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Damage scenarios for RC buildings during the 2012 Emilia (Italy) earthquake

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ABSTRACT

The main features of the Reinforced Concrete (RC) building stock that was struck by the Emilia 2012 earthquake and damage observed after the event are analyzed. Building stock characteristics and historical seismic classification are employed for the definition of two benchmark structures, representative of the whole building stock. Seismic capacity of the two structures, at different damage states, is assessed through static push-over analyses, within the N2 spectral assessment framework. Infill panels' contribution in terms of strength and stiffness is explicitly taken into account in the analytical model. Damage States are defined according to a mechanical interpretation of EMS-98 scale. Fragility functions at each Damage State are obtained through the application of a Response Surface Method. Finally large-scale damage scenarios are obtained crossing the geo-referenced census data regarding the characteristics of the Emilia RC building stock and starting from the seismic input provided by the shake map of the event. The scenarios seem to be in reasonable agreement with the observed damage.

1. Introduction

On the 20th of May 2012 a magnitude (M_w) 6.0 earthquake struck the Emilia region. The whole seismic sequence was characterized by seven events with M_w higher than 5.0. The area struck by the earthquake was very large; it included the provinces of Modena, Ferrara, Rovigo, and Mantova. Peak Ground Acceleration (PGA) registered at the closest station (epicentral distance equal to 16 km), during the mainshock, was equal to 0.27*g* [1]. Most of observed damage involved masonry buildings, precast industrial structures, and, in some cases, Reinforced Concrete (RC) buildings, as shown by the photographic documentation collected after the event in different reconnaissance reports and papers [2–5]. The M_w 6.0 mainshock of the 20th of May was followed by another significant event of similar intensity (M_w=5.8, according to INGV) on the 29th of May.

A preliminary analysis of the performances of RC buildings during the 2012 Emilia earthquake is provided herein. The general aim of the paper is to carry out a damage scenario analysis for the Emilia earthquake, thus providing a first comparison with observed damage to RC buildings reported in reconnaissance reports.

During last years, several studies reported large scale post-earthquake comparisons between observed and predicted damage to the building stock in the areas struck by different seismic events (e.g., [6–11]). Different seismic vulnerability assessment approaches were employed (observational, analytical or hybrid), and information on building stock characteristics was often provided by census data. Examples of preliminary loss assessment procedures were shown, too. These studies allowed to show and discuss accuracy and reliability of applied damage estimation methodologies through a direct comparison between the results provided by the application of such methodologies and observational damage data.

In this study, damage scenarios are based on nonlinear static analyses on two benchmark structures, and fragility curves are obtained through a Response Surface Method. The two benchmark structures are representative of two classes of RC buildings composing the whole building stock. The analysis of building stock data and the study of the evolution of the seismic classification of the area highlight that most of the structures are low-medium rise buildings designed for gravity loads only, as shown in Sections 2 and 3. Section 4 describes main characteristics of the seismic sequence and observed damage to RC structures in the epicentral area.

According to the information collected on building stock and seismic classification, in Section 5 the two benchmark structures (2- and 4-storey high) have been defined as representative of the classes of RC buildings with less than four storeys and with four or more storeys, respectively. Infills structural contribution in terms of strength and stiffness has been taken into account. Seismic capacity of the two structures in terms of spectral acceleration and PGA, at different Damage States, is assessed through static push-over analyses, within the N2 spectral assessment framework, through an appropriate strength reduction factor–ductility–period (R–μ–T) relationship [12]. The definition of Damage State

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thresholds in terms of displacement is made on a mechanical basis and through engineering judgment interpretation of the qualitative description provided by EMS-98 [13] (see Section 5).

In Section 6, vulnerability functions have been derived for the two structures representative of the two building classes at the defined Damage States, through the application of a Response Surface Method. Shake map data of the mainshock event occurred on the 20th of May 2012, according to INGV, and census data in terms of number of storeys and structural typology of the buildings [14] have been employed for the evaluation of damage scenarios for the municipalities struck by the event, and located in the epicentral area. The obtained damage scenarios are then compared with observed damage and photographic documentation collected right after the earthquake. The results of the vulnerability study and the observed damage allow a qualitative comparison given the fact that data of official usability and damage inspections are not yet available. On the other hand, a fair agreement between observation and vulnerability functions can still represent a way to check the reliability of the adopted vulnerability approach, developed on a mechanical basis. Given the occurrence of the significant event of the 29th of May, a preliminary evaluation of cumulative damage on the two benchmark structures, resulting from the two main events (20th and 29th of May), is also carried out.

2. Main features of Emilia building stock

The first step towards a vulnerability analysis is the identification of the main characteristics of the building stock in the considered area. The Italian National Institute of Statistics (ISTAT, *Istituto Nazionale di Statistica*) survey is a nation-wide census that provides information on citizens and buildings. In particular, in the 14th general census of population and dwellings (14° *Censimento generale della popolazione e delle abitazioni*) [14], information about characteristics of buildings is provided. The collected information concerns category of use (industrial or residential), structural typology (masonry, RC, …), number of storeys, and age of construction.

In the following, the above mentioned data are illustrated, referring to the area struck by the May 2012 Emilia seismic sequence. It is worth to note that age of construction needs to be accompanied by information regarding the evolution of the seismic classification, in order to identify design approach characterizing the building stock of the area (see Section 3).

The availability of ISTAT data allows to evaluate the statistics of buildings in terms of number of storeys (1-, 2-, 3-, and ≥4-storey buildings), age of construction (typically with a decennial-rate), and structural typology (masonry or RC buildings) for the spatial units of the census, referred to as *census tracts*. Nevertheless, due to privacy requirements, these statistics are provided in aggregate format. Thus, for example, it is not possible to get the number of RC buildings in a census tract dating back to a specific age of construction and characterized by a given number of storeys. The statistics for the 448 Municipalities hit by the 2012 earthquake are shown in Fig. 1.

Almost 5% of the whole building stock in the Emilia region is constituted by buildings or groups of buildings used for commerce, industry, communications or transport (Fig. 1(a)). Within the area struck by the earthquake only 15% of buildings are RC structures (Fig. 1(b)), and almost 75% of the buildings are 1- or 2-storey high (Fig. 1(c)). A quite uniform distribution of the age of construction can be observed from data shown in Fig. 1(d).

The information on RC building stock gathered from ISTAT data can be compared with the corresponding information collected for L'Aquila (Abruzzo) area after the 2009 earthquake (e.g., [15]). The comparison between Emilia and Abruzzo building stock data highlights a similar percentage of RC buildings (approximately equal to 20%) and similar distribution of number of storeys and age of construction. On the other hand, given the different evolutions of the seismic classification, similar building stock characteristics can lead to different design approaches and, in turn, to different structural performances.

3. Evolution of the seismic classification in the Emilia region

In recent years, four are the fundamental dates for the evolution of the seismic classification in Italy: 1984, 1998, 2003, and 2008. In fact, after the Friuli (1976) and Irpinia (1980) disastrous earthquakes, three different seismic categories were set up, and the third category, characterized by a PGA equal to 0.04*g*, was introduced for the first time. First and second categories were characterized by a PGA equal to 0.10*g* and 0.07*g*, respectively (see [15]). Such accelerations were determined through the seismic coefficient *S* equal to 12, 9, and 6, and decreasing with the increasing of the category form first to third. According to the latter classification [16] most of the area struck by the 2012 Emilia earthquake was classified as nonseismic.

Successively, in 1998, a reclassification proposal was provided by the *Servizio Sismico Nazionale*. Such a classification was never adopted officially by any code but it is at the basis of the classification made in 2003 [17], after the San Giuliano earthquake. The 2003 regulation document introduced also modern design rules, such as the so called *capacity design*. On the other hand, it should be noted that these new design rules worked as recommendation, since they have never become compulsory, and it was still possible to design new structures according to the previous code [18]; (see Manfredi et al. [19] for details).

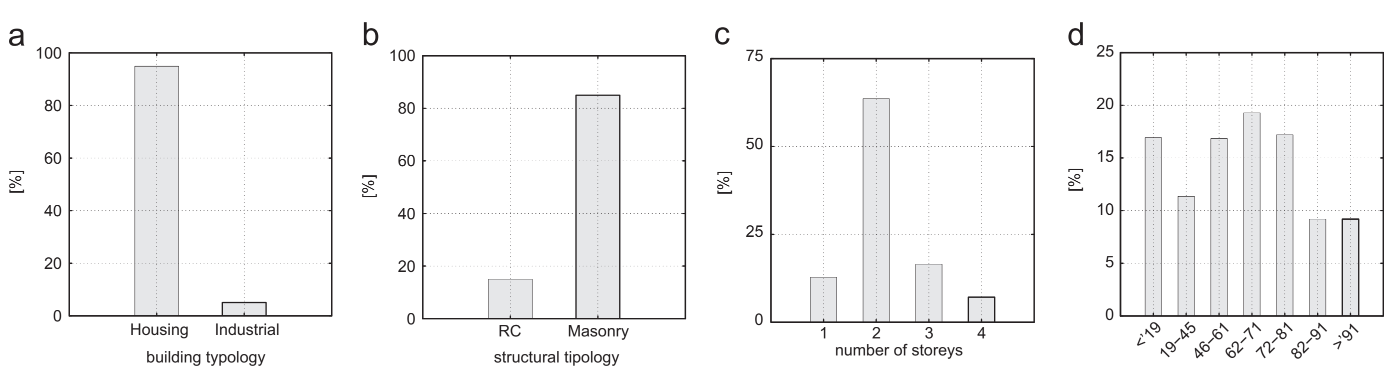

Fig. 1. Statistics for the 448 Municipalities hit by the earthquake of 20th of May 2012: building typology (a), structural typology (b), number of storeys (c), and age of construction (d).