the results of important projects funded by the European Commission (EC).

In Italy to be cited are the following recent / new applications to [3, 5, 6]:

- The "San Francesco Basilica Superiore" at Assisi (Umbria Region), which had been severely damaged by 1997 earthquake: in October 1999, it was equipped with Shape Memory Alloy (SMA) devices and innovative shock transmitters (the latter developed in the EC-funded REEDS Project, in the framework of the restoration of the Basilica (see Figure 2 and [7]).
- The "San Giorgio in Trignano" Bell Tower at San Martino in Rio (Reggio Emilia, Emilia-Romagna Region), which had been severely damaged by the Reggio Emilia and Modena earthquake of 1996: in November 1999, it was also retrofitted using SMA devices, in the framework of the EC-funded ISTECH Project.
- The San Feliciano Cathedral at Foligno (Umbria), again damaged by the 1997 earthquake and retrofitted with SMA devices.
- The "La Vista" and "Domiziano Viola" schools at Potenza (Basilicata Region), which were retrofitted in 1999 using dissipative braces (see Figure 3).
- The "Gentile Fermi" school at Fabriano (Marche Region), a reinforced concrete building constructed in the years '50s, being one of the few examples of rationalist architecture in the town, which had been also heavily damaged by the 1997 earthquake: it is being retrofitted using VEDs (see Figure 4).
- An apartment building, under construction with HDRBs at Rapolla (Potenza, Basilicata Region) close to a twin conventionally founded building (see Figure 5); this application is similar to the twin isolated and non-isolated buildings already existing at Squillace (Catanzaro, Calabria Region) [2].
- The "Rione Traiano" Civic Center at Soccavo (Naples, Campania Region), a very large construction erected with conventional foundations before the 1980 Campano-Lucano (Irpinia) earthquake, when the area was not considered as seismic: this is being retrofitted using approximately 500 HDRBs.
- A new hospital at Frosinone (Lazio Region), which has been designed using HDRBs.
- Several buildings of the new Emergency Management Center for Central Italy at Foligno (Perugia, Umbria Region), being designed using various innovative anti-seismic systems (see Figure 6).
- The new hospital at Perugia and an apartment building at Città di Castello (Umbria Region), to be isolated with HDRBs.

Figure 1a. Viaduct N. 1 of the Istanbul-Ankara freeway provided with EP devices.

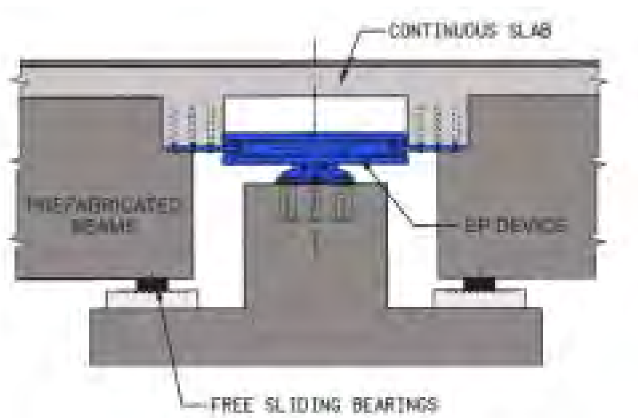

Figure 1b. Detail of the pier top of the Viaduct of Figure 1a.

Figure 2 a. SMA devices installed on the "San Francesco Basilica Superiore" at Assisi (PG).

Figure 2 b. Shock transmitters installed between nave and transept of the "Basilica Superiore".

- Two new buildings at the Navy Base of Augusta (Siracusa, Sicilian Region), to be probably isolated using HDRBs, similar to those already existing at such a Base [2].
- An electric substation at Laino (Calabria Region), to be isolated by the Italian Electricity Board (ENEL) with wire ropes, based on the results of an extensive numerical and experimental study (this will be the first electric equipment in Italy to be provided with a SI system).
- Several viaducts of the Salerno-Reggio Calabria freeway (Campania, Basilicata and Calabria Regions), for which retrofits using ED systems are being designed.
- A bronze statue of Germanicus Emperor, located in a museum at Perugia (Umbria Region), which was provided with a multistage SI system using HDRBs (this will be the second Italian application of SI of this kind, following that to the famous Bronzes of Riace at the Reggio Calabria Museum [2]).

In addition, SI might be adopted in Italy for other buildings or structures; in particular, based on the already promising results of an ongoing study funded by the National Group for the Defense from Chemical, Industrial and Ecological Risks of the National Research Council (CNR), it may be adopted for Liquefied Natural Gas (LNG) tanks, such as an existing spherical butane storage tank located in a highly seismic site, as a possible pilot application in Italy for chemical plants [8].

Finally, the possibility of reconstructing ancient villages in Marche and Umbria Regions using the original masonry materials and to make it feasible, SI is being considered in Italy: to this aim, under consideration are the village of Mevale di Visso in Marche Region (which was almost fully destroyed by the Marche and Umbria earthquakes of 1997-98, after being severely damaged by previous earthquakes) and villages around Nocera Umbra in Umbria Region (which were also severely damaged by the 1997-98 earthquakes).

Data concerning the Italian applications are available on Internet at the GLIS address: http://192.107.65.2/glis. It is noted that some applications, in particular those of the new Emergency Management Center at Foligno and (if confirmed)

Figure 3. Dissipative braces installed on the "La Vista" and "Domiziano" schools (Potenza).

Figure 4. Gentile Fermi school (Fabriano). Cut of the wall for the introduction of the braces supporting the VED.

Figure 5. Isolated under construction and already erected conventional buildings at Rapolla (PZ).

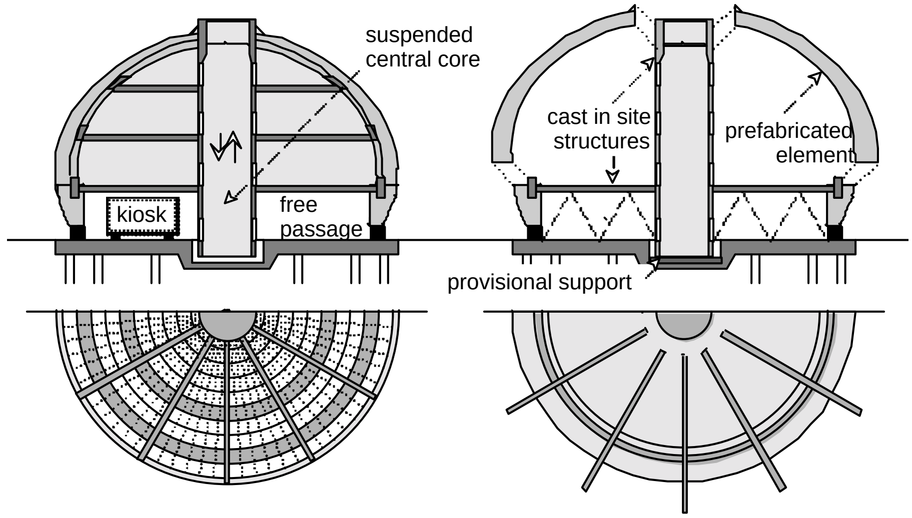

Figure 6. Sketch of one of the buildings of the Center of the new Emergency Management Center of Central Italy, Foligno, Umbria, which will be seismically isolated using HDRBs.

that to the reconstruction of Mevale di Visso, will take advantage of collaborations recently established (or being established) between ENEA and Italian Regions for carrying out pilot applications on buildings, by joining the use of innovative anti-seismic systems with the energetic-environmental quality [5, 6].

With regard to other Western European countries, new / recent important applications known to the authors are to [3]: (a) two storage tanks of Lonza Company for hazardous chemical materials, which were retrofitted at Visp (Switzerland) using HDRBs; (b) bridges in France, including a "TGV" fast train bridge at Marseille, which were provided with VEDs; (c) a French building at La Martinica to be provided with VEDs in conjunction with cables; (d) the 4 km long Santarem cable-stayed bridge over Tagus river, isolated using HDRBs (Portugal); (e) the "21th April" suspension bridge over the Tagus river (Portugal), which was upgraded using viscous dampers (VDs); (f) the new "Vasco de Gama" Tagus crossing (Portugal), which was provided with shock transmitters, VDs and elastic-plastic (EP) devices; (g) some small bridges in Greece, provided with HDRBs.

Applications in the Former USSR Countries

Some new building applications of SI were also carried out in the former USSR countries (where the total number reached 306 in 1999 [3]: these were performed in Russia, Armenia and Uzbekistan and made use of HDRBs (the previous applications mostly made use of so-called "low cost isolators"). To be cited among the aforesaid recent applications of HDRBs is the retrofit of the bank of Irkutsk-City (Russia), where isolators manufactured in the P.R. China were installed.

STATE-OF-THE-ART ON R&D

The papers presented at the Cheju Seminar also showed that most necessary R&D activity has already been completed, not only for SI, but also for most types of ED systems (further work remaining necessary for very new devices such as electromagnetic dissipators [3]). With regard to studies performed in the European Union on SI and ED systems, those previously mentioned, concerning the REEDS and ISTECH Projects for the optimization of hysteretic, viscous and viscoelastic dampers and shock transmitters, as well as the development of innovative rolling SI systems and SMA devices, had been just completed at the time of the Seminar and confirmed the excellent behavior of such devices [3].

To be cited is also the present availability, of test equipment - not only in Japan, but also in the USA (for instance, that of Caltrans at San Diego) - capable of qualifying full or at least, large scale devices, as necessary to correctly estimating safety margins: in fact, such tests, if performed on small scale devices, may be not very satisfactory even for rubber bearings (for instance because bonding conditions could be different from those of the real scale device) and are certainly not adequate for VDs, because they cannot correctly describe fluid heating conditions [3].

Regarding future studies and application of SI and ED systems, issues which were stressed were the importance of: (a) extending retrofit using the innovative anti-seismic techniques; (b) improving studies concerning innovative systems applicable to cultural heritage; (c) improving knowledge and develop systems for vertical isolation; (d) promoting more applications to hospitals and chemical plants and components; (e) widely extending application from strategic to apartment buildings; (f) performing adequate monitoring; (g) improving knowledge on seismic input, in particular for near-field earthquakes (how correct is this point was confirmed later by the aforesaid earthquakes in Turkey); (h) improving studies concerning some reliability and uncertainty issues which have not been yet fully analyzed (including scale effects for qualification tests of SI and ED devices, the behavior of such devices at earthquake levels exceeding the design value, and failure modes, at extremely violent beyond design earthquakes, of structures provided with the anti-seismic systems); (i) considering other sources of vibrations which may damage or weaken structures (for instance, traffic).

Finally, with regard to non-passive control systems (active, semi-active and hybrid systems), the papers presented by the experts at this topic stressed that also their development is further progressing well. Thus, it was decided that the attention devoted at Cheju to this topic has to be kept also at the next Seminar, to be held at Assisi (Italy) on October 2-5, 2001.

DESIGN GUIDELINES DEVELOPMENT

The only still remaining problems for a wide-ranging application of SI and ED systems that were stressed at the Cheju Seminar concern the design rules for structures provided with such systems [3]. In general, the situation did not improve much with respect to the previous 5th Seminar held at Taormina (Italy) in 1997 [9], especially because such rules are still different in the different countries, frequently still penalize the use of SI with respect to the conventional design and their application still requires heavy approval processes. The only important improvement is that there are now, at least, design guidelines available in most countries (in Italy they were published by the Ministry of Construction at the end of 1998).

An interesting recommendation made in the Closing Panel of the Cheju Seminar was to try to find the way to develop international design guidelines for structures provided with the innovative anti-seismic systems. Among others, these international guidelines should explain such systems correctly and leave official codes out of consideration. They would not have any legal value, but may be useful, because they would be based on knowledge and experience of real experts. This guidelines' development might be part of the activities of the International Earthquake Research Center that had been proposed at the main SMiRT Conference, held at Seoul (Korea) the week before that of Cheju Seminar. The problem to allow for these activities is to find the necessary funding. In the aforesaid Closing Panel, it was also proposed the guidelines of all countries represented in the Seminar to be translated in English and published in an appropriate volume at the next venue of Assisi, and that, at such a venue, there shall be papers on applications, each containing sufficiently detailed reference to the codes used in the related country. With regard to non-passive control systems, it was stressed at Cheju that the development of these techniques suffers from the fact that they are not considered at all by design rules [3].

CONCLUSIONS

Based on information collected at the 6th International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures, held at Cheju (Korea) in 1999 and more recent information that became available later to the authors, the state-of-the-art on the applications of SI and ED systems has been shortly reported and some remarks on the progress of R&D activities at word-wide level and design guidelines development have been made. It has been stressed that SI and ED technologies, which aim at ensuring the full integrity and operability of structures, are fully mature, as demonstrated by both the results of very numerous research projects and the excellent behavior of seismically isolated buildings and viaducts in violent earthquakes. It has been shown that, consequently, a wide extension of the use of these techniques is in progress, for both new constructions and retrofit of existing buildings.

The state-of-the art on the development and application of the innovative anti-seismic techniques will be updated at the 7th International Seminar to be held at Assisi, Italy, on October 2-5, 2001.

REFERENCES

1. Marioni, A., "The Effects of Recent Earthquakes on the Base Isolated Bridges of the Istanbul Ankara Motorway near Bolu", *Proc.Of IASS Symposium on Bridging Large Spans – From Antiquity to Present*, pp. 261-270, Istanbul, Turkey, 2000.
2. Martelli, A., and Forni, M., "Seismic Isolation of Civil Buildings in Europe", *Progress in Structural Engineering and Materials*, Construction Research Communications Ltd., London, Vol. 1 (3), 1998, pp. 286-294.
3. Koh, H.M., and Martelli, A., Preface – "Overview and Summary of the International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures", *Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures - Proceedings of the Post-SMiRT Conference Seminar, Cheju, Korea, August 23-25, 1999*, Vol. 1, Seoul, Korea, August 2000.
4. Zhou, F.L., Recent Development on Isolation and Energy Dissipation Used in New Seismic Design or Retrofit for

Structures in China. *Proc. Of the IASS Symposium on Bridging Large Spans – From Antiquity to Present*, pp. 230-240, Istanbul, Turkey, May-June 2000.
5. Martelli, A., and Forni, M., State-of-the-Art on Seismic Protection through Innovative Techniques. *Proc. Of the IASS Symposium on Bridging Large Spans – From Antiquity to Present*, pp. 251-260, Istanbul, Turkey, May-June 2000.
6. Martelli, A., and Forni, M., State-of-the-Art on Recent Applications and Research Needs, Session on Base Isolation System. *Proc. Of the Final Workshop on "Protezione Sismica dell'Edilizia Esistente e di Nuova Edificazione attraverso Sistemi Innovativi*; Programma MURST PRIN 97, Naples, Italy, June 2000.
7. Castellano M.G., and Martelli, A., The Influence of Shape Memory Alloy Ties on the Seismic Behaviour of Historical Masonry Buildings. *Proc. IASS Symp. on Bridging Large Spans – From Antiquity to Present*, pp. 271-280, Istanbul, 2000.
8. Martelli, A., Forni, M., Poggianti, A., and Spadoni, B., R&D in Progress at ENEA, with Particular Attention to the Industrial Plants. *Proc. Of the 16th SMiRT International Conference*, Washington, DC, USA, August 2001.
9. GLIS, *Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibrations of Structures - Proceedings of the International Post-SMiRT Conference Seminar, Taormina, Italy, August 25 to 27, 1997*, A. Martelli and M. Forni eds., Bologna, Italy, 1998.