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Seismic vulnerability of low-rise residential buildings based on damage data from three earthquakes (M_w6.5, 6.5 and 6.3)

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ABSTRACT

In June 2000 two M_w6.5 earthquakes occurred in South Iceland and in May 2008 an M_w6.3 quake struck in the same area. High PGAs (>0.6 g) were registered in all cases. The epicentres were located in an agriculture region and close to small towns and villages. Nearly 9500 residential buildings were affected. A great deal of damage occurred but there was no loss of life. Insurance against natural disasters is obligatory for all buildings in Iceland and they are all registered in a comprehensive property database. Therefore, after each quake a field survey was carried out where damage and repair costs were estimated for every structure. Most of the damage was observed in the near-fault area (0–10 km) but at longer distances it was significantly less. The damage in the two M_w6.5 events was considerably greater than in the M_w6.3 event. In all the events a high proportion of buildings were undamaged, even in the near-fault area. The main damage was non-structural, in interior walls and flooring. New buildings built after implementation of seismic codes performed better than those built pre-code.

1. Introduction

1.1. Background

Knowledge of seismic vulnerability of buildings is fundamental when evaluating earthquake risk, in disaster planning, in preparation of mitigation and retrofit programs, and in development and improvement of building codes. Earthquake intensity and vulnerability of buildings is known to be both regional and country specific. Whenever a significant earthquake strikes it is important to carry out a damage survey in order to learn from it and to construct regional-dependent seismic vulnerability relationships for building typologies in the affected area.

Destructive earthquakes are well known in Iceland. Based on a detailed property database 54% of all residential buildings are low-rise (1–3 storeys) reinforced concrete (RC) buildings and 26% are mid-rise (4–7 storeys). Almost all of these are in-situ casted shear wall buildings. Low-rise timber buildings account for 12% of the total. Typical South European-type masonry or brick buildings are rare but for a period it was common to construct hollow pumice block buildings. Buildings made of concrete frames with masonry or brick infill are practically non-existent in the area.

Four main procedures can be used to evaluate seismic vulnerability: first, judgement-based methods like those used in ATC-13 [1,2]; second, analytical methodology based on dynamic analysis of representative building typologies [3,4]; third, use of damage data from post-earthquake surveys [5–9]; and fourth, hybrid methods which combine these procedures. In these procedures various ground-motion intensity measures are used.

A key factor in 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 or provinces. Similarly the quality of the damage data can be poor. The data behind the study presented in this paper are comprehensive. It is built on a thorough property database as well as detailed and complete damage data from three recent major earthquakes in South Iceland. Two of them occurred in June 2000 (M_w6.5 and M_w6.5) and the third one in May 2008 (M_w6.3). The fault-rupture distance between them was less than 35 km (Fig. 1). All the earthquakes shook the same type of regional structures. The damage data from the 2008 event is more detailed than the damage data from the two 2000 events and has already been used to evaluate vulnerability relationships and damage statistics [10,11].

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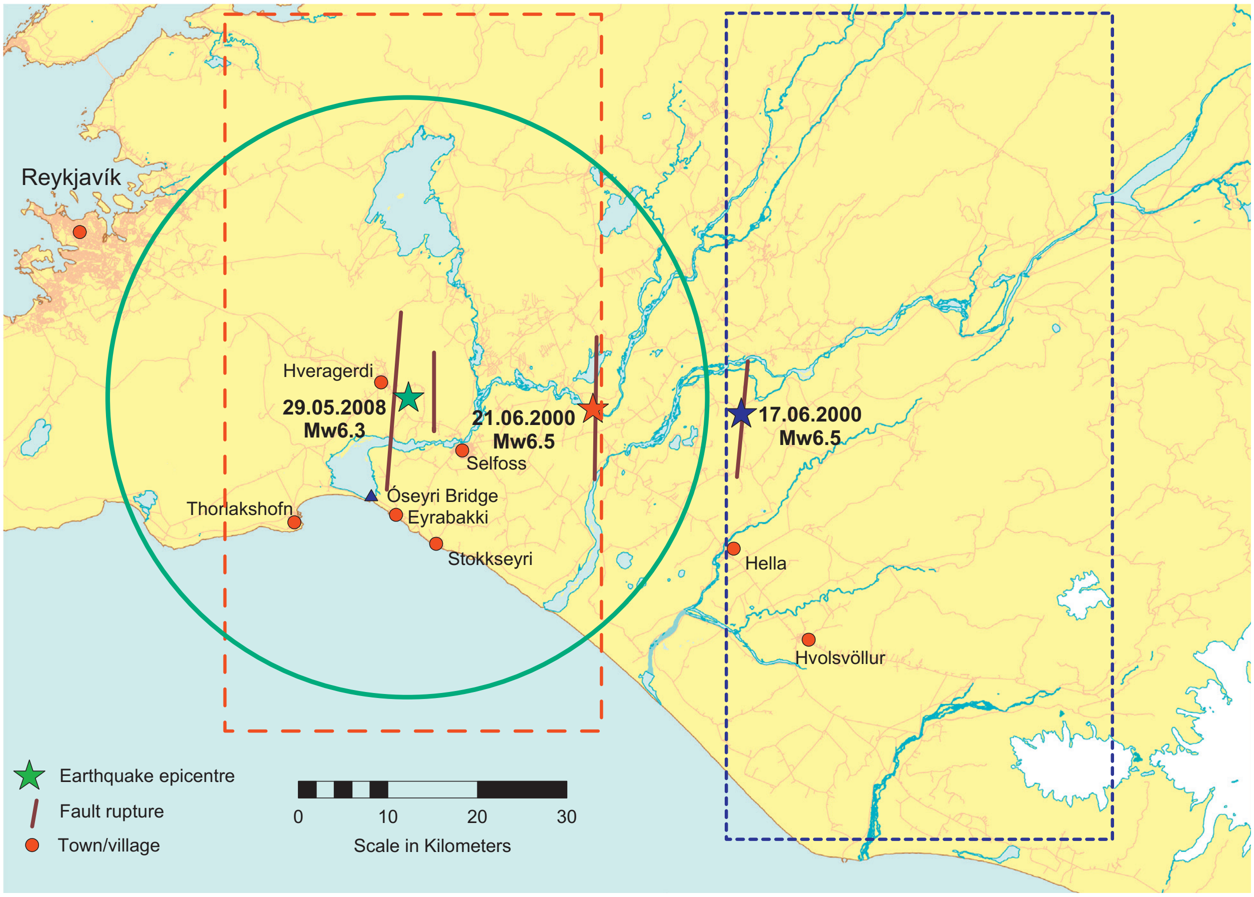

Fig. 1. Map of South Iceland showing from the west the two fault ruptures of the May 2008 Ölfus earthquake and the macro-seismic epicentre between them. Further east the epicentres and fault ruptures of two June 2000 South Iceland earthquakes are shown. The dotted (blue) rectangle to the right shows the area used in the study which was considered to be mainly affected by the 17 June 2000 earthquake. The dotted (red) rectangle to the left shows the corresponding area mainly affected by the 21 June 2000 earthquake. Finally, the circle shows the area affected by the 29 May 2008 earthquake. The map is based on data from the National Land Survey of Iceland. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1.2. Objective

The overall aim of the study presented in this paper was to learn from and analyse the comprehensive damage data after the three South Iceland earthquakes in 2000 and 2008, where almost 9500 residential buildings were affected. Having damage data to compare from more than one event where the same building typologies are affected is rare [12]. Furthermore, both damaged and undamaged buildings in the affected areas were included in this study, which is exceptional to find in post-earthquake damage studies [13]. Finally the details of the data give opportunity to distinguish between structural and non-structural damage and to sub-classify the damage. In this study the damage was defined as:

$$\text{Damage} = \frac{\text{Estimated repair cost}}{\text{Replacement cost}}$$

where the estimated repair cost is the sum of all estimated repair cost in all subclasses of structural and non-structural damage (Section 3.2). The damage cannot be greater than 1 (100%) and in practice the epithet "total damage" was assigned to residential buildings that had an estimated repair cost of more than 50–70% of their replacement value and in these cases full replacement cost was paid to the owner. The replacement value was taken from the official property database, where every building has been assigned an replacement value [14].

Destructive and damaging earthquakes in Iceland are commonly in the magnitude range of 6.0–7.0. Larger earthquakes hardly exist due to the fault mechanism, crust strength and thickness. This conclusion is supported by the effects of historical earthquakes and geological evidence [15,16]. Valuable information can therefore be drawn and reported from the observed data from these three recent earthquakes in this range and used to reflect the seismic vulnerability of the Icelandic building stock.

In the literature there is no consensus about what intensity measure to use in vulnerability analysis. In the early days it was common to use intensity scales like the Mercally scale but today it is more common to use instrumental intensity measures, like peak ground acceleration, velocity or displacement (PGA, PGV or PGD), response spectra ordinates or some energy based parameters. An analytical study of correlation of different intensity parameters with damage to medium-rise RC buildings can be found in Kostinakis et al. [17]. Their man conclusion was that acceleration spectral ordinates at the fundamental period correlated best with damage and inter-story drift and then PGV. In assessing vulnerability based on a damage survey it is necessary to rely on ground-motion prediction equations (GMPE) to estimate the intensity measure at each site. Recorded ground motion is usually only available at a few sites, if any. A number of GMPEs exist. Some are general and based on strong motion data from different regions, whilst others are area-specific and then usually based on limited data.

One can say that in post-earthquake vulnerability assessment the damage is measured, i.e. based on observations, whilst the intensity is predicted. In analytical vulnerability assessment the