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Analysis of damage data of low-rise buildings subjected to a shallow M_w6.3 earthquake

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ABSTRACT

In May 2008 a shallow M_w6.3 earthquake struck South Iceland with an epicentre close to two small towns. Nearly 5000 low-rise residential buildings were affected. The recorded maximum PGA was 0.88 g. A great deal of damage occurred, but there was no loss of life. In Iceland all buildings are registered in a detailed official database and insurance against natural disasters is obligatory. As the repair costs for every affected building had to be assessed for insurance purposes this provided an unusual opportunity to review structural performance across the whole population of buildings in the affected area. The estimated repair cost was classified in a number of subcategories covering structural and non-structural damage for five different residential building typologies. Study of these buildings showed that non-structural damage dominated the overall damage. The main monetary damage was cosmetic damage of partition walls and flooring. The structural systems performed quite well and no buildings collapsed.

1. Introduction

1.1. Background

Knowledge of seismic vulnerability of buildings is a fundamental issue when evaluating earthquake risk and expected loss. It is also useful in disaster planning in real time after an earthquake when studying consequences of different earthquake scenarios and in the planning of mitigation and retrofit programmes. Vulnerability of buildings depends on many things like building traditions, building type, materials and structural form, regularity in plan and elevation, detailing, quality of seismic design, design supervision, workmanship and inspection. These factors can be country, regional or area dependent, although many similarities can often be found among different locations. Earthquake intensity is known to be very site specific and dependent on several factors including regional seismicity, fault mechanism, attenuation characteristics, topography and soil conditions. Whenever possible, it is therefore important to carry out site-specific post-earthquake damage studies in order to learn from the results and to construct regionally dependent seismic vulnerability relationships for different building typologies.

Seismic vulnerability of different building typologies is described in several ways in the literature. *Fragility curves*, as defined in many references ([1,2]), show the probability of reaching or exceeding a specific damage state as a function of ground-motion intensity (see Fig. 1a). The damage state is defined by a descriptive damage index as none, slight, significant and collapse [3], or in a more detailed manner: none, slight, light, moderate, extensive, partial collapse and collapse [4]. Each state can have a more detailed description. For instance "slight" may be associated with "fine cracks in plaster partitions/infills" [4], and/or may be connected to the damage ratio within a given range, such as 0–5%. The damage ratio is here defined as the ratio of repair cost to replacement cost of a building. *Vulnerability curves* are used in some references [5] to show the damage ratio as a function of ground-motion intensity (see Fig. 1b). It is important to note that the definition of these terms is not universal and in some references are used interchangeably [3,4,6].

Conditional Probability Density Functions (PDF) which show the distribution of the damage ratio for a given building typology and intensity interval are also used in the literature (see Fig. 1c).

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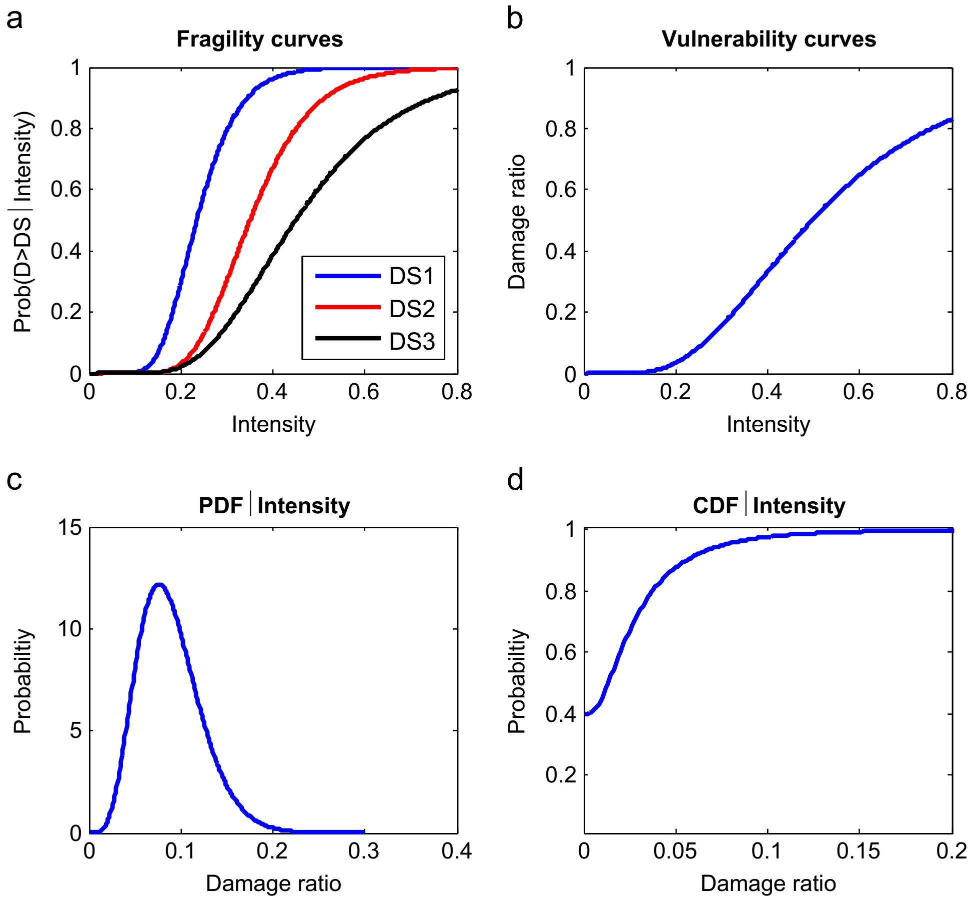

Fig. 1. Schematic presentation of different forms of damage relationships for a given building typology. a) Fragility curves showing probability of exceeding predefined damage states (DS1, DS2 and DS3) for a given intensity, b) Vulnerability curve showing expected damage ratio for a given intensity, c) Probability density function showing damage ratio for a given intensity, d) Cumulative distribution function showing damage ratio for a given intensity.

PDFs were used, for instance, to describe the vulnerability of California buildings by the Applied Technology Council [7,8]. An alternative to PDFs is to use conditional Cumulative Distribution Functions (CDF), which can take into account the fact that some fraction of building stock will be undamaged after an earthquake, a result that is then reflected by a step at the beginning of the curve (Fig. 1d [9]).

Four main procedures can be used for the evaluation of vulnerability relationships: 1) judgement-based methods like the one used in ATC-13 [7,8]; 2) analytical simulations and experiments [2]; 3) use of data from post-earthquake surveys [1,9]; and finally 4) hybrid methods which in some way combine these procedures. All these methods have their advantages and drawbacks. An overview and discussion of the different approaches can be found for instance in [1,3].

A key factor in any damage analysis based on observations is to have a detailed and accurate building inventory and comprehensive damage data. Very often the inventory is partial and limited or only available for single towns, regions and provinces. Often much work has therefore to be carried out in order to fill in gaps, combine new and old registers, and make some estimates and assumptions to cover missing data. Similarly the quality of the damage data can be poor.

The data behind the study presented in this paper were built on a complete property database as well as a detailed damage database. The damage data are based on post-earthquake observations made following the shallow M_w6.3 earthquake that struck South Iceland in 2008. The data of the estimated repair cost of the damage were classified in a number of structural and non-structural subcategories. These databases have already been used by the authors to derive conditional CDFs for damage ratios (see Fig. 1d) for five types of low-rise buildings that are most common in South Iceland [9].

1.2. Objective

The overall aim of the work presented in this paper was to learn from and analyse the comprehensive observed damage data after the South Iceland M_w6.3 earthquake of May 2008. This was done by computing fragility curves for five low-rise building typologies and by mapping how the damage was split into different subcategories of structural and non-structural damage. Finally, monetary damage (defined as the average repair cost per floor area) was computed for the five principal building typologies in the region as a function of ground motion intensities. By analysing the main weaknesses of the buildings, it is possible to improve their design and invoke countermeasures that can mitigate damage in future earthquakes. Furthermore this approach provided valuable background to create damage models for future earthquake loss studies.

2. The Ölfus earthquake of May 2008 in South Iceland

2.1. Earthquake data

The seismicity in Iceland is related to the Mid-Atlantic plate boundary which crosses the country. Within Iceland, the boundary