Vulnerability curves for low-rise shear wall buildings based on observed data

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SUMMARY:
In May 2008 a shallow Mw6.3 earthquake occurred in South Iceland with its epicentre close to two small towns in the area. The maximum PGA was registered as 0.88g. A great deal of damage occurred but fortunately there was no loss of life or serious injuries. After the earthquake, a field survey was carried out that covered every damaged structure in the affected area. The damage data was linked to the official Land Registry Database, which contains detailed information of all building in Iceland. The data was used to develop probabilistic vulnerability functions for five types of low-rise building classes, which cover the majority of all properties in the region. Four intensity levels were used in the analysis. The main findings were that these buildings have relatively good earthquake resistance. Furthermore, most of the damage was related to non-structural damage.

Keywords: Vulnerability functions, fragility curves, damage ratio, loss estimation, low-rise buildings..

1. INTRODUCTION

The seismicity in Iceland is related to the Mid-Atlantic plate boundary, which crosses the country. Within Iceland, the boundary shifts eastwards in the south and back westwards in the north through two complex fracture zones. The one in the south is called the South Iceland Seismic Zone (SISZ), whilst the other in the north, the Tjörnes Fracture Zone (TFZ). The largest earthquakes in the country have occurred within these zones, mostly associated with a strike-slip motion. In the SISZ, earthquakes tend to occur in sequences, which occur roughly every hundred years on the average, when accumulated strain energy is released (Einarsson 1991). Since 1700 AD, 16 earthquakes of magnitude greater than six (M_s) have occurred in the SISZ, and nine earthquakes in the TFZ. The maximum possible magnitude is estimated to be around 7 (M_w) for both zones; this upper bound is caused by relatively low rock strength and thin crust in the earthquake zones. In the year 2000, two earthquakes (17 and 21 June) of magnitude 6.5 (M_w) happened in South Iceland. The highest recorded PGA in these quakes was 0.84g at the Thjórsá bridge site (Bessason and Haflidason 2004). On 29th of May 2008, a magnitude 6.3 (M_w) earthquake shook the area again. The highest recorded PGA was 0.88g in a small town Hveragerdi close to the epicenter (Halldórsson and Sigbjörnsson 2009). These three events constitute an earthquake sequence, typical for the area. The last sequence, before the 2000 and 2008 earthquakes, occurred in 1896, when five earthquakes (M_s>6) struck in the area, starting in the eastern part of the SISZ and migrating towards west during a two week period. Around 1300 residential buildings collapsed in this sequence, mainly built of turf and stones (Thoroddsen 1899).

The SISZ covers the largest agricultural region in Iceland. The population is about 18,500 inhabitants (January 2008), and there are approximately 6000 residential houses, mostly low-rise buildings. In the 2000 and 2008 earthquakes, no residential buildings collapsed. However, a considerable number of houses were damaged. At least 40 houses were judged un-repairable after the June 2000 earthquakes and about 30 after the May 2008 quake.

Classical vulnerability functions, also called fragility curves in some references, show the probability of reaching or exceeding a specific damage stage on the vertical axis, and a ground motion intensity parameter on the horizontal axis (Colombi et al. 2008; Rosetto and Elnashai 2003; Rota et al. 2010). A number of damage scales exists (Hill and Rosetto 2008). In most cases they give a verbal description of the damage stage. For instance: none, slight, moderate, extensive, partial collapse and collapse etc. For loss estimation a relationship must be determined to convert the damage stage to a monetary loss. These relationships can be difficult to define. Furthermore, many ground intensity parameters have been used. Instrumentally recorded parameters like PGA and PGV, or response spectral ordinates for the characteristic vibration period of the building type in question, are most common today. When instrumental data is not available, attenuation models can be used to predict the site-specific earthquake intensity.

The main objective of the study presented here was to develop probability distribution functions (PDF) of damage for different ground motion intensity for the most common residential building types in South Iceland based on damage data from the 29 May 2008 Ölfus Earthquake. Such PDFs are suitable for earthquake loss estimation.

The presented PDFs are similar to the ones used in ATC-13 (Applied Technology Council 1985 and 2002), except that in this study the PDFs are based on field data but not expert judgement. The damage is expressed as the ratio of repair cost to the official replacement value of the building. They include the uncertainty or scatter of the monetary damage for a given earthquake intensity and building class, which can therefore be included in loss assessment. On the other hand the functions give no information about the actual physical damage or damage state. Additional data is, however, presented in the paper, which makes it possible to split the monetary damage into structural and non-structural loss.

2. DATA USED IN THE STUDY

2.1. Property database, observed damage and strong motion data

All properties in Iceland are registered with an Id-number in an official database (Icelandic Property Registry). It contains detailed information about the type of use, date of construction, number of stories, building material, and GPS-coordinates. In addition it contains results of valuation, both for taxation and reconstruction insurance value (replacement value).

Natural catastrophe insurance of buildings is mandatory in Iceland. Insurance cover is provided by a public company, Iceland Catastrophe Insurance. Therefore, in the wake of a natural disaster, all damage (if any) in every estate is recorded in order to enable compensation for the estimated repair or replacement cost. Nevertheless, it is up to the owner of each building to report damage, otherwise no registration takes place. In general everybody is well aware of the obligatory catastrophe insurance, so it is realistic to believe that all damage is duly recorded. The deductible for each property is also very low ($560), so that should not dissuade owners from reporting damage. Damage claims are estimated by two trained technicians. In order to make it possible to perform the vulnerability analysis, the data was classified into a number of subcategories and stored in an electronic database.

The Earthquake Engineering Research Institute of the University of Iceland operates a strong motion network in Iceland, which has been gradually expanded since its implementation in 1985 (Sigbjörnsson et al. 2004; Halldórsson et al. 2009). The South Iceland earthquakes of June 2000 and May 2008 added valuable data to the Icelandic strong motion database. It can be accessed through the European Strong motion database (ISESD), (Ambraseys et al. 2002). Most of the damage in the 2000 earthquakes was spread widely over the South Iceland lowland, whereas the damage of the 2008 earthquake was more concentrated in the two small towns Selfoss and Hveragerdi, closest to the epicenter (see Fig. 1). Strong motion data was obtained and is available from both these places.

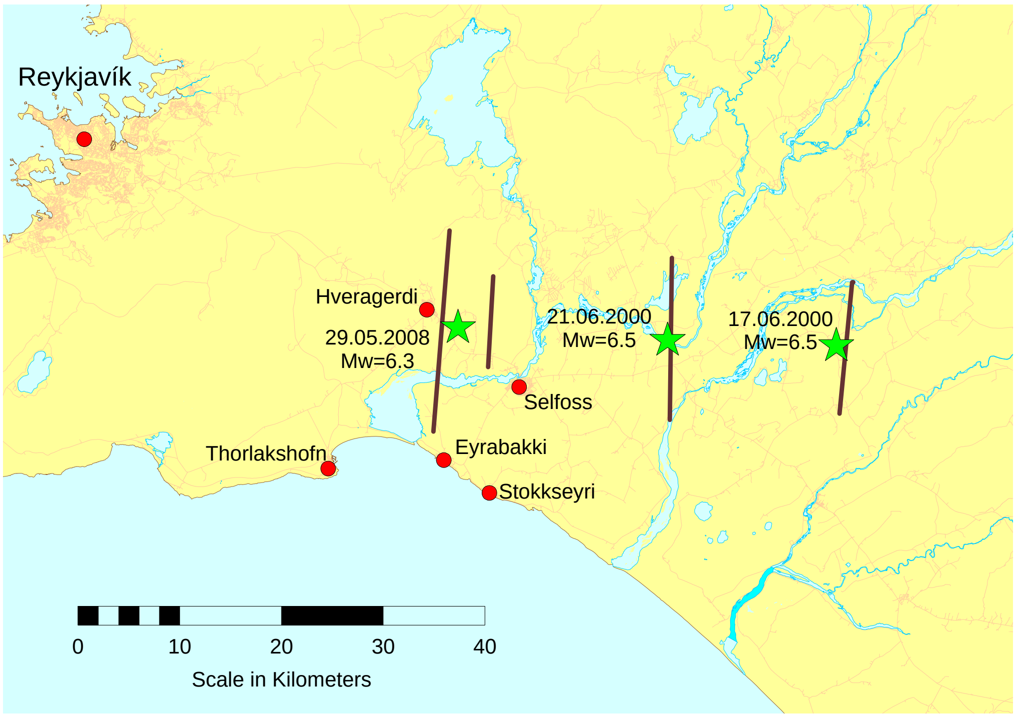

Figure 1. A map of the South Iceland lowland showing the two active faults of the 29 May 2008 earthquake and the macro-seismic epicentre between them (green star). The main centres of urbanization in the region are also shown with red dots. Further east the epicentres as well as active faults of the two South Iceland earthquakes of June 2000 are shown.

2.2. Earthquake intensity parameter

Many buildings in the region were damaged in the 29 May 2008 Ölfus earthquake. The observed and registered damage could only be directly related to recorded strong motion data, where damaged structures were located close to instrumented sites. To carry out a comprehensive analysis of the damaged structures, it was therefore necessary to assess ground motion intensity parameters at other sites by area-specific attenuation models. It was deemed important that the choice of parameter should reflect the earthquake response of the type of structures being studied. As the majority of buildings in South Iceland are stiff, low-rise buildings with a short natural period, a PGA-based parameter was considered to be preferable.

An attenuation model based on recorded PGA values from the Icelandic strong motion network (using both horizontal components at each station) was published in 1999 (Ólafsson 1999). After the two South Iceland Earthquakes in June 2000 and number of aftershocks, which provided a wealth of instrumental data, the model was recalibrated (Ólafsson and Sigbjörnsson 2002). It can be simplified and rewritten in a well-known form as:

$$\log_{10}(PGA) = -2.165 + 0.5 \cdot M_w - 1.5 \cdot \log_{10}(R) + 0.243 \cdot P \tag{2.1}$$

where PGA (g) is the peak ground acceleration, M_w is the moment magnitude of the earthquake, and R is the distance to the hypocenter (R<100 km), that is,

$$R = \sqrt{D^2 + h^2} \tag{2.2}$$

in which D (km) is the distance to the epicenter and h is the depth of the hypocentre (h=6.5 km). The last term in Eqn. 2.1 reflects error, where P is a standard normally distributed variable, i.e. $P \in N(0,1)$. The PGAs from both horizontal components are evenly distributed about the median curve (P=0). The attenuation model given by Eqn. 2.1 is considered to give reliable predictions for earthquakes in the magnitude range 5 to 6.5 and at epicentral distances up to 40 km. It can be added that the main characteristic of ground motion intensity in Icelandic earthquakes are high peak ground accelerations in the near-fault zone but more rapid attenuation with distances than found in common attenuation models (Ólafsson and Sigbjörnsson 2002).

PGA parameters can be defined in many ways; for instance: the largest horizontal component, the geometrical mean of both the two horizontal components, the arithmetic mean, or as some kind of effective PGA, and so on (Douglas 1993). In Bessason et al. (2012) different definitions of PGA are compared by using recorded data from the 2008 Ölfus earthquake at two strong motion stations, and it is then concluded that using the attenuation model given by Eqn. 2.1, with P=0, high frequency spikes are to some degree filtered out; one gets more averaged PGA value as is preferable. The conclusion was therefore to use Eqn. 2.1, with $P=0$, to estimate the intensity level at each site in the form of a median value of PGA for both horizontal components.

When creating the probability damage functions (PDFs) it was necessary to discretise the seismic action by using several intensity intervals. This can be carried out in several ways. Here, it was decided to increase the PGA values by approximately a factor of 2 (i.e. both lower and upper bound), when going from one intensity level to the next. The levels used are shown in Table 2.1 and correspond to the range of PGA values presented by Wald et al. (1999).

Table 2.1 Intensity level defined by the upper and lower bound of computed PGA values.

Intensity level	**1**	**2**	**3**	**4**
PGA – (g)	0.05 – 0.09	0.09 – 0.18	0.18 – 0.34	0.34 – 0.65

2.3. Building classes

When evaluating the damage after the 2008 Ölfus earthquake, all buildings in the South Iceland lowland where classified. For the low-rise residential buildings, two classes were chosen for concrete buildings, two for timber houses and one for pumice buildings. The age of the buildings was used as a practical means to differentiate between classes. In 1976 the first seismic building code was introduced in Iceland. It caused some changes in structural design. It was therefore decided to use the year 1980 to divide concrete and timber buildings in two classes. The pumice buildings are relatively few in number, compared to the concrete and timber houses, and as this type of structure is becoming less and less important over time, they were all grouped within one class. The classes were labeled: $concrete_{old}$, $concrete_{new}$, $timber_{old}$, $timber_{new}$, and *pumice.* Table 2.2 shows the main characteristic of each building class. More details of them can be found in (Bessason et al. 2012). In very few cases (less than 5%) the damage of buildings was related to soil failure under the foundations, mainly due to tilting caused by liquefaction or compaction due to the shaking. These cases are not included in the data sample.

Table 2.2 Building classes.

Building class	**Description**	**No of stories**
$\text{Concrete}_{\text{old}}$	Reinforced concrete – shear walls – built before 1980	1-2
$\text{Concrete}_{\text{new}}$	Reinforced concrete – shear walls – built after 1980	1-2
$\text{Timber}_{\text{old}}$	Timber – shear walls - built before 1980	1-2
$\text{Timber}_{\text{new}}$	Timber – shear walls - built after 1980	1-2
Pumice	Pumice – shear walls – mainly built before 1980	1-2

3. DAMAGE MODEL

As mentioned before the damage was classified into a number of subcategories, in order to make it possible to perform a damage analysis. Five subcategories were used for structural damage and five categories for non-structural damage. In this study the main focus is on the total damage defined as ratio of replacement value. However, supplementary information is given that can be used to split the data into structural and non-structural damage. Damage of electrical equipment, furniture and other loose objects is nevertheless not included.

In order to make the data accessible for different kinds of loss assessment, a damage model was created based on mathematical presentation in the form of damage functions. The functions show how the damage is distributed for specified building class and earthquake intensity. The field survey showed that number of houses suffered no damage, while other had some damage and for few buildings the damage was so severe, that it was not considered feasible to repair them. In such cases the damage was defined as total damage. It turned out that the best damage model was obtained by classifying the houses in three main classes, i.e. 1) undamaged, 2) damaged and 3) total damage. Table 3.1 shows how the buildings are divided in the five building classes, as well as how they are distributed according to the four intensity levels. Furthermore the table shows how buildings in each category are split into damaged and totally damaged buildings. A mathematical probability distribution function was then fitted to houses in the middle group, i.e. damaged houses. Different probability functions were tested. The lognormal distribution proved to fit the data satisfactorily.

Table 3.1 Number of houses (*N*), number of damaged houses (N_D) and number of totally damaged buildings (N_{TD}).

Building class	**Intensity level 1** 0,05 < PGA ≤ 0,09			**Intensity level 2** 0,09 < PGA ≤ 0,18			**Intensity level 3** 0,18 < PGA ≤ 0,34			**Intensity level 4** 0,34 < PGA ≤ 0,65			**Total**
	N	**N_D**	**N_{TD}**	**N**	**N_D**	**N_{TD}**	**N**	**N_D**	**N_{TD}**	**N**	**N_D**	**N_{Td}**	**N**
$\text{Concrete}_{\text{old}}$	106	3	0	362	80	0	617	487	1	252	200	3	**1337**
$\text{Concrete}_{\text{new}}$	26	1	0	165	17	0	327	196	0	260	193	0	**778**
$\text{Timber}_{\text{old}}$	45	4	0	250	61	0	211	149	1	203	114	3	**709**
$\text{Timber}_{\text{new}}$	160	22	0	282	42	0	876	447	0	245	147	3	**1563**
Pumice	39	3	0	102	36	3	144	110	5	74	48	4	**359**
Total	**376**	**33**	**0**	**1161**	**236**	**3**	**2175**	**1389**	**7**	**1034**	**702**	**13**	**4746**

Now define X as a random variable, representing the building damage ratio (total damage/ replacement cost). Three mutually exclusive events are possible during an earthquake:

$$\mathrm{E}_1 - \text{ No damage,} \quad X = 0: \qquad P\left[X = 0 \middle| E_1\right]_{ij} = 1 \tag{3.1}$$

$$\mathrm{E}_2 - \text{ Damage,} \quad 0 < \mathrm{X} < 1: \qquad P\left[X \le x \middle| E_2\right]_{ij} = F_{X,ij}(x, \alpha_{ij}, \beta_{ij}) \tag{3.2}$$

$$\mathrm{E}_3 - \text{ Total damage,} \quad X = 1: \qquad P\left[X = 1 \middle| E_3\right]_{ij} = 1 \tag{3.3}$$

Here the $F_{X,ij}$ is the lognormal cumulative probability distribution function for a given building class *i* and load intensity level *j*, and α_{ij} and β_{ij} are the distribution parameters. The probability of each event (E_1, E_2 and E_3) can easily be found by determining the number of houses with no damage, damaged buildings and total loss cases. These are denoted respectively as:

$$P(E_1)_{ij} = P[X = 0]_{ij} = P_{0,ij} \tag{3.4}$$

$$P(E_2)_{ij} = P[0 < X < 1]_{ij} = P_{D,ij} \tag{3.5}$$

$$P(E_3)_{ij} = P[X = 1]_{ij} = P_{1,ij} \tag{3.6}$$

It should be noted that since E_1, E_2 and E_3 are the only possible events, then

$$P(E_1)_{ij} + P(E_2)_{ij} + P(E_3)_{ij} = P_{0,ij} + P_{D,ij} + P_{1,ij} = 1.0 \tag{3.7}$$

Now the total probability theorem can be used to compute the probability of damage (x<1):

$$
\begin{aligned}
P[X \le x]_{ij} &= P[X \le x | E_1]_{ij} \cdot P(E_1)_{ij} + P[X \le x | E_2]_{ij} \cdot P(E_2)_{ij} + P[X \le x | E_3]_{ij} \cdot P(E_3)_{ij} \\
&= 1 \cdot P_{0,ij} + F_{X,ij}(x, \alpha_{ij}, \beta_{ij}) \cdot P_{D,ij} + 0 \cdot P_{1,ij} \\
&= P_{0,ij} + F_{X,ij}(x, \alpha_{ij}, \beta_{ij}) \cdot P_{D,ij}
\end{aligned}
\tag{3.8}
$$

The maximum likelihood method was used to compute the two parameters in the lognormal probability distribution function, $\alpha_{x,ij}$ and $\beta_{x,ij}$. From these two parameters the mean, μ, and the variance, v, of a lognormal variable can be computed as:

$$
\mu_{x,ij} = \exp\left(\alpha_{x,ij} + \frac{\beta_{x,ij}}{2} \right) \tag{3.9}
$$

$$
v_{x,ij} = \exp\left(2\alpha_{x,ij} + \beta_{x,ij}^2 \right) \cdot \left(\exp(\beta_{x,ij}^2) - 1 \right) \tag{3.10}
$$

As before the indices i and j refer to the building class and the load intensity levels respectively. In Table 3.2 the probability distribution parameters for the damage model are shown. In Fig. 2 the goodness of the fit of the damage data for concrete houses is compared to the lognormal probability function for intensity levels 3 and 4 on a special "lognormal paper" (if the data fits the straight line it is lognormally distributed). As seen the fit is fairly good for these two data sets.

Table 3.2 Parameters in the damage model

Building class	Intensity level 1[1] 0,05 < PGA ≤ 0,09				Intensity level 2 0,09 < PGA ≤ 0,18				Intensity level 3 0,18 < PGA ≤ 0,34				Intensity level 4 0,34 < PGA ≤ 0,65			
	P_0	P_1	α	β	P_0	P_1	α	β	P_0	P_1	α	β	P_0	P_1	α	β
$\text{Concrete}_{\text{old}}$	0.972	0.000	-	-	0.779	0.000	-3.43	0.865	0.209	0.002	-2.98	0.693	0.194	0.008	-3.03	0.807
$\text{Concrete}_{\text{new}}$	1.000	0.000	-	-	0.897	0.000	-4.05	0.968	0.401	0.000	-3.61	0.740	0.258	0.000	-3.47	0.725
$\text{Timber}_{\text{old}}$	0.911	0.000	-	-	0.756	0.000	-3.08	0.916	0.289	0.005	-3.15	0.837	0.424	0.015	-3.17	0.804
$\text{Timber}_{\text{new}}$	0.863	0.000	-4.06	0.508	0.851	0.000	-3.68	0.681	0.490	0.000	-3.60	0.755	0.388	0.012	-3.47	0.826
Pumice	0.923	0.000	-	-	0.618	0.020	-3.05	0.787	0.201	0.035	-2.88	0.956	0.297	0.054	-2.93	0.869

1) When number of buildings in given category is less than 9, no parameters are evaluated.

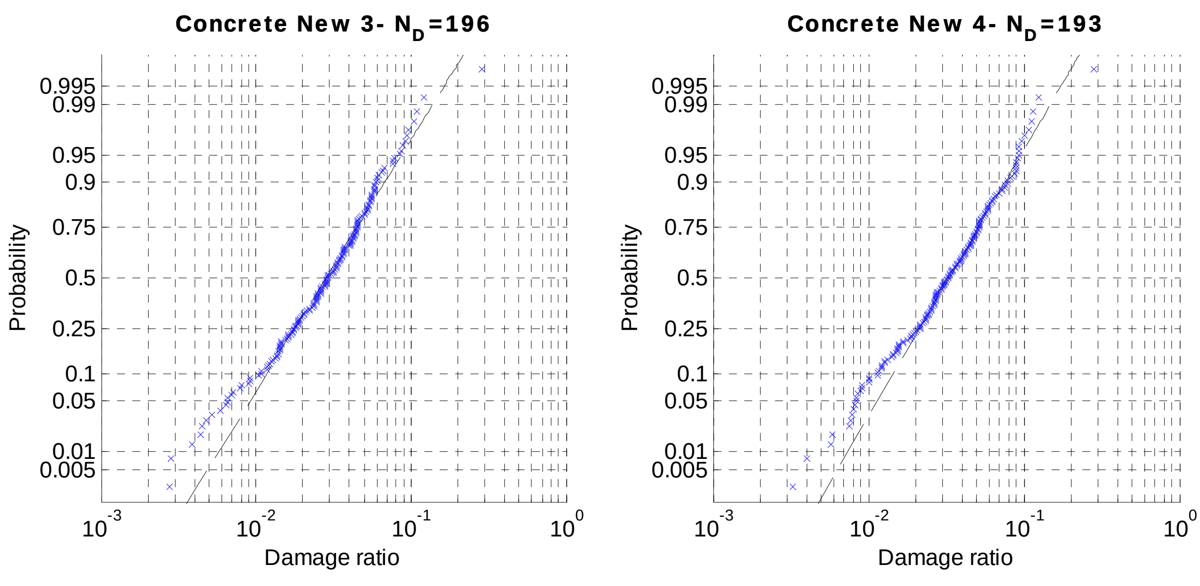

Figure 2. Goodness-of-fit of the damage data for the $\text{concrete}_{\text{new}}$ buildings to the lognormal probability function for: a) intensity levels 3, and b) intensity level 4 (N_D denotes number of damaged buildings in each case).

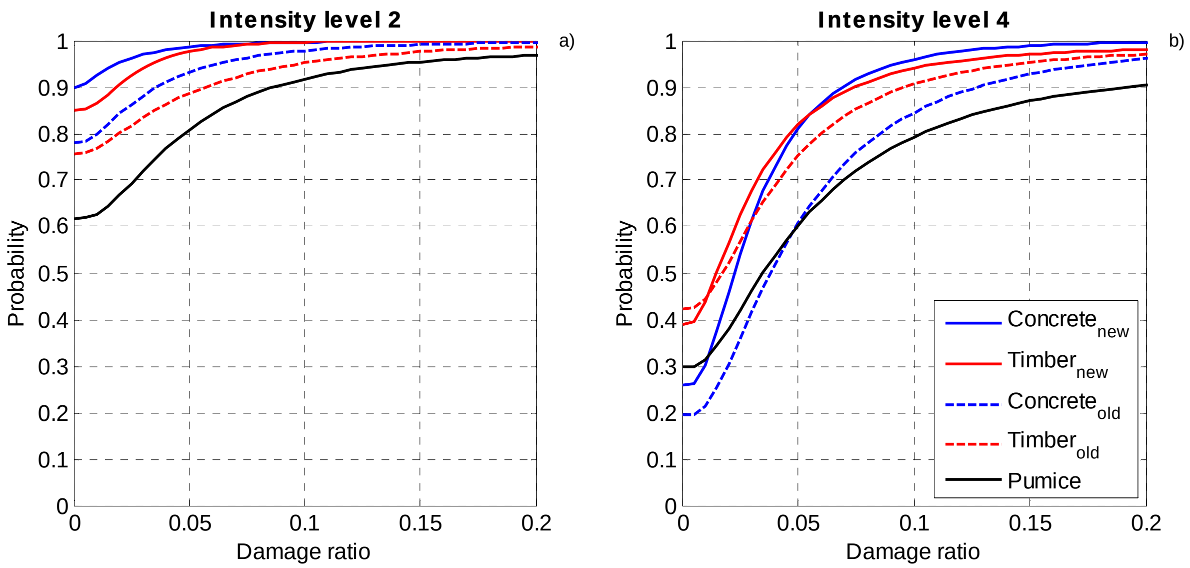

Figure 3. Comparison of probability functions for damage ratios of the building classes for intensity levels 3 & 4.

Similar fit was obtained for the other data sets (Bessason et al. 2012). An Anderson-Darling goodness-of-fit test (Anderson and Darling 1952) was carried out to see if the damage data was lognormally distributed at 5% and 1% significance level. It was found that 7 of the 16 data sets passed the test at 5% level, and 10 of the 16 data sets passed it at 1% level. In Fig. 3 the probabilistic damage curves are compared for all five building classes for intensity level 2 and 4. As seen, the timber$_{new}$ and concrete$_{new}$ houses experience significantly less damage than timber$_{old}$ and concrete$_{old}$ houses. Also, the damage curves for the pumice houses show significantly higher damage than the other building classes.

From the damage model it is possible to estimate the mean and standard deviation for all categories:

$$E[X]_{ij} = \int_{-\infty}^{\infty} x \cdot p_{X,ij}(x)dx = P_{0,ij} \cdot 0 + P_{D,ij}\mu_{x,ij} + P_{1,ij} \cdot 1 \tag{3.11}$$

$$\begin{aligned} Var[X]_{ij} &= \int_{-\infty}^{\infty} (x-\mu_{x.ij})^2 \cdot p_{X,ij}(x)dx = \\ &= P_{0,ij} \cdot (0-\mu_{x,ij})^2 + P_{D,ij}\int_{0}^{\infty}(x-\mu_{x,ij})^2 \cdot f_{X,ij}(x)dx + P_{1,ij}(1-\mu_{x,ij})^2 = \\ &= P_{0,ij} \cdot \mu_{x,ij}{}^2 + P_{D,ij} \cdot v_{x,ij} + P_{1,ij}(1-\mu_{x,ij})^2 \end{aligned} \tag{3.12}$$

where $p_{X,ij}$ is the probability density function (PDF) for building class i and intensity level j for all the data samples, while $f_{X,ij}$ is the lognormal PDF for damaged buildings solely. The parameters $\mu_{x,ij}$ and $v_{x,ij}$ are determined by Eqns. 3.9 and 3.10. Other parameters are shown in Table 3.2. Finally, Eqn. 3.8 can be used to determinate 90% confidence level for loss, which corresponds to P(X<x)=0.9. The mean value, standard deviation and 90% confidence level for different cases are shown in Table 3.3. In Figure 4 the mean value and the 90% confidence level is plotted for intensity classes 2 to 4 for all the building classes. From the figure or the table, it can be seen that there is more than 90% probability of getting less than 10% damage for new concrete and new timber buildings at intensity level 4.

It is also informative to see how the damage is split between structural and non-structural elements. Here structural elements are defined as: foundations, walls, beams, columns, roof structure etc., while non-structural damage covers the damage of partitions walls, floor and wall tiles, flooring and cladding and damage of fixtures. The division is shown in Table 3.4 and plotted in Figure 5.

Tafla 3.3 Mean damage, standard deviation and 90% confidence level, $p_{90\%}$ for loss.

Building class	Intensity level 1 0,05 < PGA ≤ 0,09			Intensity level 2 0,09 < PGA ≤ 0,18			Intensity level 3 0,18 < PGA ≤ 0,34			Intensity level 4 0,34 < PGA ≤ 0,65		
	Mean (%)	Stdv. (%)	$p_{90\%}$ (%)	Mean (%)	Stdv. (%)	$p_{90\%}$ (%)	Mean (%)	Stdv. (%)	$p_{90\%}$ (%)	Mean (%)	Stdv. (%)	$p_{90\%}$ (%)
Concrere_{old}	0.11	-	-	1.04	4.75	3.58	5.28	6.59	11.3	6.49	12.0	12.9
Conrete_{new}	0.00	-	-	0.29	2.87	0.28	2.14	3.27	5.56	3.01	3.56	6.94
Timber_{old}	0.32	-	-	1.69	7.22	5.64	4.78	8.90	10.8	4.75	12.8	9.64
Timber_{new}	0.26	1.86	1.27	0.47	3.08	1.86	1.86	3.43	5.24	3.85	11.4	7.43
Pumice	0.28	-	-	5.22	17.2	9.20	10.23	19.8	20.7	10.5	22.9	19.2

1) When number of buildings in given category is less than 9, no parameters are evaluated.

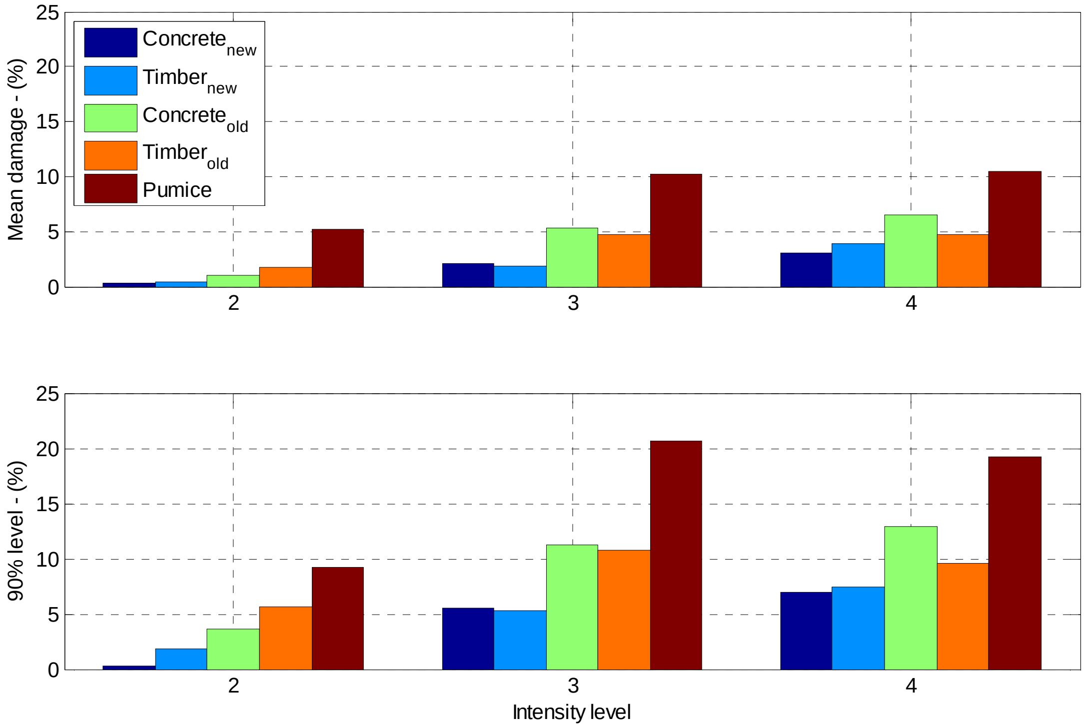

Figure 4. Mean damage and 90% confidence level damage for different building classes and intensity classes.

It is clear that damage of structural elements is only a small part of the total damage. For instance for new concrete buildings, less than 10% of the total damage was related to structural damage at all intensity levels. If information for new concrete buildings in Table 3.3 and 3.4 is combined for intensity level 4, the result is that 90% of these buildings will expect damage that is less than 1% of the replacement value.

Table 3.4 Ratio of structural damage to total damage.

Building class	Intensity level 1 0,05 < PGA ≤ 0,09 (%)	Intensity level 2 0,09 < PGA ≤ 0,18 (%)	Intensity level 3 0,09 < PGA ≤ 0,18 (%)	Intensity level 4 0,09 < PGA ≤ 0,18 (%)
Concrete_{old}		20,8	14,5	26,1
Concrete_{new}		2,03	11,4	9,0
Timber_{old}	27,3	42,9	29,6	25,3
Timber_{new}	0	7,16	11,4	19,1
Pumice	1,46	41,4	38,5	33,7

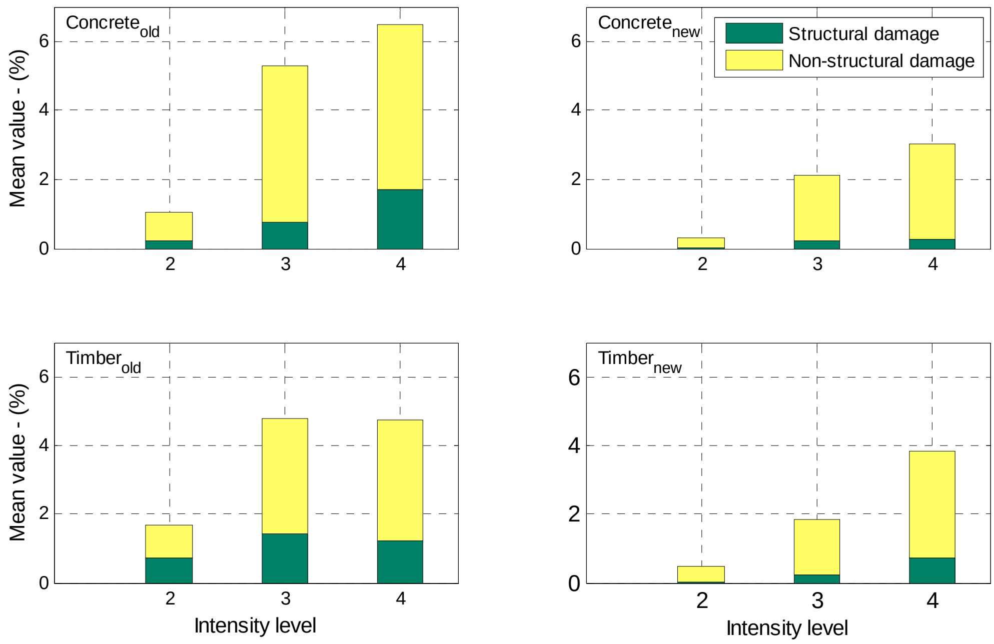

Figure 5. Division between structural and non-structural damage.

4. SUMMARY AND CONCLUSIONS

New probabilistic damage functions for low rise buildings based on reported data after the South Iceland 29 May 2008 Earthquake (M_w=6.3) are presented. The damage is defined as the ratio of repair cost to the replacement cost. The functions have been developed for loss estimation and vulnerability analysis related to catastrophic insurance issues. The functions describe damage for different seismic intensity and five residential building classes, i.e. old and new low-rise shear wall concrete buildings, old and new timber buildings and special Icelandic pumice buildings. The main structural form in all cases is shear walls. The split between old and new buildings is the year 1980. Four parameters are used to define each damage function. That is, one parameter defines the ratio of no damage, two are parameters of the lognormal probability distribution used to describe the scatter of damaged buildings, and finally one to present the portion of buildings that were classified as totally damaged.

The damage data used to evaluate the vulnerability functions is very comprehensive. There are two main reasons for this. First, a detailed official property database exists. Secondly, during damage evaluation after the 28 May 2008 earthquake, the Icelandic Catastrophe Insurance made a special effort to classify damage in every building in predefined subcategories and register the results in an electronic database. The data covers 4746 buildings in South Iceland in the epicentre area. Half of the houses were damaged (2382), and it was estimated that it would be feasible to repair them, while less than half percentage of the buildings (21) were considered “un-repairable” and got the tag “total damage”. None of damaged buildings collapsed, and there were no deaths nor serious injuries.

Four intensity levels were used to relate observed damage to seismic intensity. The levels were defined by lower and upper limits of peak ground acceleration. An area-dependent attenuation model was used to estimate the median peak ground acceleration at each site. The model is based on recorded strong motion data from Iceland where both the horizontal acceleration components are used.

The thus evaluated damage functions show that there is a small difference between new concrete and new timber houses. These two building classes seem to have a fair earthquake resistant capability. For instance the probability is more than 90% that a building belonging to either of these classes will suffer damage that is less than 10% of replacement value at the highest intensity level. If only structural damage is considered, it is below 1.5% for both the building types. The reason is that structural damage is only a small portion of the total damage, i.e. 9% for new concrete buildings and 19% for new timber houses at intensity level 4. The damage functions also show that significantly less damage is expected for new buildings compared to the old buildings.

Building traditions in all regions in Iceland are similar. Therefore, it may be relevant to use the damage curves presented in all regions in the country. The curves may also be of value in considering potential losses from seismic ground shaking for similar buildings in other countries. However building traditions vary considerably between countries and local information must be taken into account before they are applied.

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