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A WebGIS platform for managing the seismic risk at regional scale: the case study of the Emilia-Romagna Region

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Abstract

The Emilia-Romagna Authority commissioned Eucentre to carry out a regional scale seismic assessment of residential buildings and to update spectrum- and seismic- compatible natural accelerograms for the ground response estimation in the microzonation studies of level III. The results of these studies are available in a specially developed WebGIS platform that is accessible according to two different roles: the technicians of the regional Authority and the practitioners. While the former can benefit from all the platform functionalities, the latter can only download the accelerograms to be used in technical activities such as seismic microzonation. The platform shows on a regional scale map: (i) the seismic hazard, on outcropping bedrock or with ground amplification; (ii) the exposure in terms of number of buildings, dwellings, and population; and (iii) the fragility curves, specifically calibrated for the Emilia-Romagna exposed asset. Furthermore, the platform provides tables and maps with the seismic risk of the building stock calculated for predetermined time windows and return periods, according to the level of the seismic hazard specified by the Italian Building Code.

Keywords: WebGIS platform; seismic risk; fragility curves; ground shaking; accelerograms; risk management

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1. Introduction

In Italy, the administrative offices of the Regions have the mission to manage the programming and urban planning of their territory so that urban and productive settlements are safe and every activity is sustainable. It is therefore essential for administrations to have up-to-date documents that allow them to adequately consider risks arising from natural or anthropogenic disasters.

The main references used so far for seismic risk assessment are the Seismic Classification Map (published with OPCM 3274/2003, and subsequent regional modifications) and the MPS04 map (Stucchi et al., 2004), a seismic hazard map realized in 2004 by the National Institute of Geophysics and Volcanology (published with OPCM 3519/2006). However, these maps do not provide the distribution of seismic risk over the territory but take into account only the hazard. MPS04 represents the basic seismic hazard (i.e., the expected shaking at reference ground conditions), which is only one of the components of seismic risk. Moreover, MPS04 provides values of expected shaking on rigid ground and horizontal topographic surface. Nevertheless, it is well known that the geological and geotechnical characteristics of a site can influence the level of the seismic ground shaking experienced by structures and consequently their damage. Furthermore, it has been proven that seismic damage is generally more significant on soils with poor properties than on rock. It is also important to emphasize that for a correct evaluation of the local seismic response, it is essential to use input accelerograms compliant with the requirements of the current earthquake regulations (NTC18, D.M. 17.01.2018 and Circolare n. 7 of 21.01.2019). Finally, concerning structures, the latest earthquakes in Italy have highlighted the low seismic resilience of the national as-built. This is mostly due to the age of the buildings and the criteria with which they were designed. Most of the existing Italian buildings have been either designed for gravity loads only, i.e. before the introduction of the seismic classification established by OPCM 3274/2003, or by adopting anti-seismic procedures far from those understood and accepted today.

To meet all these needs, the Emilia-Romagna Region (RER hereinafter) commissioned Eucentre to develop a WebGIS platform that: (i) interfaces the user to the exposure, vulnerability and hazard data; (ii) allows to consult risk maps for residential buildings; and (iii) provides updated reference accelerograms for the Region to be downloaded and used for the estimation of the local seismic response and seismic microzonation studies of level III.

2. An overview of the WebGIS platform for the Emilia-Romagna Region

The platform developed for the RER allows displaying the seismic risk of residential buildings on the regional territory and its three components. The seismic risk is the outcome of the convolution of three random variables, assumed statistically uncorrelated:

- The expected ground shaking, including local amplification effects, that are all those phenomena that modify the reference seismic hazard (i.e., referred to outcropping rock and ground-leveled topographic conditions);
- The exposure, that is, the economic, cultural and social value of the asset whose risk is to be calculated, which therefore includes its consistency, destination of use and location on the territory;
- The seismic vulnerability of buildings, i.e., their propensity to be damaged when subjected to an earthquake of a given intensity.

The base unit for defining the risk, and consequently its components, is the “census section”, which is the smallest area in which each municipality is divided. The seismic hazard has been calculated in this project for each census section both on the rigid ground and on soil conditions (i.e. considering the effects of local amplification, which can vary within a few hundred meters). The platform includes two types of users: regional users, i.e. RER officials, who can see all the results of the project, and practitioners who can only download the reference accelerograms. Figure 1 shows the “Homepage” of the WebGIS platform that is displayed after login.

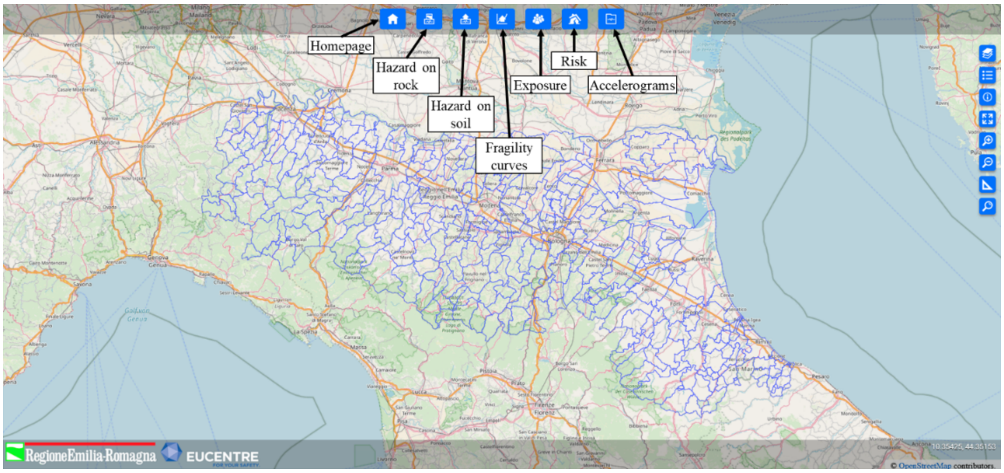

Fig. 1. Homepage of the platform: the boundaries of the RER municipalities are indicated in blue colour.

Eucentre has gained experience in developing methodologies and platforms for seismic risk calculation. For several years, with funding from the Italian Civil Protection Department, Eucentre has been developing tools and then implementing in WebGIS platforms to evaluate the Italian seismic risk and damage scenarios of residential buildings (Faravelli et al. 2017, 2018), school buildings (Faravelli et al. 2017, 2018), critical infrastructures of the transportation network, such as roadway network (Di Meo et al. 2018, Cosentini and Bozzoni 2022), maritime ports (Bozzoni et al. 2018), airports (Bozzoni et al. 2020), and dams (Bozzoni et al. 2015; Bozzoni and Lai 2017). Since 2018, Eucentre has also been working on the development, for the Italian Civil Protection Department, of a new platform, called IRMA (Italian Risk MAps) (Dolce et al. 2021, Borzi et al. 2021), which allows the scientific community to produce seismic risk maps using exposure and fragility models uploaded by them. IRMA contains several modules, one for residential buildings, one for schools, and one (still ongoing) for churches. The maps obtained for residential buildings through IRMA using models developed by the Italian scientific community (ReLUIS and Eucentre) at the end of 2018 were published in the National Risk Assessment Report (ICPD 2018). These national scale maps have the municipal territory as a minimum unit of definition. In the study developed for the RER and herein outlined, different assumptions were adopted in assessing the risk components with respect to those in IRMA. Consequently, the results from the RER study are not comparable with those reported by the National Risk Assessment Report (ICPD 2018) for the Emilia-Romagna Region nor with the risk of the other Italian regions calculated according to national-level assessments.

3. The seismic risk at the regional scale

The three components of risk already mentioned, i.e., seismic hazard, exposure, and seismic vulnerability, were calculated for the Emilia-Romagna territory and then included within a purposely developed WebGIS platform. Seismic hazard, described in §3.1, was calculated with reference to census sections both on rock and considering the effects of litho-stratigraphic amplification. The information about the exposed elements in each census section as well as the fragility curves developed and adopted in this study for the seismic vulnerability assessment of residential buildings are described in §3.2. How these three elements contributed to the calculation of seismic risk is illustrated in §3.3. Finally, §3.4 presents the methodology adopted for selecting spectrum-and seismic-compatible natural accelerograms and how practitioners can access them from the platform.

3.1. Expected ground shaking for different return periods

In the WebGIS platform, the reference seismic hazard is mapped for the territory of the RER, defined within a probabilistic framework according to the prescriptions of the current Italian building code (NTC18, D.M. 17.01.2018).

In the specific, NTC18 provides the design spectra at the nodes of a regular grid covering the Italian territory, for nine probabilities of exceedance in 50 years (i.e., 2%, 5%, 10%, 22%, 30%, 39%, 50%, 63%, and 81%). The design spectra are based on the results of a Probabilistic Seismic Hazard Assessment (PSHA) carried out for Italy from 2003 to 2009 by a working group established by the Italian Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV), which computed the seismic hazard for Italy in terms of (i) horizontal Peak Ground Acceleration (PGA_{RProck}) and (ii) spectral accelerations for 10 periods for the nine probabilities of exceedance mentioned before (corresponding to nine return periods). In the WebGIS platform, the seismic hazard maps are expressed in terms of PGA, since it is the input intensity measure for the adopted methodology for vulnerability assessment. It is worth remarking that such results are referred to standard conditions, i.e. outcropping rock and ground-leveled topographic conditions. To include amplification effects, a procedure was implemented by Eucentre starting from the outcomes of the seismic microzonation studies carried out across the RER.

More specifically, the litho-stratigraphic amplification factor for the PGA associated with the return period of 475 years (namely $FPGA_{475}$) was mapped by the RER technical staff for the whole Region by using the results obtained in the microzonation at the municipal scale. This chart, along with the map of PGA at the free surface, was provided as raster files to Eucentre staff, who processed them to compute the expected ground shaking at a regional scale for various return periods. The procedure set up by Eucentre consists in scaling the starting map for return periods different from 475 years. It exploits a code-based approach for estimating the amplification effects (NTC18) by using the litho-stratigraphic amplification coefficient (called Ss). Only the litho-stratigraphic amplification was considered and any topographic amplification effects were neglected. Since the considered exposed assets are residential buildings and based on the RER available data, this assumption appears reasonable, in first approximation, for the spatial scale of the risk assessment. For a given point of the regional territory and for each object return period (RP), the litho-stratigraphic amplification factor, $FPGA_{RP}$, was computed by using the following equation:

$$\mathrm{FPGA_{RP}}=\mathrm{FPGA_{475}}\left(\frac{\mathrm{Ss_{RP}}}{\mathrm{Ss_{475}}}\right) \tag{1}$$

where the amplification factor referred to the return period of 475 years is scaled based on the value of the ratio between the litho-stratigraphic amplification coefficient of the object return period, Ss_{RP}, and the one referred to the 475-year return period, Ss_{475}. Then, the peak values of the horizontal component of the acceleration at the free surface for a given point of the regional territory and for a specific return period (PGA_{RP}) were obtained as:

$$\mathrm{PGA_{RP}}=\mathrm{FPGA_{RP}}\mathrm{PGA_{RProck}} \tag{2}$$

To compute the litho-stratigraphic amplification coefficient, a ground category according to the Italian building code (NTC18) was assigned to each site located in the RER territory (i.e., to each pixel of the raster file representing the regional territory). This activity was carried out as follows:

- For the Emilia-Romagna plain area, the ground category was inferred based on the available amplification map provided by RER for the return period of 475 years;
- For the Apennine area of the regional territory, the ground category was provided directly by RER technical staff.

To check the definition of the ground categories in the plain area of the Region, the map with the distribution of the PGA values at the free surface referred to 475 years provided by RER was compared with that calculated in this study. The excellent agreement between the two maps validates the procedure. Finally, the maps in terms of peak ground acceleration for overall 9 return periods (i.e. 30, 50, 72, 101, 140, 201, 975 and 2475 years, in addition to 475 years) were integrated into the WebGIS platform. Figure 2 shows an overview of the WebGIS platform for the RER focusing on the expected ground shaking.

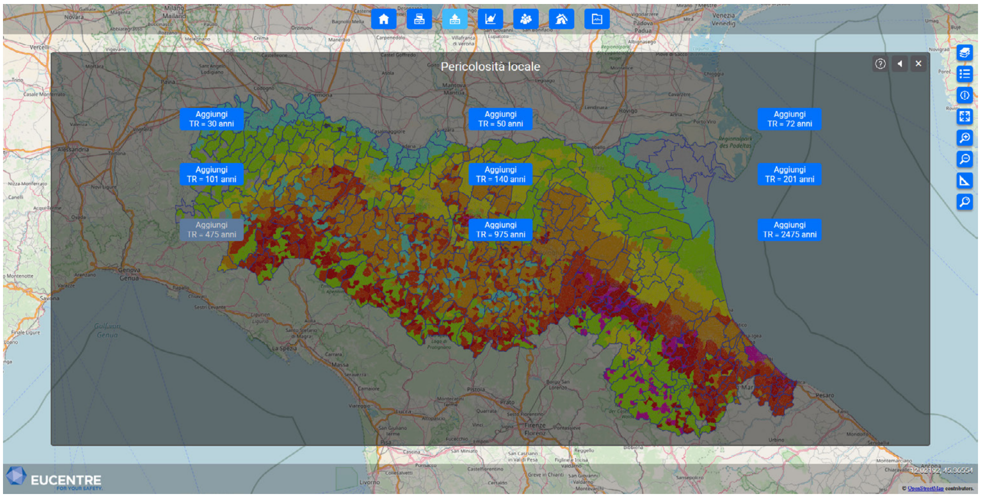

Fig. 2. Overview of the WebGIS platform for the RER focusing on the expected ground shaking.

3.2. Exposed assets and vulnerability assessment

To produce risk maps, the exposure database from ISTAT (Italian National Institute of Statistics) referred to the 2011 Census of Housing and Population was adopted. This database provides the number of buildings, dwellings, and resident population for each census section present in the municipality. In particular, for buildings, the database reports the number of floors, the material (e.g., masonry, reinforced concrete) and the year of construction. These last two information, are used to define the vulnerability classes for residential buildings, i.e.: Class A (masonry buildings with high vulnerability), Class B (masonry buildings with medium vulnerability), Class C1 (masonry buildings with low vulnerability), Class C2 (reinforced concrete buildings not seismically designed), Class D (reinforced concrete buildings seismically designed). For masonry buildings, the probability of belonging to the different classes of vulnerability has been elaborated according to the Angeletti et al. (2002) studies on damage data observed in past earthquakes. For instance, Angeletti et al. (2002) assign the following percentages to masonry buildings constructed between 1919 and 1945: 52% in class A, 41% in class B, and 7% in class C1. Multiplying the number of buildings constructed in a given period by the percentages provided by Angeletti et al. (2002), the number of buildings that belong to each vulnerability class was obtained. For reinforced concrete buildings, vulnerability classes are defined by comparing the year of construction with the seismic classification year of the municipality. This allows seismically designed buildings to be distinguished from non-seismically designed ones.

The seismic vulnerability of buildings can be numerically defined through the use of appropriate fragility models. Such models are represented by functions, called "fragility curves", which provide the probability of reaching or exceeding a given level of damage for a specific severity of ground shaking (defined by PGA in this project). The fragility curves used to calculate the seismic risk in the RER describe the performance of residential buildings according to the damage levels of the EMS98 scale (Grünthal 1998), i.e., from D0 (no damage) to D5 (collapse). The adopted fragility curves have been calculated using the SP-BELA (Simplified Pushover Based Earthquake Loss Assessment) mechanical methodology (Borzi et al. 2008a and 2008b). In SP-BELA, classes of buildings are created to represent the considered structural typology. For each class, a sample of buildings is created using the Monte Carlo method. The fragility curves are derived by comparing the demand imposed by the earthquake with the building capacity. The SP-BELA methodology has been improved over the years (Faravelli et al. 2019), in particular by analysing the observed damage data that come from the damage survey forms. This data can be downloaded from the platform of the Department of Civil Protection, developed by Eucentre, called "Da.D.O." (Database di Danno Osservato, Dolce et al. 2019). For the RER project, the fragility curves produced with SP-BELA were further calibrated and improved to obtain ad-hoc curves that best represent the vulnerability of residential buildings in this Region. The calibration has been performed by comparing the observed damage scenario associated to the Emilia 2012 earthquake (Mw=5.8) with the simulated one. Figure 3 shows this comparison for both masonry and reinforced concrete buildings after the calibration process. In particular, the graphs report the percentage (%) of buildings reaching the different damage levels.

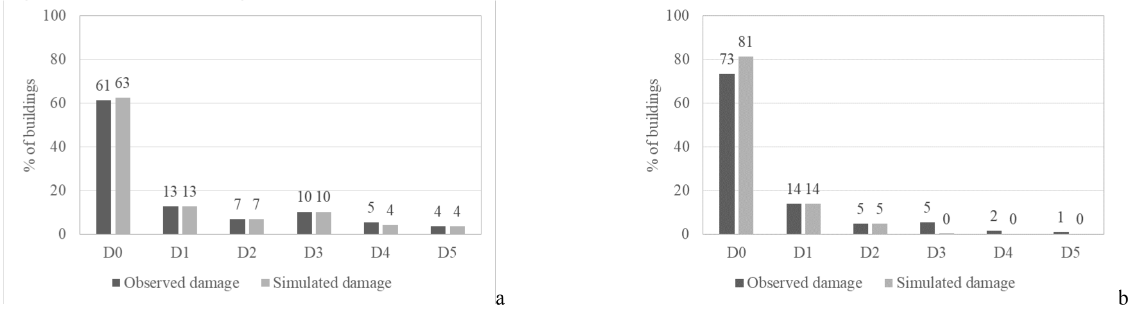

Fig. 3. Comparison between the observed damage scenario (in dark grey) and the simulated damage scenario (in light grey) calculated for masonry (a) and reinforced concrete (b) buildings for the Emilia 2012 earthquake.

3.3. Seismic risk

Once all the components of the seismic risk have been defined, the calculation of the seismic risk can be carried out and accessible from the platform. Two different types of seismic risk are made available in the RER platform: the “conditional risk” and the “unconditional risk”. In the “conditional risk” the probability of damage is conditioned to the occurrence of shaking of prefixed intensity. In the “unconditional risk” the condition is eliminated by considering the probability that shaking will occur in an observation time window. Conditional risk has been determined for all the 9 return periods considered in the MPS04 seismic hazard model. Unconditional risk has been assessed by considering the probability of occurrence of shaking of a certain severity in a one-year observation time window. Risk calculations have been performed both considering and neglecting site effects. An example of a conditional risk map is reported in Figure 4, which shows the risk related to the damage level D3 for return period of 475 years in terms of percentage of dwellings.

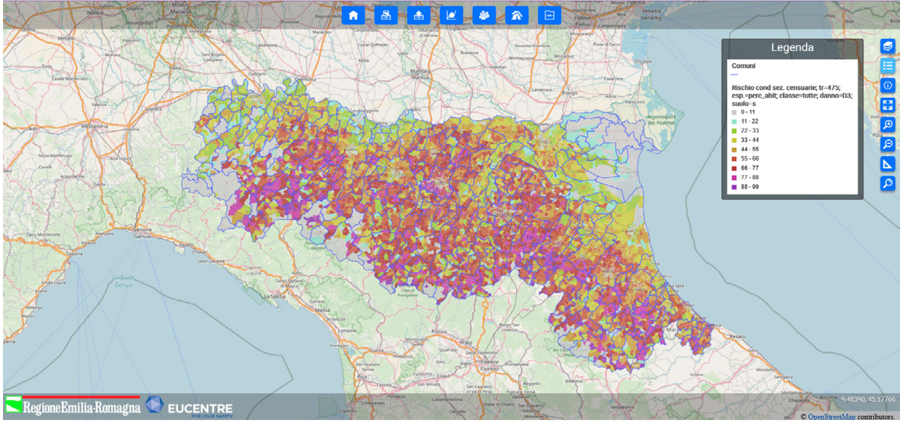

Fig. 4. Conditional risk map for RP=475 years, accounting for site effects, in terms of the percentage of dwellings, all vulnerability classes, and damage level D3.

3.4. Selection of spectrum- and seismic- compatible natural accelerograms

The WebGIS platform allows to retrieval of the updated reference accelerograms for the RER associated with three return periods of interest (i.e., 101, 475, and 975 years). The locations for which the seismic input can be retrieved are the nodes of the grid adopted by NTC18 (D.M. 17.01.2018) to define the seismic action, falling within the RER. The seismic input is provided in terms of a set of seven natural accelerograms (horizontal component) recorded at freefield stations located on outcropping rock and satisfying the average spectral compatibility requirements prescribed by NTC18.

The methodology adopted to define the seismic input involves four main steps (Rota et al. 2012, Zuccolo et al. 2014): the first step consists of grouping the response spectra with similar shapes, followed by the identification of a reference response spectrum for each group, which is the second step. The third step concerns the selection of spectrum-compatible real records with respect to the reference response spectrum of each group. This has been performed with an updated version of the code ASCONA (Corigliano et al. 2012). The final step is to linearly scale the selected accelerograms, to guarantee the spectrum compatibility with respect to other spectra of the group different from the reference response spectrum. Due to the criteria adopted for both the identification of the groups of spectra and the definition of the reference response spectra and the threshold scaling factors enforced in ASCONA, the scaling factors (SF) applied to the original accelerograms vary between 0.32 and 3.69. Table 1 shows the range of variation of SF as a function of the return period. The number of cases in which SF ranges between 2/3 and 1.5 is also reported, showing that for the short return periods (101 e 475 years) almost 50% of the scaling factors are close to unity, while this number is reduced to about 20% for the longest return period (975 years). This trend reflects the difficulty in selecting spectrum-compatible records with low SF for the longest return period, presumably due to the lack of recordings on rock characterized by large acceleration values.

Table 1. Minimum, maximum and mean value of the scaling factor (SF) applied to the original accelerograms.

RP (years)	SF Min	SF Max	SF Mean	% of cases with SF between 2/3 and 1.5
101	0.32	3.25	1.24	51.0
475	0.34	3.34	1.53	45.7
975	0.43	3.69	1.93	21.7

4. Conclusive remarks

With the realization of the platform herein described, Eucentre has provided the RER with a support tool to plan interventions aimed at reducing the seismic risk of residential buildings. This study allowed to integrate the wide knowledge available for the Emilia-Romagna territory including information and technical data about the expected seismic hazard, the exposure, the vulnerability and the seismic risk of residential buildings in its territory. The RER platform is also useful to practitioners by allowing them to easily retrieve sets of natural accelerograms selected according to the current building code.

Future developments could focus on the following main topics: (i) the evaluation of the litho-stratigraphic amplification effects by using an alternative approach, based on shear wave velocity measurements available across the regional territory; (ii) the inclusion of topographic amplification effects, e.g., by using approaches based on Digital Elevation Model (DEM); and (iii) the assessment of the seismic risk concerning other exposed assets, such as industrial buildings, strategic buildings (e.g. schools, hospitals), and critical infrastructures (e.g., ports, airports, railway, and roadway). About the accelerograms, it would be appropriate to extend the selection to other return periods. Finally, an upgrading of the platform could consist in adding tools able to assess in (near) real-time seismic damage and induced losses in the immediate aftermath of a seismic event.

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