Soil Dynamics and Earthquake Engineering 105 (2018) 139–149

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Post-earthquake reconstruction: A study on the factors influencing demolition decisions after 2009 L'Aquila earthquake

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ARTICLE INFO

Keywords:
Reparability
Demolition probability
Reconstruction
Costs
Logistic regression
Reinforced concrete buildings

ABSTRACT

The evaluation of building reparability after damaging earthquakes is a complex issue, involving factors such as the damage state, residual capacity and post-earthquake safety, initial performance level with respect to design earthquake and repair and retrofit costs. In the post-earthquake reconstruction process after the 2009 L'Aquila earthquake, the funding request had to be accompanied by a detailed assessment of repair costs, the pre-earthquake safety level with respect to new building standard (%NBS) and, if needed, by a detailed design of retrofit intervention and costs. The paper examines the database of severely damaged buildings after L'Aquila, collecting information of repair and retrofit costs as well as the final decision on reparability or demolition and reconstruction; 122 out of 472 severely damaged RC buildings were demolished. It illustrates the most important factors influencing demolition decisions for Reinforced Concrete (RC) buildings. A logistic regression is performed to estimate the probability of demolition p_{dem} for building typologies. Considering pre-earthquake information, the construction age is the most influential parameter, with older buildings having a higher p_{dem}. Another significant parameter is %NBS. Considering post-earthquake information, the repair cost is expectedly the most important parameter. It results that p_{dem} can be expressed as a function of construction age, %NBS and repair costs. A case study illustrates the possible application of the results for a town district in Campania Region, southern Italy.

1. Introduction

Severe earthquakes striking densely built areas may produce disastrous damage and casualties, as unfortunately happened after recent Central Italy earthquakes in 2016 or after L'Aquila earthquake in 2009. After this kind of catastrophic events, the recovery process may have very different duration and final outcome with respect to effective community relief. Short term recovery, concentrated in the first months after the event and including building tagging procedures and provisional sheltering of impacted population, is generally undertaken by civil protection with governmental funds. On the other hand, different experiences related to the reconstruction process as part of long term recovery, including repairing/rebuilding of the damaged houses and resettlement of homeless in place or delocalized, show that it can be undertaken with different level of national government leadership, very different housing recovery programs and financing process (individual funding, public supported funding, insured properties, etc.). The reconstruction process, with the repair, strengthening, or demolition and reconstruction of damaged buildings, starts few months after an earthquake and may last several years. This is a very controversial post-earthquake phase, often delayed due to the lack of clear repair standards and criteria for re-occupancy after a damaging earthquake [1]. Another issue complicating and elongating the time for reconstruction, and having a significant impact on final reconstruction costs, involves decisions on reparability. Indeed, for many substandard buildings, the key question in the aftermath of damaging earthquakes is not only if a damaged building should be simply repaired or also retrofitted, but often if it is more convenient to repair and retrofit or to demolish and rebuild it. The evaluation of building reparability is a complex issue, involving factors such as the damage state, residual capacity and post-earthquake safety, initial performance level with respect to design earthquake and repair and retrofit costs [2–5]. The final decision may be often dictated by economic convenience, but there may be other significant factors influencing it, as discussed in [6]. Local context can play a key factor in decisions. For example, in the case of the New Zealand 2010–2011 Canterbury earthquake sequence, the re-classification of large areas in Christchurch as liquefaction-prone zones obliged homeowners to relocate; also, the special requirements for foundation upgrading even in green-labeled areas (towards liquefaction risk) led to disproportional raising of repairing/rebuilding costs with an

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https://doi.org/10.1016/j.soildyn.2017.12.007
Received 30 April 2017; Received in revised form 2 November 2017; Accepted 3 December 2017

undeniable influence on demolition decisions.

Taking advantage from the availability of a large database on damaged buildings after 2009 L'Aquila earthquake, and on the final decision on the post-earthquake action (repair, repair and retrofit or demolish and rebuild) for those building, this paper studies the influence of several factors on reparability decisions. In particular, we examine the database of severely damaged buildings after L'Aquila, collecting information of repair and retrofit costs as well as the final decision on reparability, to determine factors that are most influential on demolition decisions for Reinforced Concrete (RC) buildings; 122 out of 472 severely damaged RC buildings were demolished. The database was assembled starting from the paperwork presented for funding requests by private owners; such documents had to be accompanied by a detailed assessment of repair costs, the pre-earthquake safety level with respect to new building standard (%NBS) and, if needed, by a detailed design of retrofit intervention and costs.

The present study does not claim to be representative for other countries. Indeed, in addition to safety level and costs, also the different characteristics and value of building stocks with respect to local culture and traditions, the different tendency to heritage preservation and attitude to move from original residence place may have a very different and strong influence on final demolition decisions. Still, the results presented here may be useful for preliminary ranking within earthquake damaged building stocks in Italy and for first level evaluation of demolition probability and rough assessment of expected associated losses.

In the following section the post-earthquake reconstruction process enforced after L'Aquila earthquake is explained. Section 3 presents the database for RC buildings. Section 4 describes the analysis of the database and the logistic regression performed to evaluate demolition probability as a function of relevant factors. Finally, a case study illustrates the possible application of the results for a town district in Campania Region, southern Italy.

2. Post-earthquake reconstruction process after 2009 L'Aquila earthquake

Housing recovery is often a combination of a proactive government role in the reconstruction process, funding, community participation and resilient improvements in infrastructure and planning [7]. Indeed, depending on the governmental programs, often issued in emergency phase, the safety levels for dwellings and permits for repairs/ strengthening are ruled and the public/private funds balance regulated. This certainly have an influence on the effectiveness of recovery towards reconstruction of more resilient cities as well as on the decisions on the fate of damaged buildings that ought to be repaired and strengthened or demolished and rebuilt.

The 2009 L'Aquila earthquake in Italy resulted in thousands of buildings with structural or non-structural damage which left approximately 67,000 homeless people. To evaluate the safety conditions of the buildings and to enable people to return to their houses, the damage and seismic usability assessment of public and private buildings started immediately after the earthquake [8]. The usability and damage assessment has been carried out by using the AeDES survey form [9] which is filled based on the visual in situ inspection of the building. The usability concept is related to the use of the building during the seismic crisis; according to the AeDES survey form, the buildings can be classified into the following categories: A. Usable buildings (slightly damaged, can keep on housing the functions to which it was dedicated); B. Building usable only after short term countermeasures (buildings with limited or no structural damage but with severe non-structural damage); C. Partially usable building (buildings with limited or no structural damage but with severe non-structural damage located in a part of the building); D. Building to be re-inspected (due to atypical damage scenario a specific, but still visual, investigation is required); E. Unusable building (high structural or non-structural risk, high external or geotechnical risk); F. Unusable building for external risk only.

Once the usability assessment of buildings was completed, a second stage of the emergency management involved the definition of suitable ordinances to regulate the reconstruction process. The Ordinances issued by the Italian government to pursue this goal were Ordinances of the President of the Council of Ministers (OPCM): OPCM no. 3779 and relevant Annex [10,11], OPCM no. 3790 and relevant Annex [12,13], and OPCM no. 3881 [14]. The ordinances established that the financial support of the Italian government to the reconstruction was given and managed by private owners. According to the "*build back better*" principle a government financial support was established including measures not only for damage repair but also for seismic vulnerability reduction. Repair and energy efficiency upgrading works were totally covered by public grants, along with strengthening interventions to increase the seismic safety level of buildings. If economically more convenient or technically required (i.e. partially or totally collapsed buildings, poor concrete quality or elevated columns residual drift in RC structures), the public contribution covered the demolition and reconstruction of the buildings severely damaged by the earthquake (buildings with E usability rating according to post-earthquake surveys). In particular, OPCM no. 3881 [14] allowed demolition and reconstruction for buildings with usability rating E. The property owners may select demolition and reconstruction instead of repair and strengthening interventions, if economically viable. In these cases, the practitioner should compare the costs for repair and strengthening works (to meet at least 60% of New Building Standards, %NBS) as well as health-hygiene and energy and acoustic efficiency upgrading with those for demolition and reconstruction computed according to specific provisions issued by the Resolution Regional Council DGR no 615 [15]. The minimum between these two costs was granted by the public contribution.

Documentation was required to illustrate the damage and the design of repair and strengthening interventions, to assess the building's original and post-intervention seismic capacity (for buildings with usability rate E) and to quantify the government financial support required.

A team was set up to oversee the applications for funding request and relevant technical projects. This team, called "Filiera" (i.e. an Italian word to indicate a supply chain mechanism) comprised three groups, each of which had separate responsibilities: Fintecna, a company totally owned by the State through the Italian Ministry of Economics and Finance, to evaluate the formal suitability and comprehensiveness of the application and documentation (administrative check); ReLUIS, an interuniversity consortium with the purpose of coordinating the university laboratory activity of seismic engineering, to evaluate the consistency between repair intervention and damage and the compliance between designed local (or global) strengthening interventions and current seismic code provisions and ordinances issued after the L'Aquila earthquake; Cineas, a university consortium for Insurance Engineering, to evaluate the appropriacy of the application for a financial rebate, also based on the technical assessment made by ReLUIS. The Filiera activity began in August 2009 and ended in March 2013. The applications for funding were related to the L'Aquila municipality and other municipalities. They concerned 5775 buildings (3564 buildings of usability rating B or C and 2211 buildings of usability rating E). In order to accelerate the recovery process, so-called "light damage" reconstruction relevant to less damaged buildings (B or C usability rating) started prior to "heavy damage" reconstruction of severely damaged or collapsed buildings (E usability rating), [16,17]. The first phase of the reconstruction started in August 2009 and the approval process as well as the relevant grant allocation was almost completed (i.e. for 90% of the applications) within September 2010. In the second phase ("heavy damage") the approval process of funding applications and the relevant grant allocation had been completed for 74% of the applications by September 2013 (three years after the "light damage" reconstruction phase ended). The total amount of public funds allocated for B or C and