EARTHQUAKE ARCHAEOLOGY

INQUA PALEOSEISMOLOGY AND ACTIVE TECTONICS

# EARTHQUAKE ENVIRONMENTAL EFFECTS, INTENSITY AND SEISMIC HAZARD ASSESSMENT: THE EEE CATALOGUE (INQUA PROJECT #0418)

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***Abstract (Earthquake Environmental Effects, intensity and seismic hazard assessment: the EEE Catalogue (INQUA Project #0418):*** *Earthquake Environmental Effects (EEE) are the effects produced by an earthquake on the natural environment, either directly linked to the earthquake source or triggered by the ground shaking. These include surface faulting, regional uplift and subsidence, tsunamis, liquefaction, ground resonance, landslides, and ground failure phenomena.*
*The EEE catalogue is a data collection of Earthquake Environmental Effects from modern, historical and paleoseismic earthquakes compiled at global level by the INQUA TERPRO Project #0811 WG.*
*The damages caused by recent catastrophic seismic events have been mostly linked to the vulnerability of physical environment enhancing the crucial role of EEEs, including tsunamis, for seismic hazard purposes. Therefore, these events have confirmed that the EEE Catalogue is an essential tool to complete traditional SHA based on PGA maps, since it allows to identify the natural areas most vulnerable to earthquake occurrence and to objectively compare in time and in space the earthquake intensity through the ESI scale.*

***Key words***: *Earthquake Environmental Effects, ESI intensity scale, seismic hazard.*

## INTRODUCTION

Earthquake Environmental Effects (EEE) are the effects caused by an earthquake on natural environment, including surface faulting, regional uplift and subsidence, tsunamis, liquefactions, ground resonance, landslides and ground failure, either directly linked to the earthquake source or provoked by the ground shaking (Michetti et al., 2007).
Most of the damage resulting from moderate to large earthquakes is typically related with the vulnerability of the physical environment. This point has been sadly and dramatically confirmed by the two relevant seismic events occurred in the last months in countries with strong economy and modern building codes, i.e., the February 22, 2011, Mw 6.3 Christchurch and the March 11, 2011, Mw 9.0 East Japan earthquakes.

The March 11, 2011, earthquake occurred in the Pacific Ocean near the coast of NE Japan. Most of the damage in terms of dead toll (more than 20,000 people) and destruction was caused by the huge tsunami (run up values larger than 38 m; more than 5 km inland penetration in the Sendai coastal plain). Comparatively, the amount of damage induced by the vibratory ground motion itself was modest. The size of the 2011 tsunami was fairly larger than those recorded in the affected area in the last century, but comparable with the tsunamis affecting the same areas in 869 A.D. recently well documented by means of geological and paleoseismic studies (Sawai et al., 2007; HERP, 2009).
Nevertheless, the relevance of EEE has been also shown by the moderate-size event occurred on February 22, 2011, very close to the town of Christchurch, New Zealand.

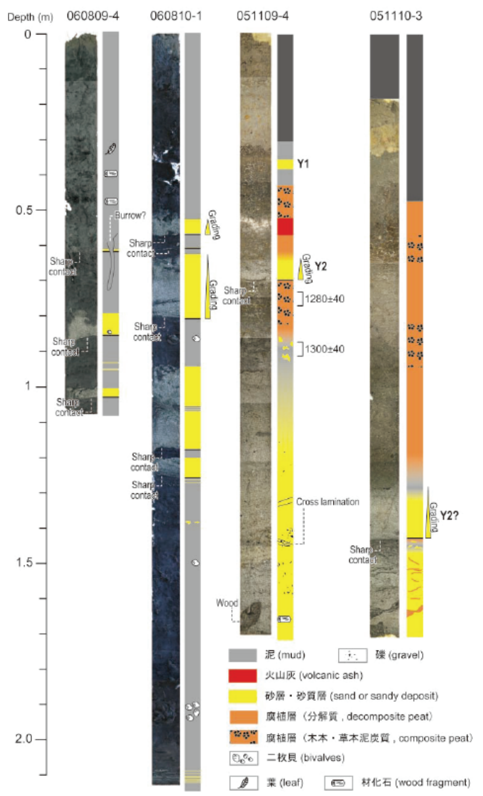


*Fig. 1: – Geological record of past tsunamis at Watari and Yamamoto, Myagi prefecture (Sawai et al., 2007). The characteristics and spatial distribution of these deposits allowed to identify ancient tsunamis comparable with the March 11, 2011 event.*

This was basically an aftershock of the 2010 September 4, Mw 7.0 event. However, while the main shock did not cause victims or large damage, the 2011 event caused the death of at least 75 people and the destruction of several districts in the Christchurch area. This scenario of bad damage was mainly linked to local effects of site amplification, which depends largely on the stratigraphic characteristics (geological history) of the recent deposits over which the town is built; as well, the same sediments are particularly susceptible to liquefaction. As a consequence, also houses designed in agreement with the local seismic codes have collapsed, due to liquefaction within the foundation soils.

Both events, although not comparable in size and geodynamic setting, have confirmed once again i) the relevance of earthquake environmental effects as a major source of seismic hazards, in addition to vibratory ground motion; ii) the need of re-evaluating the significance of macroseismic intensity as unequivocal measurement of the final earthquake impact on the local natural and built environment, and iii) the relationships between epicentral intensity, earthquake size, and source geometry. As a matter of fact, intensity is a parameter able to describe a complete earthquake scenario, based on direct field observation. Thus, the knowledge of the characteristics and spatial distribution of EEE induced by past earthquakes will strongly improve standard seismic hazard assessments, that typically consider only the vibratory ground motion hazard.

## THE EEE CATALOGUE

Nowadays, a significant amount of data about Earthquake Environmental Effects is available for a very large number of recent, historical and paleo-earthquakes. However available information is located in several different sources (scientific papers, historical documents, professional reports), and often difficult to access.

The EEE Catalogue has been promoted with the aim to properly retrieve the available information about EEE at global level and archive it into a unique database, in order to facilitate their use for seismic hazard purposes. Its implementation has been endorsed at global level by the INQUA TERPRO Project #0811, through a Working Group coordinated by ISPRA - Geological Survey of Italy.

The EEE catalogue collects the characteristics, size and spatial distribution of coseismic effects on nature in a standard way from modern, historical and paleoearthquakes. For each event, we have assessed epicentral and local intensities based on EEE data through the ESI 2007 scale (Michetti et al., 2007), that integrates and completes the traditional macroseismic intensity scales, allowing to assess the intensity parameter also where buildings are absent or damage-based diagnostics saturates. This procedure has allowed an objective comparison in terms of earthquake intensity, for events occurred in different areas and/or in different periods.

The information is collected at three levels of increasing detail (Earthquake, Locality, Site). Also available imagery documentation (photographs, video, sketch maps, stratigraphic logs) can be uploaded into the database.The quality of the database in terms of completeness, reliability, and resolution of locations is strongly influenced by the age of the earthquake so that it is expected to be very variable.

Nevertheless, even where the information is less accurate (historical earthquakes), the documented effects are typically the most relevant i.e. most diagnostic for intensity assessment. Similarly, the information from paleoseismic investigations, although poorly representative of the entire scenario, still includes significant data (i.e. local coseismic fault displacements) very helpful of a minimum size of the earthquake.

A first official release of the EEE Catalogue has been done in the frame of the XVIII INQUA Congress, held in Bern in July 2011. However, the implementation of the EEE catalogue is always in progress at http://www.eeecatalog.sinanet.apat.it/login. Data can be explored on a public interface (Fig. 2) based on Google Earth at http://www.eeecatalog.sinanet.apat.it/terremoti/index.php. Earthquake records validated by the Scientific Committee of the Project can be also downloaded from the site.

## THE ADDED VALUE

The major added value of the EEE Catalogue in terms of seismic risk is the possibility to explore the scenarios of environmental effects induced by past earthquakes and therefore identify the areas where the anthropic settlements and infrastructures are more exposed to this source of potential hazard. To this end, a good accuracy of EEEs location becomes crucial. Typically, EEEs from recent earthquakes are mapped with good accuracy immediately after the event. Nevertheless, even for some historical earthquakes it is possible to retrieve with very good detail this information. It is the case of the December 28, 1908 Messina Straits earthquake and consequent tsunami (Fig. 3), where the EEE Catalogue allows to locate the earthquake/tsunami effects over the present urban texture with a spatial resolution of a few meters, pointing out the areas characterized by the highest risk. Furthermore, the EEE Catalogue allows to reveal possible trends in the spatial distribution of primary and secondary effects. For example, Fig. 4 shows the spatial distribution of EEEs induced by the October 8 2005, Muzaffarabad, Pakistan, earthquake (Ali et al., 2009): it is quite evident that the location and amount of surface faulting is consistent with the spatial distribution of coseismic slope movements, in terms of both areal density and size.

A similar result is shown by the spatial distribution of EEEs induced by the 1811-1812 New Madrid, Missouri, earthquakes, mapped in Fig. 5. Indeed, the most relevant primary and secondary effects are located along the Mississippi valley near New

Madrid, consistently with the surface projection of the causative faults, and unquestionably provide diagnostic elements for assessing an epicentral intensity equal to XI.

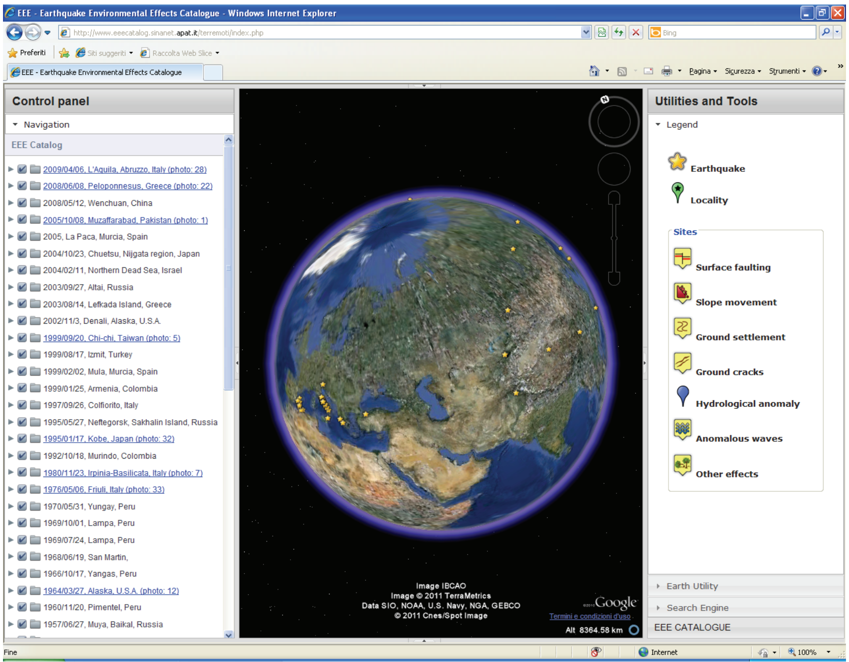


*Fig. 2: The public interface of the EEE Catalogue, developed on Google Earth http://www.eeecatalog.sinanet.apat.it/terremoti/index.php.*


*Fig. 3: EEEs induced by the December 28, 1908 Messina Straits, Italy, earthquake in the area of the Messina harbour. If information from contemporary sources is very precise, it is possible to use the EEE Catalogue also for local seismic microzonation.*

**FINAL REMARKS**

The recent catastrophic earthquakes occurred in Japan and New Zealand have clearly pointed out that traditional seismic hazard assessment based only on vibratory ground motion data need to be integrated with information about the local vulnerability of the territory to earthquake occurrence.
The collection of Earthquake Environmental Effects provided by the EEE Catalogue aims at identifying the areas most vulnerable to earthquake occurrence. This information must complement traditional SHA based on PGA maps.

Moreover, based on EEE characteristics, size and spatial distribution it is possible i) to assess the earthquake intensity through the ESI scale, and ii) to objectively compare the earthquake intensity of events occurred in different areas and/or in different periods.

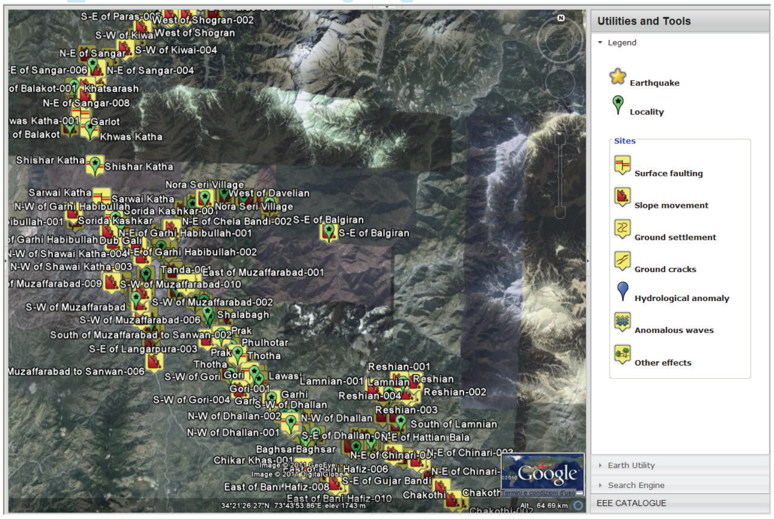


*Fig. 4 :Surface faulting and slope movements induced by the October 8, 2005 Muzaffarabad earthquake.*

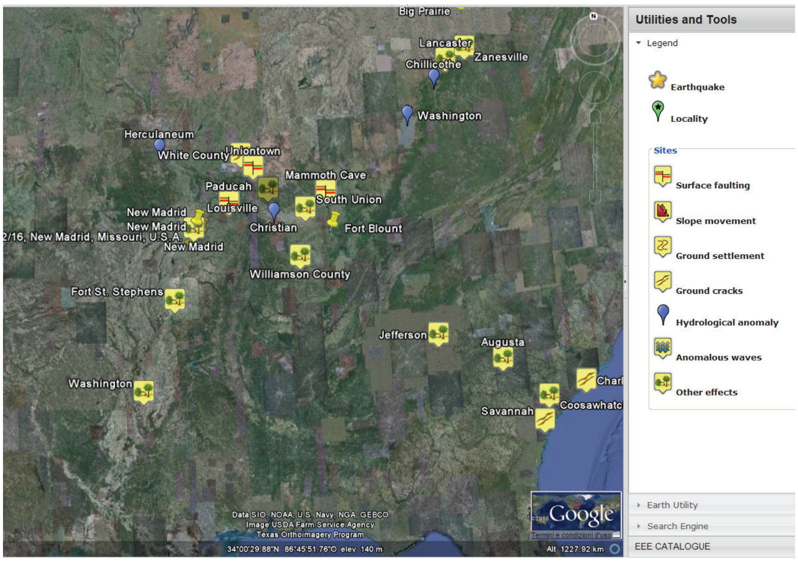


*Fig. 5 : EEE induced by the December 16 1811 New Madrid, Missouri, earthquake. Primary and secondary effects indicative of intensity XI in the ESI 2007 scale are located in the epicentral area along the Mississippi Valley.*

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