Ongoing Research Projects at ENEA and Pilot Applications for the Seismic Protection of Cultural Heritage

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ABSTRACT

Large efforts have been devoted by the Italian Agency for New Technology, Energy and Environment (ENEA) to the development, validation and application of Innovative Antiseismic Techniques (IATs). New activities at ENEA are in progress concerning IATs for cultural heritage structures (CUHESs) to be restored or reconstructed, or masterpieces to be seismically protected. The ongoing activities foresee: IATs applications for damaged CUHESs restoration after recent earthquakes; a feasibility study for the reconstruction in the original site, with Seismic Isolation (SI) and original masonry materials, of an historic village destroyed by a seismic event; the design and application of an innovative three-dimensional SI system for seismic and ambient vibration protection of a roman ship excavated at Ercolano, near Naples; the integrated protection of works of art and archives manuscripts against natural catastrophes and incidental events.

1. INTRODUCTION

Large R&D and application efforts are going on at ENEA for the seismic protection of the various kinds of structures through IATs, namely seismic isolation (SI), passive energy dissipation (ED), hydraulic coupling by means of shock transmitters (ST), coupling through shape memory alloy (SMA) devices, and semi-active control (SAC). This work is performed by the ENEA Section “Prevention of Seismic Risks and Mitigation of Their Effects” (PREV), in the framework of the ENEA Program RITA (1999). ENEA began devoting particular attention to IATs applicable to CUHESs within both national and international collaborations (Martelli and Indirli, 2000; Indirli et al., 2001 and 2002). In this framework, the EC-funded ISTECH Project (FIP Industriale et al., 1995) allowed for the development of SMA devices (SMADs) capable of improving the stability, in particular seismic protection, of CUHESs (Various Authors, 2001; Indirli et al., 2000; Castellano et al., 1997, 2000, 2001).
SMADs were applied, for the first time in the world, to the restoration of three ancient structures: the Bell Tower of the San Giorgio in Trignano Church (Indirli et al., 2001; Bongiovanni et al., 2000), severely damaged by the 1996 Modena and Reggio Emilia earthquake - November 1999 - (Figure 1); the Upper Basilica of St. Francis at Assisi in October 1999 (Figure 2) and the Cathedral of St. Feliciano at Foligno - July 2000 - both severely damaged by the 1997-98 Marche and Umbria earthquake. In the St. Francis Upper Basilica restoration, use was also made of innovative STs developed in the framework of the REEDS Project (ENEL et al., 1996).

Figure 1. The Trignano Bell Tower: the typical flexural collapse and SMADs application

Figure 2. St. Francis Upper Basilica transept tympanum: damaged and restored by SMADs insertion

It is worthwhile stressing that CUHESs seismic protection is quite an important issue in a country like Italy, characterized by ancient and precious buildings and a non-negligible seismicity in a large part of its territory. In fact, CUHESs are seismically rather vulnerable: earthquakes, even those with moderate intensity, may cause collapse or heavy damage of many of them. The aforesaid seismic events, which may be classified as moderate (Indirli et al., 1997 and 1998), are significant examples of this behavior. Several existing still standing CUHESs, even not yet severely damaged, have been at least weakened by previous earthquakes. In addition, their earthquake resistance has been lowered by other factors, like chemical attacks to the masonry materials due to air pollution and traffic-induced vibrations. Thus, there is an urgent need for many of them to be seismically rehabilitated – or at least, “improved” – in order to make them capable to withstand future earthquakes without collapsing or becoming affected by severe damage.

An additional issue concerns the reconstruction of collapsed or severely damaged historical
villages at their original site and using original methods and materials. Unfortunately, the CUHESs rehabilitation problems, in order to make them capable of resisting violent earthquakes, are much more difficult to solve than those related to modern r.c. or steel structures, because there are specific conservation requirements for the interventions on CUHESs (i.e. integrity, compatibility, reversibility and durability), not very easily compatible with seismic requirements. An additional problem for the seismic rehabilitation of existing CUHESs is that their characteristics (material properties, construction aspects, state of integrity) are frequently not very well known, so that, for instance, a localized intervention (e.g. of strengthening) might cause even more severe damage to other parts of the structure in the next earthquake. This and other factors make each CUHES different from the other ones, by leading to the need for undertaking the rehabilitation design every time in a specific way, without much possibility of adopting standardized procedures. In is also noted that, in addition to R&D, large efforts are being devoted by ENEA to promote IATs pilot applications in various Italian Regions, seeking formal agreements with Local and Regional Governments. Finally, IATs use is very promising to protect museum buildings and single masterpieces from environmental vibrations, such as seismic events and traffic.

2. ONGOING PROJECTS FOR CUHESs

The most recent ENEA activities on seismic protection of CUHESs by means of IATs are being performed in the frame of the following projects: a feasibility study for the reconstruction in the original site, with SI and original masonry materials, of a village destroyed by the earthquake; the PROSEESM Project, funded by the Italian Ministry of University and Scientific and Technological Research (MURST) in 2001, which foresees pilot applications of SI and other IATs to the restoration of CUHESs damaged by earthquakes; a study for the design and application of an innovative three-dimensional SI system for the seismic/ambient vibration protection of a roman ship excavated at Ercolano; the ART-IN-SAFE project, funded by MURST, concerning especially the integrated protection of works of art and archives manuscripts against natural catastrophes and incidental events.

2.1. Reconstruction of Heavily Damaged Ancient Villages Using the Original Materials and SI

New activities for the development of IATs applicable to CUHESs are now in progress at ENEA, with the collaboration of the Faculties of Architecture of Ferrara and Naples “Federico II”. In particular, based on preliminary studies (Bertocchi, 2000; Procaccio, 2001; Bertocchi et al., 2002), ENEA proposed, to the Marche Regional Government and its Technical-Scientific Committee, a feasibility study concerning the SI use for the reconstruction of the historic village of Mevale di Visso (Macerata, Marche Region) by means of the original materials (Indirli, 2000). In fact, masonry constructions, if in good conditions, are the structures for which SI provides the best behavior (since they are the most stiff) and the largest protection advantages (since they have no ductility). Mevale di Visso had always suffered severe damage during the numerous earthquakes which had struck its area in this and the past centuries; in particular, it had already been partially destroyed by the 1979 Valnerina earthquake. The 1997-78 seismic event nearly completely destroyed again the village, including buildings reconstructed or rehabilitated after 1979 (Figure 3).
Figure 3: Historical village of Mevale di Visso (Macerata, Italy) rehabilitated after the 1979 Valnerina earthquake (top) and completely destroyed after the 1997-98 earthquake (bottom).

Figure 4: Geo-seismological amplification data and site spectra.

Red: conventional reinforcement and SI
Blue: conventional reinforcement and fixed base
Yellow: reinforced concrete frame and fixed base

Acceleration amplification (roof/base)

Figure 5: Analytical study for a sample building located at Mevale and first results.
The aforesaid Regional Institutions entrusted to ENEA the feasibility study, according to their new politics of possibly reconstructing the village in its original site and to the purpose of bringing the village back to its original appearance as much as possible, by also taking the opportunity for reconstructing parts of it that had collapsed during previous earthquakes and getting rid of some illegally built modern constructions. In the past, the usual politics in Italy was not to reconstruct such villages at their original site, but to move them to a different location and rebuild them using modern methods and materials, like reinforced concrete (r.c.). By going on in this way, more and more parts of the Italian cultural heritage will be fully lost forever. Thus, it is necessary to find ways for reconstructing these villages where they are, using original methods and materials (masonry, stone, wood, etc.) as much as possible and, at the same time, making them capable of resisting violent earthquakes. The feasibility study is now in advanced progress. The ongoing detailed investigations are confirming the existence of the particularly adverse site conditions (Fig. 4), anticipated by preliminary seismological and geological studies, showing quite a significant local amplification of the seismic motion. To avoid the need of moving the village to a different site and keep the possibility open of on-site reconstruction, the ENEA feasibility study is including: on-site investigations and observations; SI system design and buildings’ response calculation for a significant part of the village (such as to be easily extended to the entire village); evaluation of the decrease of seismic risk with respect to more conventional reconstruction (r.c. structures or steel reinforced masonry); quantification of costs related to the use of SI and the possible kinds of conventional reconstruction leading to at least an adequate (if not equal) level of seismic protection. The so far obtained numerical results demonstrate SI effectiveness (Figure 5).

2.2. PROSEESM Project

To assess methodologies for the application of IATs to CUHESs through the indispensable wide-ranging studies, a group of partners (Impresa Pouchain et al., 2000) proposed the PROSEESM Project to MURST, which approved it in 2000. PROSEESM is at the same time a R&D and training project, coordinated by the “Impresa Generale di Restauro Pouchain” (a well known Italian building company specialized in cultural heritage restoration). The technical coordination for R&D has been entrusted to ENEA; other partners are the Company ENEL.HYDRO, the engineering companies Studio Croci and Tekno In, and as far as training activities are concerned, the Universities of Basilicata, Perugia, and Rome “La Sapienza”. External support is provided by the Italian Central Institute of Restoration (ICR) and the Superintendencies for Cultural Heritage of Marche and Umbria Regions. PROSEESM aims at the “development and application of integrated innovative technologies and assessment of comparison methodologies to optimize the interventions of seismic protection of cultural heritage by respecting the safety and conservation requirements”. Some pilot applications of both IATs and more conventional techniques, even to CUHESs damaged by the 1999-1998 earthquakes, have been planned in Marche and Umbria Regions in the framework of the project. As previously mentioned, three churches located in the Perugia Province, heavily damaged by the aforesaid seismic event, are candidates for rehabilitation by means of sub-foundation and SI: the Santa Croce Church at Case Basse and the Santa Lucia Church at Aggi, near Nocera Umbra, and the San Giovanni Battista Church (Figures 6-8) at Apagni, near Sellano (Mucciarella et al., 2002). For them, the formal agreement of the Superintendency for Cultural Heritage of Umbria Region has already been
obtained by the PROSEESM partners and further funds have been allocated in order to cover the extra-costs related to SI sub-foundations, taking also advantage of the already signed agreement (two years ago) between ENEA and Umbria Region.

The Apagni Church had been damaged by previous earthquakes, including that of Valnerina in 1979, after which it had been restored with conventional methods. This restoration, although correctly performed, was clearly insufficient as to protect the church against even moderate earthquakes: in fact, the 1997-78 seismic events (which, as previously stressed, may be classified as moderate) damaged the church again (Figure 7). Studies for the insertion of SI by means of sub-foundation are now in progress. Further structures will be soon identified for pilot applications of IATs, also different from SI.

2.3. Ercolano Roman Ship.

The wooden ship of the Ercolano Suburban Thermae (8.5 m length and about 2.6 m maximum width – see Figure 9) was discovered in 1982, during the excavation of the ancient harbor of the Roman city (Meucci et al., 2002). During the very violent and destructive 79 a. C. Vesuvio eruption, the ship were capsized and moved; the massive pyroclastic flow, which entirely “sealed” the city by the accumulation of tufa materials, penetrated also through the damaged keel of the boat, filling up the interior. Thus, the ship slightly dropped down into the seabed and the wood carbonization process occurred. The ship structure is complete and clearly shows the construction methods. All the components of the ship are very fragile; thus, the Archaeological Superintendence of Pompei (Naples) planned a complex intervention to completely restore the ship and permanently exhibit it in a special museum area. The ship overall restoration is funded by the Campania Region and coordinated by the Italian Central Institute of Restoration (ICR). Now the ship is wrapped in a protective shell, consisting of a complex multi-layer structure (cloths, silicon rubber, fiberglass) and placed on a metallic frame. The final exhibition of the structure foresees the completion of the following two main items: a rigid supporting frame with IAT devices; a reticular contact frame, made from special plastic materials. Both will be designed with the aim of reducing loads and stresses and distributing them uniformly. At the end of the overall work, the protective shell will be removed. The use of IATs has been judged as necessary by all the concerned parties, because the extremely fragile ship structure could be damaged even by small excitations (both in the horizontal and vertical directions). In fact, the Ercolano area is affected by periodical
volcanic eruptions and tremors, and by earthquakes with epicenters nearby or in the region. IAT devices being developed in the EC-funded SPACE project (Maurer Söhne et al., 1999) will be evaluated as they could provide the necessary isolation from vertical ground-borne vibrations, and horizontal and vertical seismic actions. This part of the intervention has been entrusted by the Archaeological Superintendency of Pompei (Naples) to ENEA. In addition, a complete monitoring system (excitation and microclimate) of the ship will be implemented. The dynamic characterization of the whole system will be carried out. The results obtained in the framework of a recent test campaign performed at ENEL.HYDRO (Fuller et al., 2002) will be compared with those elaborated with a finite element model that will allow to study the seismic response of the ship to real earthquake excitation, selected on the basis of the seismic input analysis of the site.

![Figure 9: Sketch of the Ercolano Roman ship after excavation a), actual location of the ship in Ercolano b), scheme of supporting system including 3D isolation system c), a single 3D device d), test on the shaking table e)](image)

2.4. The ART-IN-SAFE Project

ART-IN-SAFE (Application and Research of Innovative Techniques for the Protection of Works of Art from Catastrophic Events), is a recently approved project merging together R&D and training, funded by the Italian Ministry of University and Scientific and Technological Research (MURST). Coordinated by ENEA (2002), it foresees the participation of: the University of Basilicata; the Impresa Pouchain; the Russian Research Centers of Saint Petersburg and Moscow; TIS, an Italian industry which produces IAT
devices, Rome. The research concerns especially the integrated protection of works of art and archives manuscripts against natural catastrophes (mainly earthquakes) and incidental events (fires, attempts, explosions, etc.). It aims to individuate permanent or temporarily buildings (new or retrofitted) in which the objects can have the maximum level of safety. ART-IN-SAFE is related to other ENEA projects, developing real/virtual restoration of ancient manuscripts, digital cataloguing/filing, on-line fruition and multimedia activities.

3. CONCLUSIONS

The main features of the ongoing projects, concerning the development of IATs for CUHESs at ENEA, have been summarized. It is worth noting that the importance of these reference projects and demo-applications is crucial; in fact, the spread and heavy damage, due to recurrent seismic events, in many European and Mediterranean seismic-prone countries, with a huge amount of precious CUHESs, archaeological areas and museums, every time brings to an irreparable loss of parts of unique historical tissue; a meaningful example is quite the Umbria-Marche 1997-98 earthquake, sadly renowned because of the vaults collapse in the St. Francis Basilica frescoed by Giotto and Cimabue; this very impressive failure, that caused the death of four persons, filmed by a cameraman and transmitted all over the world, shocked people and drew public opinion’s attention to the need of protecting CUHESs, especially masonry buildings, from earthquakes. It is a difficult task, in a field which certainly requires a very careful approach, showing hurdles consisting of a lack of references, codes and recommendations, as well as the not sufficient awareness of decision makers; but, at the same time, it represents a fascinating challenge and a duty for the years to come.

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