RECENT PROGRESS OF APPLICATION OF MODERN ANTI-SEISMIC SYSTEMS IN EUROPE – PART 2: ENERGY DISSIPATION SYSTEMS, SHAPE MEMORY ALLOY DEVICES AND SHOCK TRANSMITTERS

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ABSTRACT :

As mentioned in a separate paper presented at this conference, there are already well over 8,000 structures in the world that are protected by seismic isolation (SI), energy dissipation (ED) and other modern seismic vibration passive control (SVPC) devices, such as shock transmitter units (STUs) and shape memory alloy devices (SMADs). The number of applications is increasing everywhere more and more, not only for SI, but also for the other SVPC systems. The conclusive influence of earthquake experience and availability and features of the design rules used on the extension of application has been confirmed for the latter systems, as well. Although the data concerning ED systems, SMADs and STUs are more uncertain than those related to SI, Italy is most probably fourth at worldwide level (after Japan, the P.R. China, the USA) and again first in the European Union for the number of applications of these systems (also thanks to the numerous bridges and viaducts and some important cultural heritage structures protected by them). Italy is now followed by Taiwan, New Zealand, Canada, Mexico, South Korea and Canada. Important applications, although limited to bridges and viaducts, also began in other European countries, namely in Greece, Portugal and Spain; many of them make use of devices manufactured in Italy. Italian devices have also been installed in several other countries. This paper focuses on the application in Italy and other European countries (including the entire Russian Federation) of ED devices, SMADs and STUs, while a separate paper, presented in Special Session S05-01, deals with that of SI systems.

KEYWORDS: Energy dissipation, shape memory alloy devices, shock transmitter units, retrofits, civil structures, cultural heritage.

1. INTRODUCTION

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

In several countries, similar to the applications of SI systems, the number of structures protected by ED and other SVPC devices is increasing more and more, although, for these too, the extent of their use is strongly influenced by earthquake experience (Figures 1 and 2) and the features of the design rules used. Applications concern both new and existing civil structures of all types: bridges and viaducts, civil and industrial buildings, industrial components and cultural heritage, such as some ancient churches. As shown by Dolce et al. (2006), Martelli and Forni (2008), and Martelli et al. (2008), those to civil buildings already include the construction and retrofit of high-rise buildings, erection of structures on soft soils and retrofits of strategic and public buildings (e.g. hospitals, schools, churches, commercial centres, hotels, airports, etc.).

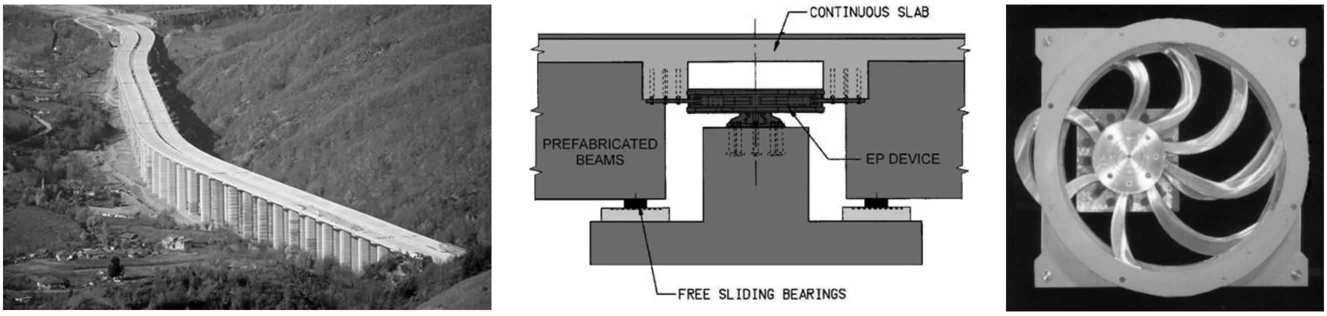

Figure 1 *Bolu Viaduct* of the Istanbul – Ankara freeway (Turkey), during its construction. It was protected by "half-moon" – shaped Elastic-Plastic Dampers (EPDs), manufactured in Italy (an EPD is shown on the right, during a failure tests). They saved the viaduct from collapse during the 1999 *Duzce* earthquake (M=7.2), although this earthquake was characterized by a peak ground acceleration of 0.87 g, namely more than twice the design value (0.4 g). Thus, they made seismic retrofit possible (see Figure 2).

Figure 2 An EPD of the viaduct of Figure 1 (left) and its deck hardly still supported by some very inclined piles (centre) just after the 1999 *Duzce* earthquake. Right: one of the Friction Pendulum System (FPS) devices that were later used to retrofit the viaduct (usually 700 mm diameter, but 900 mm diameter at fault crossing).

2. APPLICATION IN ITALY

Taking into account its numerous applications of ED devices and STUs to bridges and viaducts, Italy is most probably at the fourth place at worldwide level for the number of applications of SVPC systems different from SI, after Japan, the P.R. China and the USA (in these countries there are already hundreds of buildings protected by ED devices, as shown, for instance, by Martelli et al., 2008).

Figure 3 *Coltano (former Mortaiolo) Viaduct* of the Genoa-Rosignano freeway, protected by EPDs, rubber bearings (RBs) and STUs in 1990.

The Italian applications to bridges and viaducts (see, for instance, Figures 3 and 4) began immediately after the 1976 *Friuli* earthquake (see the aforesaid separate paper presented at this conference) and were over 150 already at the beginning of the years 1990. This made Italy the worldwide leading country for these applications, a position which it is most probably still keeping. In addition, ED devices and STUs manufactured in Italy have also been installed in several bridges and viaducts abroad (see, for instance, Figures 18-22).

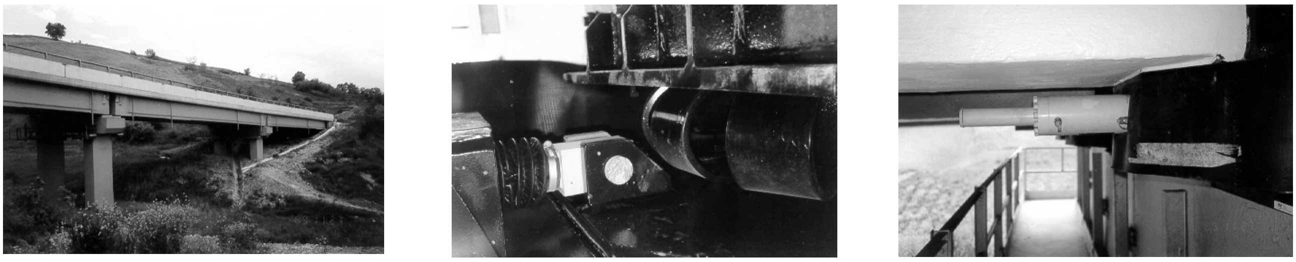

Figure 4 *Agrifoglio Viaducts* of the Naples-Bari freeway at Vallata (Avellino), which were retrofitted by means of EPDs and STUs in the 1990s.

Figure 5 From left to right: (a) cumulative number of building applications of ED devices, STUs and SMADs in Italy; (b) *Headquarters Building of the New Fire Station at Naples*, erected in 1981 with a seismic protection system formed by 24 Neoprene Bearings (NBs) with mechanical dampers at the top and 80 floor dampers; (c) the adjacent *Mobile Brigade Building*, erected in 1985 with a seismic protection system formed by 120 NBs at the top, 120 STUs and 60 floor dampers.

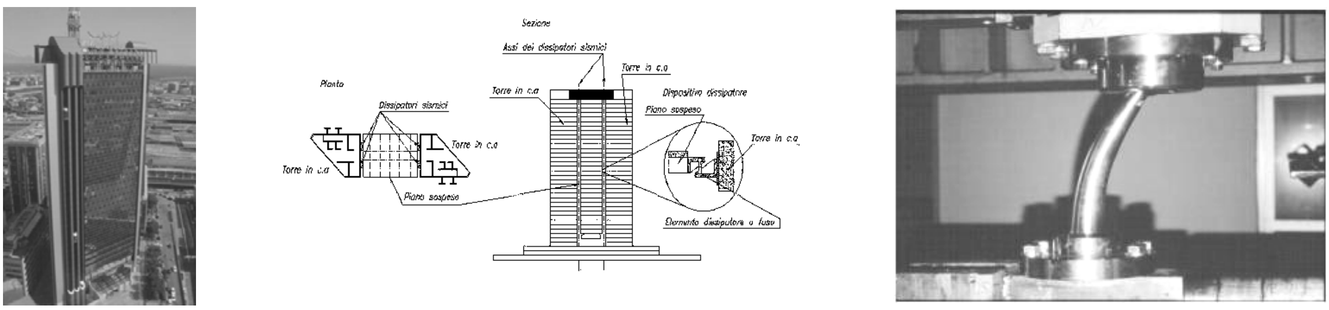

Figure 6 *Twin Towers of the ENEL Headquarters at Naples* (height of the central 29-storey 90,000 m^3 suspended cores = 120 m), each protected by 116 EPDs in 1993, and view of an EPD during lateral deformation tests.

With regard to building applications of systems different from SI, Italy is probably preceded by Taiwan too (where 85 applications were reported in 2005). In fact, although the number of Italian applications is now very rapidly progressing, at the end of 2006 there were 19 buildings protected in Italy by ED devices or SMADs and 28 provided with STUs. We note that, in the years 1990s, the use of such devices suffered problems similar to those of SI, namely lack of design rules and too complicated and time consuming approval process (Figure 5a).

Figure 7 (a-b) Left and centre: *Domiziano Viola School* at Potenza (seismic zone 1), seismically improved in 2000 (similar to the *La Vista School* in 1999) and its dissipative braces with EPDs. (c) Right: *Giacomo Leopardi School*, again at Potenza, seismically improved with the same system in 2004.

Figure 8 *Gentile Fermi School* at Fabriano (Ancona, seismic zone 2), an example of rationalist architecture, damaged after the 1997-98 *Marche and Umbria* earthquake and with some static problems even previously (left); its structural and seismic improvement with Visco-Elastic Dampers (VEDs) in 2000 (centre and right).

Figure 9 (a-b) Left and centre: views, during construction in 2005, of the new building of the *Polytechnical University of Marche* at Ancona (seismic zone 2), protected by 86 Buckling Restrained Braces (BRBs). (c) Right: *Perticari High School* at Senigallia (Ancona, seismic zone 2), rationalist architecture like the *Gentile Fermi School* of Figure 8, recently seismically retrofitted with dissipative braces, because of its bad concrete quality and non-symmetric shape.

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The first building applications of ED devices and STUs were performed in 1981 and 1985: they concerned two buildings of the *Naples Fire Station Centre* that has already been cited in the separate paper dealing with SI (Figures 5b-c). As to civil buildings, these were followed by a *hospital in Siena*, which was protected by friction dampers in 1988, *Laboratories of the National Research Council* at Frascati (Rome) in 1990 (provided with EPDs), and the *Twin Towers of the Headquarters of the Italian National Utility (ENEL)* at Naples in 1993 (where both EPDs and STUs were installed, see Figure 6).

In the meantime, STUs were used for the first time in Italy to retrofit cultural heritage, namely the *San Gorgio in Carife Church* near Avellino (with 18 STUs installed on the roof) and the *New Library of the University of Naples "Federico II"* (with 24 STUs and 34 NBs). In 1999 application of dissipative braces began for retrofitting existing schools, initially located at Potenza and in its area (which are in seismic zone 1), then in other sites, as well (Figures 7-9.).

Figure 10 Above: *Upper Basilica of St. Francis* at Assisi, damage caused to the tympana by the 1997-98 *Marche and Umbria* earthquake and view of the transept roof after installation of 47 SMADs between it and each tympanum. Below: one of the SMADs, two STUs in position and their location.

Figure 11 From left to right: (a-b) the *Bell Tower of the San Giorgio in Trignano Church*, cut into 2 pieces by the 1996 *Reggio Emilia and Modena* earthquake; (c) one of the 4 SMADs used in series to the vertical ties to retrofit the bell tower in 1999; (d) the *Bell Tower of Badia Fiorentina* at Florence, seismically improved with 18 SMADs in series to ties in 2006.

In the same years SMADs, developed in the framework of the ISTECH Project funded by the European Commission (EC), were used for the first time in the world to retrofit the an ancient church, namely the famous *Upper Basilica of St. Francis* at Assisi, which had been severely damaged by the 1997-98 *Marche and Umbria* earthquake (Figure 10) and the *Bell Tower of the San Goirgio in Trignano Church*, which had been severely damaged by the (although moderate) 1996 *Reggio Emilia and Modena* earthquake (Figure 11a-c). In the retrofit of the *Upper Basilica of St. Francis at Assisi*, STUs, optimized in the framework of the REEDS EC-funded Project, were also installed to stiffen the church body during earthquakes (Figure 10).

Figure 12 Further ancient churches retrofitted with SMADs. From left to right: (a-b) *San Feliciano Cathedral* at Foligno (Perugia, seismic zone 1), damaged by the 1997-98 earthquake (with view of its SMADs); (c) *San Serafino Church* at Montegranaro (Ascoli Piceno), damaged by the same earthquake; (d) *San Pietro Church* at Feletto (Treviso), also damaged by a significant earthquake in the past.

Figure 13 *Santa Maria di Collemaggio Cathedral* at L'Aquila, an unique example of Abruzzo Romanic style (partly destroyed by a violent earthquake, then reconstructed in baroque style and finally returned to its original style), which was retrofitted by installing EPDs on the roof (it had considerably vibrated during the 1997-98 *Marche and Umbria* earthquake, in spite of the large distance from the epicentre).

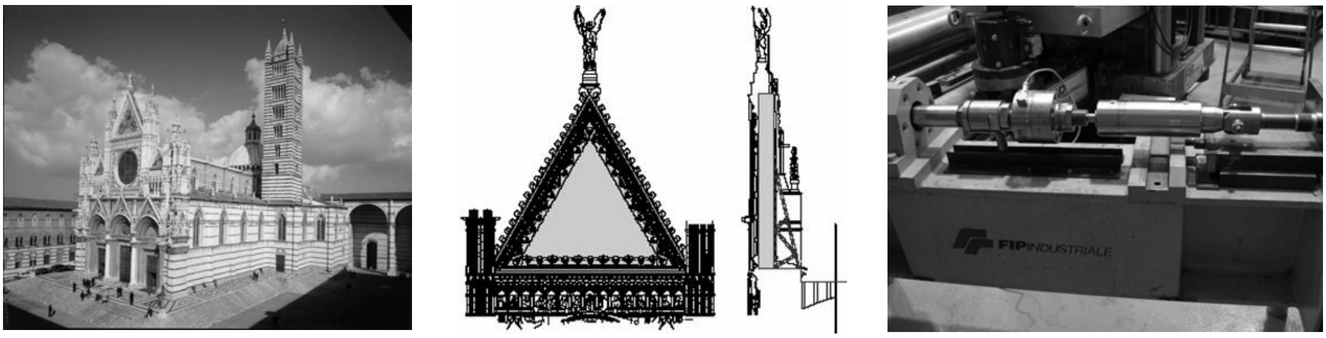

Figure 14 *Dome of Siena* and one of the re-centring Viscous Dampers (VDs) which were installed during its retrofit, performed to avoid overturning of the façade.

For the protection of ancient churches, the aforesaid SMAD applications were later followed by others (Figures 11d and 12) and by a few applications of ED systems (Figures 13 and 14). Among the most recent of ED systems to new or relatively new Italian churches (which are high seismic risk structures, see Figure 15) it is worthwhile stressing those of Figures 16 and 17.

Figure 15 *Church at Pisco* (Peru) severely damaged by the earthquake of August 15, 2007. Most victims were due to the collapse of churches, similar to other events in other countries.

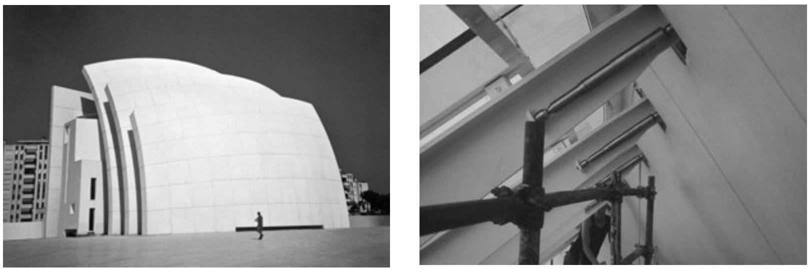

Figure 16 The new *Dives in Misericordia Church*, erected in Rome (seismic zone 3) in 2003, first application of the SVPC systems to new Italian churches, and some of the 32 VDs that were installed in the church to ensure the adequate seismic protection of this quite an irregular structure.

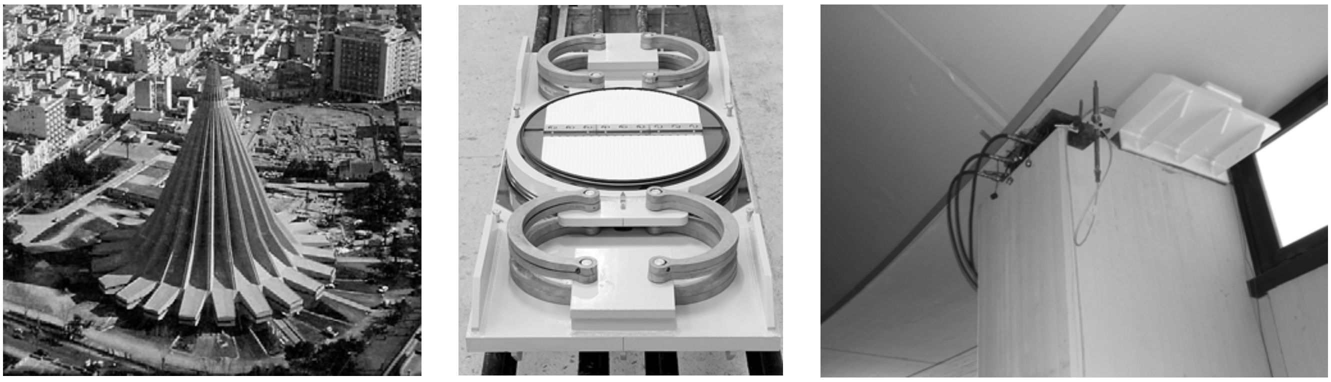

Figure 17 *Madonna delle Lacrime Sanctuary* at Syracuse (seismic zone 2), which may contain up to 11,000 persons, retrofitted by uplifting the dome (22,000 tons) and replacing the previously existing rubber supports by EPDs in 2006.

3. APPLICATION IN OTHER EUROPEAN COUNTRIES

As to building application of SVPC systems different from SI in the countries considered in this paper other than Italy, the only ones known to the author are in the Russian Federation (e.g. that of VEDs to the *National Drama Theatre* at Gorno-Altaisk, see the separate paper on SI). The applications of such systems to the bridges and viaducts are much more numerous: they mainly concern Greece, Portugal and Spain. Many of such applications make use of devices manufactured in Italy, as shown, for instance, by Figure 18 for the *Rion-Antirion Bridge* and its approaches in Greece. ED devices and STUs manufactured in Italy have also been installed in several bridges and viaducts and some buildings in non-European countries. A few examples are provided by Figures 19-22.

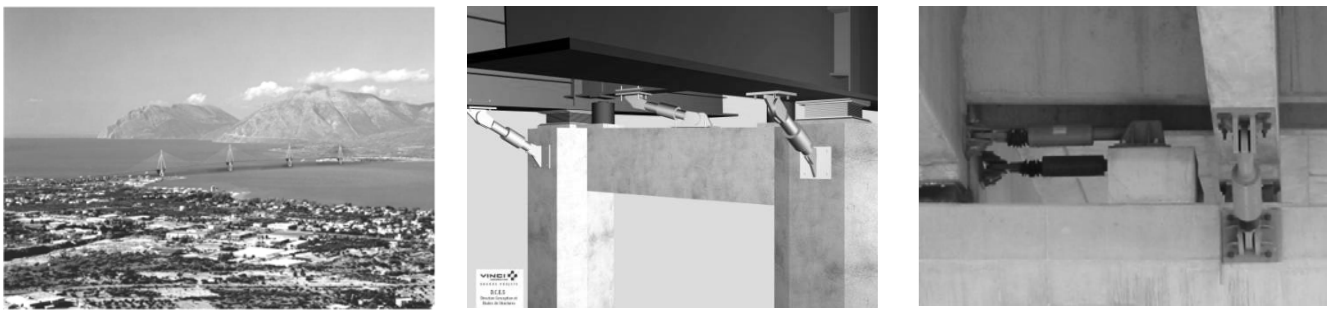

Figure 18 The 12 km long *Rion-Antirion Bridge* in Greece. The main bridge and its approaches were protected by SVPC devices manufactures in Italy (including 188 VDs).

Figure 19 *Carquinez Bridge*, California (USA), retro-fitted with STUs manufactured in Italy (centre, above).

Figure 20 *Marquam Bridge*, Oregon (USA), retrofitted with Italian isolators and EPDs (centre, below).

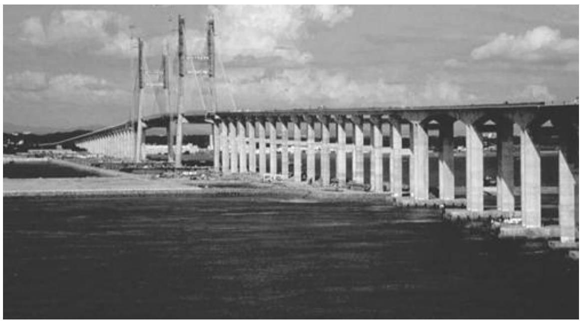

Figure 21 Approaches of the *Seo-Hae Granel Bridge* in South Korea (overall length = 5820 m, height of the piles = 12-60 m), which were seismically retrofitted by means of 54 VD (K = 100 kN/mm) manufactured in Italy in 2000-01 (centre, above).

Figure 22 *Caracas – Tuy Medio Railway* in Venezuela (26 viaducts, overall length = 7,8 m, 217 isostatic spans), with over 1500 Italian SI/ED devices (centre, below) in 1999-2003.

4. CONCLUSIONS

Like for SI, Italy (where the contributions provided by ENEA and GLIS have been again of fundamental importance) is largely the leading country in Europe as to the development and application of ED systems, STUs and SMADs. The latter concerns several bridges and viaducts (for which Italy is among the worldwide leading countries), new and existing strategic and public buildings and some important cultural heritage structures. The cited SVPC systems have already been used in other European countries too, especially for bridges and viaducts. Many of these make use of Italian devices. The latter have also already installed in several further countries.

REFERENCES

Dolce, M., Martelli, A. and Panza, G. (2006). Moderni Metodi di Protezione dagli Effetti dei Terremoti (Modern Methods for the Protection from Earthquake Effects), A. Martelli ed.: 21mo Secolo, Milan.

Martelli, A. and Forni, M. (2008). State of the Art of Development and Application of Antiseismic Systems in Europe and Other Countries. *Proc. of the 2008 Seismic Engineering International Conference Commemorating the 1908 MEssina and Reggio Calabria EArthquake (MERCEA'08)* **2**, 1272-1293.

Martelli, A., Sannino, U., Parducci, A. and Braga, F. (2008), Moderni Sistemi e Tecnologie Antisismici - Una Guida per il Progettista (Modern Anti-Seismic Systems and Technologies – A Guide for the Designer), 21mo Secolo, Milan.