

Seismic Vulnerability Categorization of the Greek Building Stock

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The essential goal of vulnerability assessment of buildings and other assets to ground shaking is to estimate their expected performance to ground motion. This will in turn affect the life quality and safety of people living or working inside them, being in their vicinity or depending upon their functionality. Seismic vulnerability of assets, i.e. buildings, critical facilities, lifelines etc., is thus defined as the likelihood of damage from future earthquakes. Vulnerability is an integral component of seismic risk assessment (i.e. the probabilistic estimation of economic loss, life loss or injury, downtime and business interruption). Relationships that define vulnerability are typically classified into empirical, analytical or hybrid, according to the type of data and method used for their determination.

In most cases researchers emphasize on fragility and vulnerability assessment of standard buildings, given that they are the most common among the elements at risk. For the existing Greek building stock, fragility curves have been proposed from hybrid methodologies (Kappos et al., 2006; Kappos and Panagopoulos, 2010), based on a combination of real observed damage data and analytical models. Karababa and Pomonis (2011) have proposed a set of empirical fragility curves resulting from the 2003 Lefkada earthquake observed damage data. Following, Pomonis et al. (2013) presented a database of observed damage to 29,000 Greek reinforced concrete (RC), unreinforced masonry (URM) and mixed structure buildings compiled from post-earthquake damage surveys carried-out by government authorities and University researchers after four damaging crustal earthquakes (Kalamata 1986, Pyrgos 1993, Aegion 1995 and Lefkada 2003).

A successful attempt to categorize the entire country's building stock in vulnerability classes and for each municipality was performed during the implementation of the research project "Greco-Risks" (Kouskouna et al., 2014). In detail, the structural characteristics of the Greek building stock, derived from the December 2000 Building Census was analyzed, using parameters, such as the construction material, the period of construction and the number of floors. This led to building classification according to the vulnerability classes proposed by the European Macroseismic Scale (EMS-98).. The level of analysis was set to the Kallicratis municipality administrative system. The full combinations resulted in 368 building sub-classes, many of which (79 sub-classes) contain zero or less than 10 buildings (77 sub-classes). To further simplify the analysis, from the seismic risk point of view, the existing buildings can be grouped into:

- 3 periods of construction (before 1961, 1961-1995, after 1995 incl. under construction), according to the evolution of the Greek earthquake code (the first compulsory seismic design code of Greece was introduced in March 1959 and the second in January 1995 – although interim guidelines were also developed in 1986 following experiences of the 1981 Corinth Gulf earthquakes of February-March 1981);
- 3 classes of height (low-rise i.e. buildings with 1 to 3 floors incl. the ground floor; medium-rise i.e. buildings with 4 to 6 floors incl. the ground floor; and high-rise (i.e. buildings with 7+ floors incl. the ground floor) and
- 6 construction material classes (wood, metal, reinforced concrete, stone, brick or concrete block, other materials).

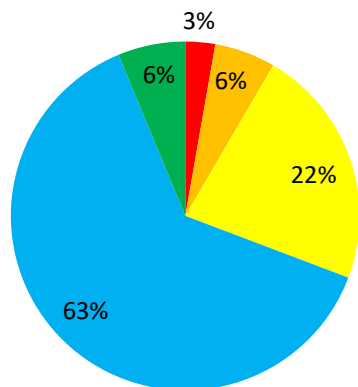
This grouping results in 54 seismic vulnerability classes. It is worth noting though that only 12 classes contain 97.8% of the Greek building stock. More than a third of the country's building stock (34.3%) is in one class, i.e. low-rise reinforced concrete buildings built in 1961-1995.

In the framework of the HELPOS project, the National and Kapodistrian University of Athens (NKUA) is carrying out research, based on the above procedure. The results of the vulnerability assessment will be updated by using, after homogenization, the most recent data of the Greek building stock, derived from the February 2011 Building Census which contains 4.053.451 buildings. The data are categorized in 11 periods of construction, 5 height classes (number of floors) and 5 construction material classes. It should be noted that 52.186 buildings "under construction" and 77.263 of "Other" construction material were also enumerated (the class "under construction" will be excluded from the analysis, the class "Other material" warrants further investigation as to its definition, given that it may include highly vulnerable buildings, such as aging adobe or rammed earth buildings). Regarding seismic risk assessment, the buildings will be grouped into 4 periods of construction (before 1961, 1961-1995, 1995-2005 and after 2005, as a new seismic code came into force in 2004), 3 classes of height (low-, medium- and high-rise) and 5 classes of construction material (wood, metal, reinforced concrete, stone, brick or concrete block). The analytical final results of the aforementioned methodology will present the categorization of the Greek building stock and the percentage of vulnerability classes at municipality and prefecture level.

An example of this implementation is shown in Figure 1a,b for the Prefecture of Eastern Attica, which includes 13 municipalities. During the period 2001-2008, the area experienced a building boom, which led to an increase of modern buildings, according to the revised Greek seismic design code (2004). A decrease of buildings belonging to the EMS-98 vulnerability classes A, B is observed, which is due to their replacement by new constructions and the increase in the size of the stock. Also, a decrease by about a quarter of the incidence of vulnerability classes C and D, respectively, was more than compensated by the increase of class E, which reached 23%. Further investigation of such results may also reveal

possible societal changes.

**a) EMS98 Vulnerability Classes
CENSUS 2001**



**b) EMS98 Vulnerability Classes
CENSUS 2011**

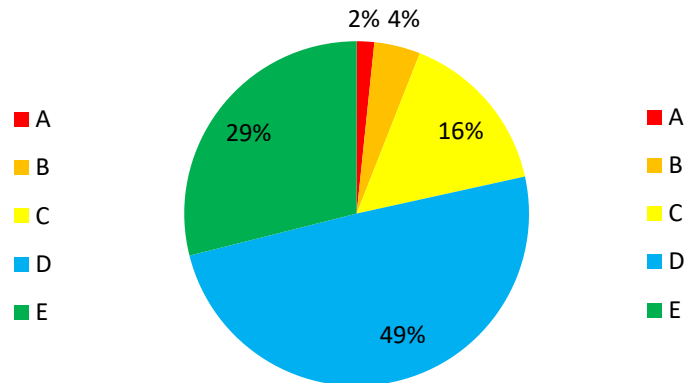


Figure 1. Vulnerability categorization for the Eastern Attica building stock, based on the a) 2001 Census and b) 2011 Census

The procedure will be applied to the entire Greek building stock and all the municipalities, with a detailed table of how the census data are mapped to the EMS-98 classes. We expect that the results will show that the country's present stock consists in large part of better designed and more resistant buildings, while municipalities with aging and vulnerable stock will also be identified.

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