RESEARCH, DEVELOPMENT AND APPLICATION
OF ADVANCED ANTISEISMIC TECHNIQUES
FOR CULTURAL HERITAGE IN ITALY
MAIN ONGOING ACTIVITIES

- feasibility study for the in-situ reconstruction of Mevale di Visso, destroyed by the Marche-Umbria earthquake
- PROSEESM project retrofitting of ancient churches damaged by the Marche-Umbria earthquake
  - new applications of Shape Memory Alloy Devices (SMADs)
    - Churches of San Serafino (Montegranaro) and San Pietro (Feletto)
    - statues of Scylla and Neptune at Messina Regional Museum
- 3D seismic isolation of the Ercolano Roman Ship
- activities at San Giuliano di Puglia after the recent earthquake
THE 2002 31st OCTOBER MOLISE EARTHQUAKE

October 31st
time 11:32 am
5.4 Richter
VIII-IX MCS

November 1st
time 16:08 pm
5.3 Richter

epicenter:
San Giuliano di Puglia

complete collapse of the primary school
27 children and a teacher killed
collapse or heavy damage in many buildings
other 2 fatalities
San Giuliano di Puglia was not classified as a seismic area before the October 31st earthquake, even if some non negligible earthquakes occurred in the past.

San Giuliano di Puglia suffered a major damage (about 2 MCS degrees) with respect to the other epicentral villages.
THE 2002 31st OCTOBER MOLISE EARTHQUAKE

San Giuliano Technical Scientific Group TSG

team formed by ENEA (M. Indirli, B. Spadoni, P. Clemente),
GLIS members (M. Dolce, A. Dusi, G. Mancinelli) and other
experts (L. D’Alesio, M. Mucciarella), for the post-
emergency phases and reconstruction, within a
cooperation with the Local Municipality, National Fire
Department, Molise Region, Cultural Heritage
Superintendence and Campobasso Province

- detailed evaluations of building damage
- demolitions (about 200)
- providing safe conditions to the buildings to be
  repaired
- allowing residents to safely reenter their non-
damaged houses (10% of the 1200 village
inhabitants)
- preparation of the reconstruction plan
  including the ancient historical center
  rehabilitation

large participation of ENEA to the post-
earthquake emergency activities in various cities
and villages of Molise, supporting the National Civil
Defense Department
8th World International Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures

Yerevan, Armenia, October 6-10, 2003
Three zones with different damage intensities

A the historical center
(medieval times, on limestone-marn soil)

B the “saddle”
(earlier decades of 1900, with subsequent floor additions, on clay-marn and soft soil layer)

C the Northern area
(again on limestone-marn soil, with more recent constructions, mainly r. c.)
CAUSE OF DAMAGE

HIGH STRUCTURAL VULNERABILITY

- heavy concentration of damage in the “saddle” area
- lack of ant seismic requirements
- subsequent floor extensions on poor materials (load bearing masonry or stone, mixed structures)
- large presence of openings
- historical center
  - bad maintenance of many buildings
  - unrestored masonry
  - lack of transversal connections

ADVERSE SITE CONDITIONS AND AMPLIFICATION FACTOR

The microzoning studies: amplification factors $A$ and geo-morphological risk $G_M$ (a: high, m: medium, b: low).

Reference: ITALIAN CIVIL DEFENSE DEPARTMENT

1.6
PROPOSALS FOR THE RECONSTRUCTION PLAN

IN-SITU RECONSTRUCTION

application of the new seismic reclassification
(2\textsuperscript{nd} category for San Giuliano di Puglia)

application of the new Italian code, which includes
the use of SI and ED

reconstruction of the demolished buildings
by using SI

retrofitting of the unsafe (not demolished)
buildings by using ED
PROPOSALS FOR THE RECONSTRUCTION PLAN

restoration of the historical center
coupling conventional and advanced antiseismic techniques for the interventions as SMADs (Shape Memory Alloy Devices) and CAM (Masonry Active Ties)

Observance of the conservation requirements

Photo by Franco Esse
ENEA FOR THE ANTISEISMIC PROTECTION OF CULTURAL HERITAGE

1996-99: EU ISTECH Project
SMADs (San Giorgio, Trignano; San Francesco, Assisi; San Feliciano, Foligno)

1996-99: EU REEDS Project
Shock Transmitters (San Francesco, Assisi)
FURTHER SMADs APPLICATIONS

2002: San Serafino Church at Montegranaro (Ascoli Piceno)

damaged by the 1997 Marche-Umbria earthquake (wooden truss collapse and roof partial failure)

- reinforcing system against overturning mechanisms
- retaining system of the frontal tympanum

the SMADs are designed for working only in tension, with a peak force of 39 kN and a peak displacement of 20 mm
FURTHER SMADs APPLICATIONS

2003: San Pietro in Feletto Church (Treviso)

the intervention has been planned in the framework of restoration works

• the 6 (single tensional effect) SMADs are very small

• peak force of 2 kN (4 SMADs) and 5 kN (2 SMADs)

• peak displacement of 15 mm

the SMADs, in series with steel ties, are applied at the extrados of the chapel vault

Designer Davide Beltrame
SMADs FIP
FURTHER SMADs APPLICATIONS

The relative position of the statues on their support in the Regional Museum of Messina is aimed at reproducing their original position in the original fountain of which they were part.

Designer
Prof. Enzo D’Amore
University of Reggio Calabria

The isolation system is formed by:

- 4 free sliding bearings (50 kN design vertical load and 600 mm design displacement) on sliding surfaces PTFE/stainless steel
- 2 SMADs (26 kN maximum force and 600 mm maximum displacement)
PROSEESM PROJECT

2000-2004: San Giovanni Battista Church (Apagni, Sellano)

the church was damaged by the 1979 Valnerina earthquake and then conventionally restored

the intervention (which interested especially the walls and the cover), although correctly performed and formally in line with the existing codes at the time of the intervention, was clearly insufficient as to protect the church and turned out to be counterproductive when the building was struck again by the 1997 Marche-Umbria earthquake
PROSEESM PROJECT

2000-2004: San Giovanni Battista Church (Apagni, Sellano)

the church was again conventionally restored, in order to: repair damages and strengthen the weak points of the masonry structure; joining one each other roof, concrete string-course and walls; eliminating the mutual actions due to the additional parts

in-situ experimental campaign for dynamic characterization was also performed by ENEA, before and after the conventional intervention. The experimental analysis will continue after the completion of the innovative intervention

ENEL.HYDRO completed the diagnostics investigation campaign on foundations and masonry wall structures, foreseen by PROSEESM
PROSEESM PROJECT

2000-2004: San Giovanni Battista Church (Apagni, Sellano)

A project for the SI application to the church is now in progress, in order to carry out the intervention in the next months.

Static and dynamic calculations (ABAQUS) are in progress by ENEA.

A first part (217 000 Euros, coming from the Restoration Program of Ministry of Cultural Heritage and Umbria Region) of the necessary funds to cover the extra-costs related to SI sub-foundations has been provided.
FEASIBILITY STUDY OF MEVALE DI VISSO

contract between Marche Region and ENEA

2002-2003: Mevale (Visso, Macerata)

• Valnerina historical village, with a strategic position in the environment

• a beautiful Romanesque church and the ruins of an ancient castle are present

• Mevale was always hit by past seismic events, and almost completely destroyed by the 1997 Marche-Umbria earthquake (disruption of about the 87% of the covered surfaces and complete collapse of the village core)
MEVALE DI VISSO

**HIGH STRUCTURAL VULNERABILITY**

- poor materials and techniques
- weak walls and lack of connections
- wrong interventions and extensions, in particular using heavy r. c. floors laying on weak masonry

*Similar problems were found at San Giuliano di Puglia!*
MEVALE DI VISSO

ADVERSE SITE CONDITION

Similar problems were found at San Giuliano di Puglia!

- Mevale lays on a lengthened hill (810 m) with very sloping mountainsides
- geological analyses showed a surface layer of degraded soil (0.2-4 m) and then a very fractured clay-marn substratum until 80 m
- microzoning analyses pointed out a significant local amplification (until 2.4, quite in the center of the village) of the seismic motion in the range of 2-10 Hz
MEVALE DI VISSO

ENEA ACTIVITIES

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 included:

- 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
the ship structure is complete and clearly shows the construction methods; all the components of the ship are very fragile.

the Archaeological Superintendence of Pompeii (Naples) planned a complex intervention to completely restore the ship and permanently exhibit it in a special museum area.

the intervention foresees the following two main items:

- a reticular contact frame, made from special plastic materials
- a rigid supporting frame with 3D SI devices

The use of the 3D SI system has been judged necessary because the 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.
ERCOLANO ROMAN SHIP

support and 3D SI system has been entrusted by the Archaeological Superintendence of Pompeii to ENEA

the 3D SI system will provide the necessary isolation from vertical ground-borne vibrations, and horizontal and vertical seismic actions

a complete monitoring system (excitation and microclimate) of the ship is foreseen

the 3D SI devices has been developed in the EC-funded SPACE project
the results obtained in the framework of a shaking test campaign performed at ENEL.HYDRO will be compared with those elaborated with FEMs, which 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.

- MSC.Marc code (above), elaborated in cooperation with the University of Ferrara, for simplified static analyses
- ABAQUS code (bottom), used for dynamic calculations
activities regarding the application of advanced antiseismic techniques for Cultural Heritage protection has been summarized

their importance is crucial

spread and heavy damage, due to recurrent seismic events, in Mediterranean seismic-prone countries, every time brings to an irreparable loss of parts of unique historical tissue

meaningful examples are still the Marche-Umbria but also the recent Molise earthquakes, in which many Cultural Heritage historical towns and works of art were damaged

San Giuliano di Puglia could be a laboratory for in-situ reconstruction

SI and ED for demolished and unsafe houses, also in the area with the highest amplification factor

SMADs and CAM (Masonry Active Ties), coupled with a correct use of conventional techniques, for churches and historical palaces restoration and for the overall rehabilitation of the ancient center