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Nota Prévia

A Associação Portuguesa de Geomorfólogos (APGEOM), em colaboração com o Instituto de Geografia e Ordenamento do Território (IGOT) da Universidade de Lisboa, organizou em Lisboa, nos dias 8 e 9 de Outubro de 2015, o VII Congresso Nacional de Geomorfologia – Geomorfologia 2015. Este evento deu continuidade a congressos realizados com a periodicidade de 2 anos, que se efetuaram, desde 2002, em Lisboa, Coimbra (em duas ocasiões), Funchal, Braga e Porto.

O VII Congresso de Geomorfologia contou com 24 comunicações orais e 25 comunicações em poster (também com apresentação pública), envolvendo cerca de 150 autores de 9 nacionalidades: Portugal, Brasil, Argentina, Marrocos, Espanha, Itália, Dinamarca, Cuba e França. As comunicações foram organizadas em quatro sessões temáticas: Geomorfologia Estrutural e Património Geomorfológico, Geomorfologia Fluvial, Dinâmica de Vertentes e Geomorfologia Litoral. Adicionalmente, o congresso contou com duas conferências, da responsabilidade de Diamantino Pereira da Universidade do Minho ("*Unidades geomorfológicas e avaliação da geodiversidade: aplicação ao caso de Portugal Continental*") e Jordi Corominas da Universidade Politécnica da Catalunha ("*Landslide Hazard Analysis: progresses and challenges*").

Os trabalhos submetidos ao congresso repartiram-se pela investigação fundamental relacionada com os processos e as dinâmicas geomorfológicas, o desenvolvimento de novas técnicas e metodologias na investigação geomorfológica, a valorização e salvaguarda do património geomorfológico e a avaliação de perigos e riscos geomorfológicos e a sua aplicação no ordenamento do território. Todos os artigos publicados no Livro de Atas, editado em formato eletrónico na Coleção das Publicações da Associação Portuguesa de Geomorfólogos (Volume IX), foram sujeitos a um processo de revisão por pares, nos quais participaram os 41 membros da Comissão Científica do congresso.

A organização do VII Congresso Nacional de Geomorfologia contou com a valiosa colaboração de várias pessoas e entidades. A Comissão Organizadora e a Direção da Associação Portuguesa de Geomorfólogos expressam o seu agradecimento ao Instituto de Geografia e Ordenamento do Território da Universidade de Lisboa, ao Centro de Estudos Geográficos, à Casa Agrícola Rebelo Lopes, aos membros da Comissão Cientifica e a um grupo de alunos do IGOT que, voluntariamente, se disponibilizou para colaborar com a Organização do congresso.

A Comissão Organizadora

INVENTORY OF COSEISMIC EFFECTS FOR LOCAL SEISMIC HAZARD ASSESSMENT AND COMMUNCATION. THE CASE STUDY OF 2012 EMILIA EARTHQUAKES

INVENTÁRIO DE EFEITOS CO-SÍSMICOS PARA A AVALIAÇÃO LOCAL DO RISCO SÍSMICO LOCAL E COMUNICAÇÃO. O ESTUDO DE CASO DOS SISMOS DE EMILIA 2012

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RESUMO

Nos últimos três anos tem sido produzida muita literatura relacionada com a sequência sísmica de 2012 na região de Emilia e com os efeitos ambientais por ela induzida. No entanto, apesar das numerosas fontes de dados sísmicos e catálogos de efeitos co-sísmicos disponíveis até à presente data, um catálogo uniformizado ainda não existe. Este fato orientou este trabalho para a elaboração de um inventário mais abrangente, obtido a partir da observação de fotografias aéreas e integração dos diferentes catálogos existentes. Este inventário integrado tem como objetivos: (i) inventariar as centenas de efeitos co-sísmicos induzidas pela sequência sísmica de 2012 na planície do Po (Itália); (ii) ser uma importante fonte de informação quer na avaliação local do risco sísmico quer na comunicação às populações. Este estudo, apoiado em literatura relacionada com fenómenos de liquefação, apresenta a influência dos diferentes aspetos sismotectónicos, geológicos e geomorfológicos na ocorrência dos efeitos ambientais derivados da ocorrência dos sismos e na sua distribuição espacial na planície do Po durante os eventos sísmicos de 2012.

ABSTRACT

In the past three years a wide literature related to the 2012 Emilia seismic sequence and its induced environmental effects has been produced. Despite the important and numerous seismic datasets and coseismic effects catalogues built up until present, one uniformed catalogue is still missing. This lack has oriented our work towards the implementation of a more comprehensive inventory, starting from the aerial photos observation and from the contributions of existing databases. This integrated inventory, intends to: (i) to store the hundreds coseismic effects induced by the 2012 seismic sequence in the Po Plain (Italy); (ii) to be an important source of information for local seismic hazard assessment and communication. The study, supported by literature investigation on liquefaction phenomena, introduces those aspects that from the seismotectonic, geological and geomorphological point of views have influenced the earthquake environmental effects (EEE) occurrence and their spatial distribution in the central Po Plain during these 2012 seismic strong events.

Palavras-chave: fenómenos de liquefacção, Inventário de efeitos co-sísmicos, sismos de Emilia 2012 (Itália)

Keywords: Liquefaction, coseismic effects inventory, 2012 Emilia earthquakes (Italy)

1. INTRODUCTION

On May 2012 a seismic sequence struck the Po Plain across the provinces of Modena, Ferrara, Rovigo and Mantova in northern Italy. These events caused widespread damages: 27 victims, over 400 persons injured and thousands of families evacuated.
The first main shock hit the low Modena Plain on 20th May (ML = 5.9); nine days later, on May 29 a second event (ML= 5.8) occurred roughly 10 km to the SW of the first main epicenter. This seismic swarm has consisted of another five shocks of ML>5 and more than 2500 aftershocks of lower magnitude during almost one year (Figure 1).

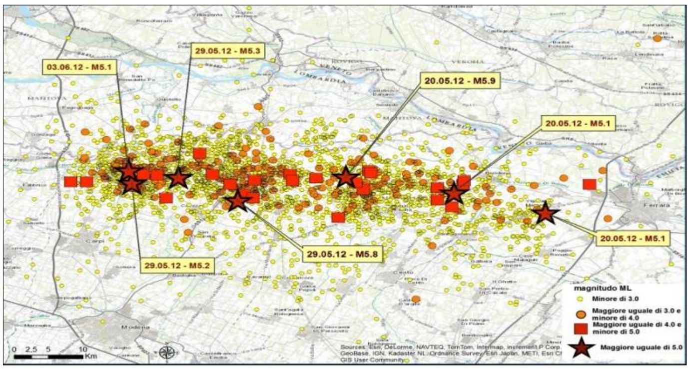

Figure 1 - The seismic sequence from 19th May 2012 to 19th May 2013 (INGV)

The earthquake sequence was caused by the thrust front of the buried Apennines faulted -folds (known as Ferrara Folds), formed by N-verging arcs covered by Plio-Quaternary sediments (Pieri and Groppi, 1981). The most external structures, the active Ferrara and Mirandola thrusts and folds, were responsible for this earthquake (Bignami *et al.*, 2012). The seismic sequence concerned the upper 10 km of the crust, while minor seismic activity with depths from 10 km to 30 km has prolonged for 50 km towards the southern sector of the epicentral area. It is also important to mention that the entire epicentral area uplift 10 to 15 cm as proved by the InSAR interferometry results (Salvi *et al.*, 2012). Besides the collapse of various industrial and residential buildings, the 2012 earthquake has widely damaged the old masonry and the historical heritage (as churches or ancient public buildings) of city centers, having strong repercussions on local communities. The approximately 2000 coseismic effects induced by the two strongest quakes have also impressed the population and leaved temporary evidences in both urban and rural areas over a large part of the Po Plain.

1.1. Liquefaction phenomena

The induced earthquake environmental effects (EEE) detected trough field surveys, and aerial photo interpretation mainly consisted of liquefaction phenomena as sand boils or sand water ejections, ground cracks. Some artificial canals showed uplifting, bulging and cracks of on the bottom as fissures and soil slips on the banks.
Furthermore, hydrogeological anomalies such as strong water-table fluctuations, emission of hot water and sand from ground cracks and water wells, have been recorded. As is possible to appreciate in the Figure 2, the coseismic effects appeared concentrated and aligned on specific patterns; theirs spatial distribution was mostly controlled by the presence of paleo-riverbeds, out-flow channels and crevasse splays of the main rivers crossing the area.

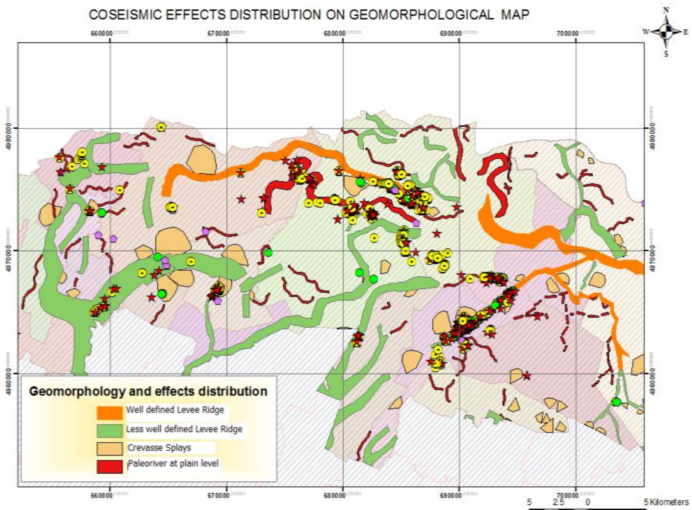

Figure 2 - Location of the environmental earthquake effects (EEE) on the Geomorphological Map of the Po Plain by Castiglioni *et al.* (1997). The map displays how the EEE are concentrated along paleorivers, crevasse splays and on ridges of abandoned streams.

The epicentral area is characterized by subsoil consisting of recent and poorly consolidated fluvial deposits (with sandy layers in the uppermost 5 m) and by high water table, factors that greatly has favoured liquefactions. In general liquefaction evidences are caused by the upward flow of water activated by the excess pore pressures generated in deeper confined sandy soil strata. Depending on the time necessary to dissipate the pore pressures, level ground liquefaction may take place even after the seismic event has ceased. In these cases, also, liquefactions have been induced by the build-up of water pressure in the buried and confined sand layers, as it was observed in San Felice Sul Panaro, San Carlo, Sant'Agostino, and Bondeno villages. In details, as mentioned in many studies 1/3 of liquefaction phenomena were originated by the 20th May main shock. The second shake on the May 29 has reactivated some of them and triggered new effects in the area surrounded Medolla and Mirandola (Caputo and Papathanasiou, 2012; Di Manna *et al.*, 2012; Emergeo 2013). Most of the reported earthquake environmental effects appeared distributed along the well elevated levee ridge in the locality of San Carlo, located within a sandy belt, corresponding to a Reno river paleochannel of medieval age, elevated about 3-4 meters over the present alluvial plain (Ninfo *et al.*, 2012).

1.2. Online inventories of Italian earthquake- induced ground effects

Italian earthquake catalogues with associated environmental induced effects have been published online during the last decades. As summarized in Martino *et al.* (2014) at the end of the 1990s, the first Italian Catalogue of Earthquakes Induced Ground Failure (CEDIT) was public on internet. In that catalogue, geological induced effects related to the big earthquakes from the years 1000 to 1984 have been discriminated by typologies: landslides, cracks, surface faulting, liquefactions and ground changes. The current version of the CEDIT counts over 160 earthquakes (VII -VIII grade intensity of MCS), and the updated catalogue (Martino *et al.*, 2014) relates about more 1,800 places that were affected by historical earthquakes, listing also within the 3000 earthquake environmental effects, those of the 2012 induced in the Po Plain. The huge contribution from INGV (*Istituto Nazionale di Geofisica e Vulcanologia*) is appreciable in the "Catalogo Parametrico dei Terremoti Italiani" (http://emidius.mi.ingv.it/CPTI), as well as in the recent website done by Emergeo Working Group (EWG), that it specifically displays the coseismic effects related to the 2012 Emilia earthquake (http://www.esriitalia.it/emergeo). Moreover, the EEE catalogues from ISPRA (*Istituto Superiore per la Protezione e Ricerca Ambientale*) allows comparisons among earthquakes over a wide historical and geological time-window. Concerning the Po plain seismic sequence, 112 earthquake environmental effects are referred to the 20th May event while 61 effects to the second seismic main shock of 29th May 2012 (http://www.eeecatalog.sinanet.apat.it).

2. METHODS, MATERIALS AND RESULTS

The provisional presence of geological coseismic effects has pressured, soon after the 20 th may strongest quake (ML = 5.9), different Italian and European research working teams to survey in field the affected area in order to record and describe those phenomena. As mentioned before, part of this research contribution beyond this paper it aims to outcome an homogeneous and integrated inventory related to the earthquake environmental effects that occurred during the 2012 earthquake within the Emilia Region. The under construction inventory has merged and processed in a single geodatabase with ArGis 10.0 (GIS environment) the scattered datasets of all the evidences that have been recorded. The raw environmental effects data have been stored from different investigation techniques: field and aerial surveys, internet crowd sourcing and personal communication through interviews.
Evidences of earthquake environmental effects have concerned an area of almost 1200 square kilometres, involving 19 districts of the Emilia Region.
The following scheme (Figure 3) simplifies the EEE inventory procedures and the tools implemented for an immediate comprehension of the methodology applied.

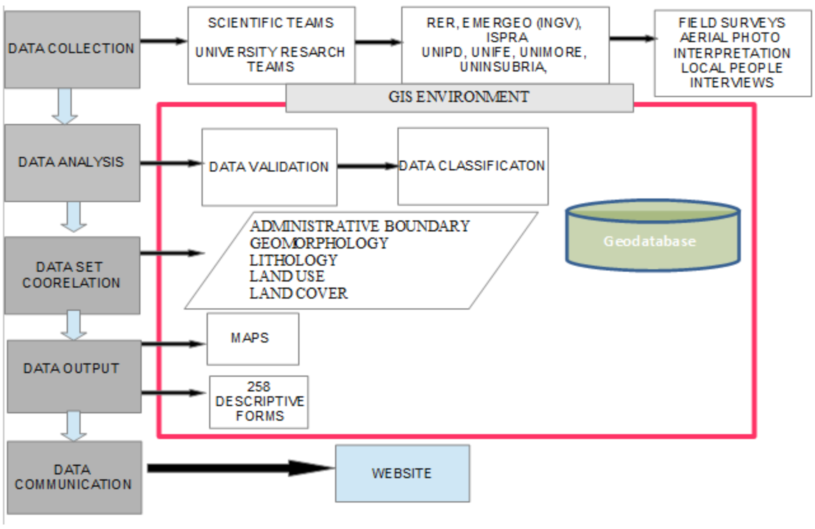

Figure 3 - Methodological scheme for the inventory implementation procedures.

The data collection procedure has considered the main web databases that have been implemented by those institutions that directly surveyed the area: INGV, ISPRA, RER (Regione Emilia Romagna) and several Italian Universities (between them the Modena and Reggio Emilia, Ferrara, Insubria, Padova, Milano Universities).The attributes was georeferenced on WGS_1984_UTM_Zone_32N projection, as points shape file. In some cases where the datasets were uncompleted, it was possible to identify evidences only through a careful notes reading and photos analysis. The catalogue under contraction is composed by a series of 258 descriptive forms, directly linked to the location of surface effects spatial distribution in the website. The sheets (Figure 4) have been created in order to add more detailed information related to the place of occurrence.

Also exhaustive descriptions of coseismic effects associated to thematic cartography and photographic documentation complete the EEE inventory. To define a clustering criterion, the study area has been subdivided over a net of squares having a side of 350 m that corresponds to the average cross length of the paleoridges. Our final purpose will be the inventory publication through an open source mapping interface in order to free communicate more details on coseismic features and theirs distribution in relation to the 2012 Emilia earthquake.

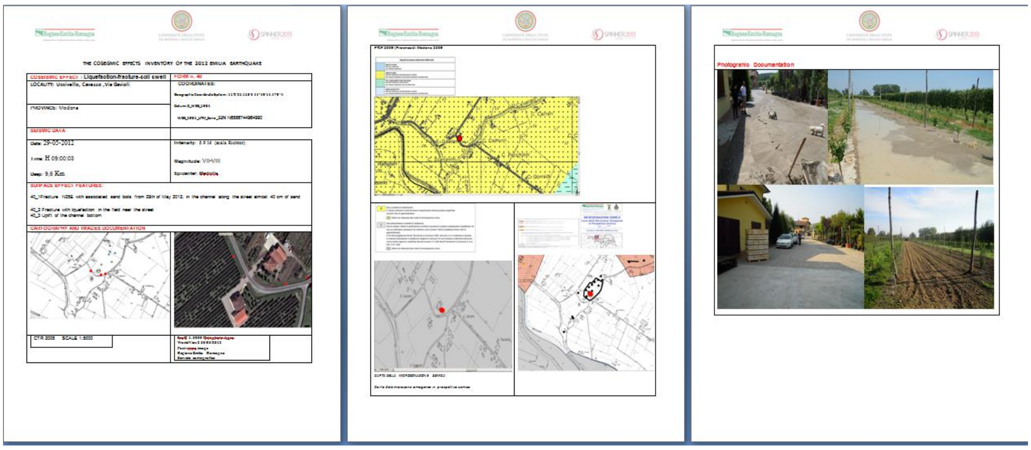

Figure 4 - Example of Data Sheet for environmental earthquake effects inventory. The data sheets contain information of earthquake environmental effects: typology, epicentres, evidence location with precise coordinates, brief descriptions, subsets of different seismic hazard and risk cartography and photos.

The about 2000 coseismic effects have been characterized and classified in four categories (Figure 5): liquefaction, cracks, cracks with liquefaction and others (this class corresponded to water level changes, water temperature changes, ground uplifts, lateral spreads etc.).

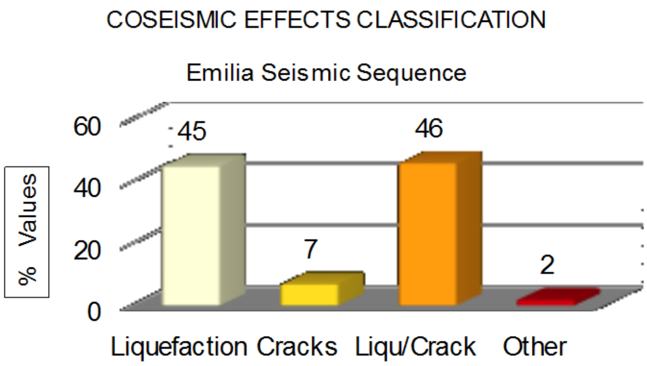

Figure 5– Chart showing the percentage values of coseismic effects distributed in four classes.

The lithological and geomorphological maps overlaid lets us to recognize that 60% of earthquake environmental effects follows on specific geomorphological features. The Table 1 allows to appreciate the correlation between the effects relative distribution and the specific geomorphology and lithological subsoils; this relation let us to infer which could be the predisposing factors that induce liquefaction susceptibility.

Table 1 – Relative percentage of Coseismic effects distributed on geological and lithological features

GEOMORPHOLOGY	EFFECTS %	LITHOLOGY	EFFECTS %
Well defined Levee Ridge	17	Paleoriver medium coarse sand	4
Less well defined Levee Ridge	52	Silty Clay	32
Crevasse Splays	22	Sandy/Silty	2
Paleoriver at plain level	9	Medium Fine sandy	62
	100		100

3. DISCUSSION AND CONCLUSIONS

Directly influenced by the geomorphological and lithological site conditions and disjoint from anthropic elements, the environmental earthquakes effects represent a useful parameter to assess local seismic intensity. For these reasons, the integration of ESI (Environmental Seismic Intensity) within macroseismics intensity evaluations have been fundamental for characterizing the 2012 seismic-hazard assessment.

Beside the scientific aspects, catalogues on earthquake environmental effects are important source of information. Inventories should be conceived as tools that allow enhancing local knowledges, in relation to hazardous events that are generally perceived in a wrong way or are unknown within the population. During the 2012 Emilia seismic events the local people was involved by the scientific community to relate and describe about the seismic environmental induced phenomena observations. Despite this central informative role during the effects recognition, the population in this part of Italy have showed an evident lack of seismic perception; for instance is still consolidate the conviction that the deposits of alluvial soil contribute to reduce the effects of seismic shocks, when, in fact, the opposite is true. One of the reason for the spread of the low seismic risk perception is the loss of historical memory about strong seismic events of the past; but also it could be related to the fact that this sector of Italy is classified as "low seismic hazard" (INGV, 2012). Nevertheless, this definition does not mean that strong earthquakes cannot occur in this area of northern Italy. The strongest quakes of this sequence and the related induced phenomena found the local population psychologically unprepared. According to this view, many people have attributed the causes of these earthquakes to actions carried by man, such as exploitation of subsurface resources or fracking activities.

In spite of the experts explaining in all possible ways the origin of earthquakes and emphasizing their unpredictability, the population has given credit to various groundless alarms such as gas emission, bubbling water and ground cracks (Bertacchini *et al.*, 2014). In order to effectively thwart the spreading of wrong convictions about earthquakes, scientific information should be bestowed by scientific community and actions towards a better natural hazard understanding and awareness should be applied.

In our point of view, the most important contribution in terms of informations and communication has concerned the production of preliminary final reports and maps illustrating the spatial distribution of the environmental effects and their correlations with the triggering causes and predisposing factors of liquefaction susceptibility. The study supporting this paper wish to demonstrate how catalogues and the cartographic instruments could have a key role in natural hazard and risk communication and assessment, in particular for the seismic-hazard, in which the triggering and predisposing factors are less geographically visible than for others natural hazards. It is crucial to enhance the population awareness in seismic hazard and risk in order to develop models of resilient strategies and sustainable action of governance and land use planning.

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