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Prevention and preparedness projects in civil protection and marine pollution. Prevention Priorities

KnowRISK

Know your city, Reduce seISmic risK through non-structural elements

Prevention and preparedness projects in civil protection and marine pollution. Prevention Priorities

Deliverable Report

Deliverable C2 – Identification of the most vulnerable non-structural components in the pilot study area (Iceland case)

Task C – Non-structural seismic risk reduction

Deliverable/Task Leader: EERC

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Preface

This report is a deliverable for the C2 task within the EU Project KnowRISK, **Know** your city reduce your seismic **risk** through non-structural elements. Task C2 focuses on identifying the most vulnerable non-structural components in the Icelandic pilot study area.

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1 Introduction

This report is a deliverable for the C2 task within the EU Project KnowRisk, **Know** your city reduce your seismic **Risk** through non-structural elements.

The objective of task C2 was to identify the *most vulnerable* Non-Structural Components (NSC) in three study areas, i.e. one in Italy, one in Portugal and one in Iceland by analysing damage pattern in recent earthquakes. Physical vulnerability to earthquake damage is the relationship between ground motion intensity and damage, i.e., how damage changes with increasing ground motion intensity. Other factors can affect damage, for examples floor motions can be considerable different from ground motion. Elements that are considered *most vulnerable* are either those that are *most fragile* for a given motion (most likely to be damaged) or elements that are more likely to experience a higher level of shaking due to their location.

In this study the NSC of a building include all those components that are not part of the structural system. More specifically they include architectural, mechanical electrical and plumbing systems, as well as fixtures, equipment, and contents. Examples of NSC are furniture windows, partitions, piping, ceilings, air conditioning ducts, elevators, computer, hospital equipment, file cabinets, and retail merchandise.

In some references the NSC is grouped into two parts, i.e. objects fixed to the structure and "content" which can be moved at the owners or users discretion. In some cases the term non-structural refers only the fixed objects, as in as study by Taghavi and Miranda (2003) who compare cost distribution between structural, non-structural, and building content within offices, hotels, and hospitals (Fig. 1-1). In all cases the sum of non-structural and content is more than 80% of the total cost. In hospitals the proportion of content is highest (44%) but less than 20% in office and hotels. Apartment buildings are believed to be more like offices and hotels rather than hospitals. The proportions for apartment buildings are estimated to be 20%-60%-20% when referring to cost of structural, non-structural and content, respectively. The height of a building also affects cost distribution, for instance the cost of elevators and escalators may be as high as 5% of the total cost in tall buildings (Taghavi & Miranda 2003).

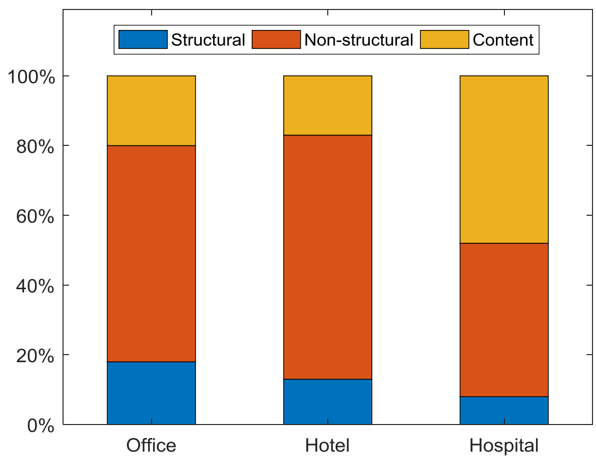

Figure 1-1. Typical breakdown of cost within three types of buildings (Taghavi & Miranda, 2003)

This report focuses on the study area in Iceland and is based on observed damage in two destructive earthquakes in June 2000, 17^{th} and 21^{st}, both of Mw6.5, and one in May 2008, of Mw6.3 which all took place in the South Iceland. Two different datasets from these events exist and were used in this study. Both contain damage data for low-rise residential buildings, which dominate the building stock in the area.

The first dataset is based on insurance claims and covers both structural and non-structural losses of residential buildings from the June 2000 and May 2008 earthquakes. However, the data does not include losses of household content like furniture, bookcases, electronics (TVs, computers, toasters etc.) and other loose items. This dataset is called the "**Insurance loss data set**" in this report. The dataset has to some extend been analysed and modelled where the total damage, i.e. both structural and non-structural damage, has been the main focus (Bessason et al. 2012; 2014; 2016).

The second dataset was collected by the Earthquake Engineering Research Centre (EERC) via site visits and telephone interviews in the wake of the 2000 and 2008 earthquakes. It consists of photographs and completed questionnaires in paper form. In this study the main focus was on using the photos to map the damage of loose household content and vulnerability of different rooms within buildings. This dataset is called the "**EERC data set**".

Chapter 2 outlines the background data, which includes information about seismicity and the study area, information about the building stock, ground motion prediction model (GMPE) as well as discussion of damage states and disruption states. Then Chapter 3 provides information and results based on the Insurance loss data set and Chapter 4 provides information and results based on the EERC data set. Chapter 5 presents a discussion and the report ends with concluding remarks in Chapter 6. In addition to this document, the Task C2 report also includes an Excel file: EERC–C2–analysis_2017.xlsx

2 Background data and damage states

2.1 Seismicity and study area

The seismicity in Iceland is related to the Mid-Atlantic Plate boundary that crosses the country. Within the country, the boundary shifts eastward in the south and back toward the west in North Iceland through two complex fracture zones. The southern zone, called the South Iceland Seismic Zone (SISZ), is located in the South Iceland lowland, while the other, the Tjörnes Fracture Zone (TFZ), lies mostly off the northern coast of Iceland (Einarsson, 1991). The largest earthquakes in the country have occurred within these two zones (Fig 2-1).

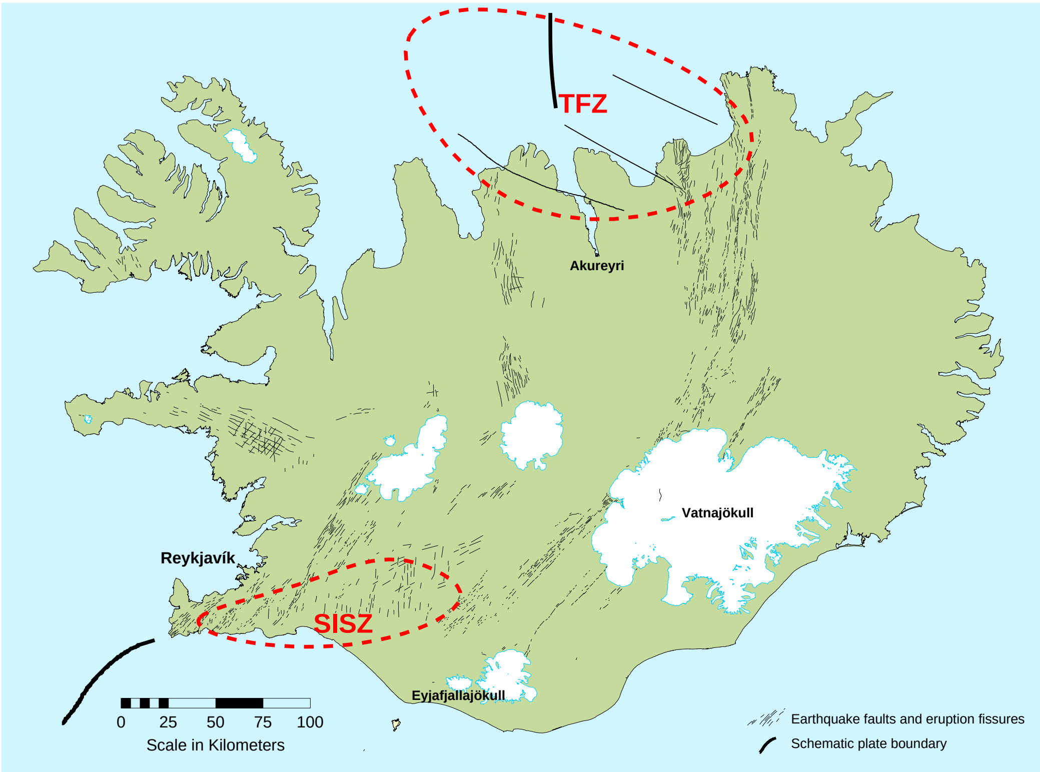

Figure 2-1. The South Iceland Seismic Zone (SISZ) and the Tjörnes Fracture Zone (TFZ).

The study area is located in the South Iceland Lowland which is the largest agricultural region in Iceland. It is surrounded by mountain and highlands in west, north and east (Fig. 2-2). In the region there are number of farms, small towns and villages, schools, medical centres, industrial plants, and in fact all infrastructure that characterise a modern society. The population is about 18,500 inhabitants (as of January 2008) and there are approximately 6,000 residential houses. The South Iceland Seismic Zone (SISZ) crosses the region and since 1700 there have been 16 earthquakes of magnitude six or larger in the area (Halldórsson et al. 2013). The largest one of these was of magnitude 7.0 in 1912.

2.2 The south Iceland earthquakes of June 2000 and May 2008

In June 2000 two earthquakes of Mw6.5 struck in the SISZ (Fig. 2-2). The first struck on June 17, 2000, 15:41, (GMT) in the eastern part of the area (Eq1). It was a right-lateral strike-slip quake, with fault striking in the north-south direction and had a focal depth of 6.3 km. The second earthquake, also M_w6.5 struck on June 21, 2000, at 00:52, (GMT) further west (Eq2). It was also a right-lateral strike-slip earthquake, with the fault striking in the north-south direction and with a focal depth of 5.3 km. The highest recorded PGA in these two events was 0.84g (Thorarinsson et al. 2002).

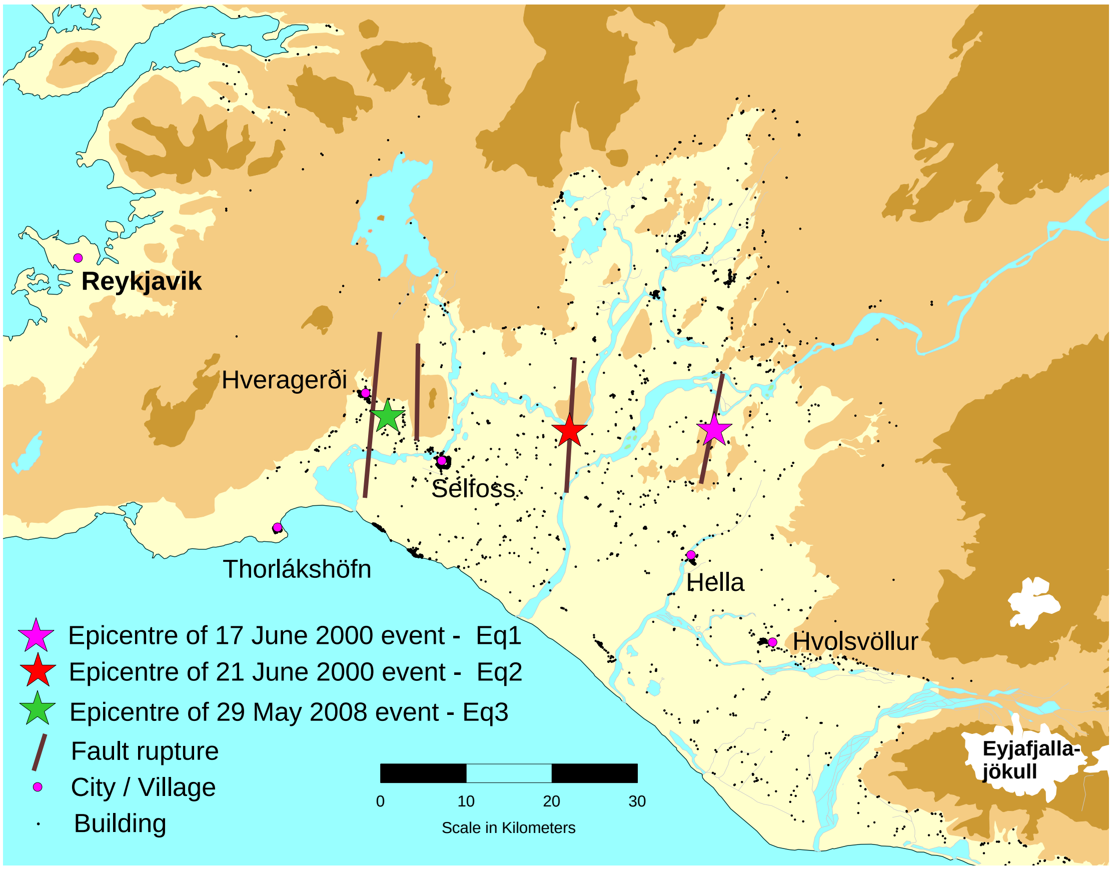

Figure 2-2. The South Iceland Lowland as well as epicentre and fault rupture of the of the two June 2000 and May 2008 earthquake.

In May 2008 the third earthquake in this century struck the area (Eq3). It consisted of two events on separated faults. The first was initiated on the eastern fault west of the town Selfoss, and that earthquake triggered a second event on the western fault, about one second later (Fig. 2-1). The magnitude of the combined event has been estimated as Mw6.3. In Hveragerdi the PGA of the largest component was recorded as 0.66g and in Selfoss as 0.54g in the Icelandic Strong Motion Network (Halldórsson & Sigbjörnsson, 2009; Sigbjörnsson et al. 2009)

2.3 Building stock

All buildings in Iceland are registered in an official inventory called Icelandic Property Registry (2017). It contains information of building year, main construction material, number of storeys, geographical coordinates. It also contains results of valuation, both for taxation and reconstruction insurance value (replacement value), use of building, etc. From the inventory it can be seen that the vast majority of residential buildings in the study area are made of reinforce concrete (RC), timber or masonry (Fig. 2-3). Furthermore, most of them are low-rise single-family buildings, but there are also two-family duplexes, town houses and apartment buildings (blocks).

No buildings are higher than five storeys (Fig. 2-4). Walls are used to resist lateral seismic forces for all the three typologies. Frame buildings or walls with infill hardly exist. Most of the RC buildings are in-situ cast although few pre-fabricated buildings exist. Prescribed wind loads are very high in Iceland, among the highest in Europe. The *fundamental value of base wind* according to the Eurocodes and the Icelandic. National Annexes is $v_{b,0}$=36 m/s (CEN 2005, IST 2010) and is the same for the whole country. Based on old tradition and craftsmanship, the Icelandic timber houses, especially the newer ones, are therefore strongly built and well suited to withstand earthquake forces. The bottom floor slab and the foundations are usually reinforced concrete, as in the concrete houses. The masonry buildings were built of unreinforced manufactured hollow pumice blocks in walls and tied together with rigid RC floors. The masonry buildings were mainly built before 1980 and are outgoing in the building stock.

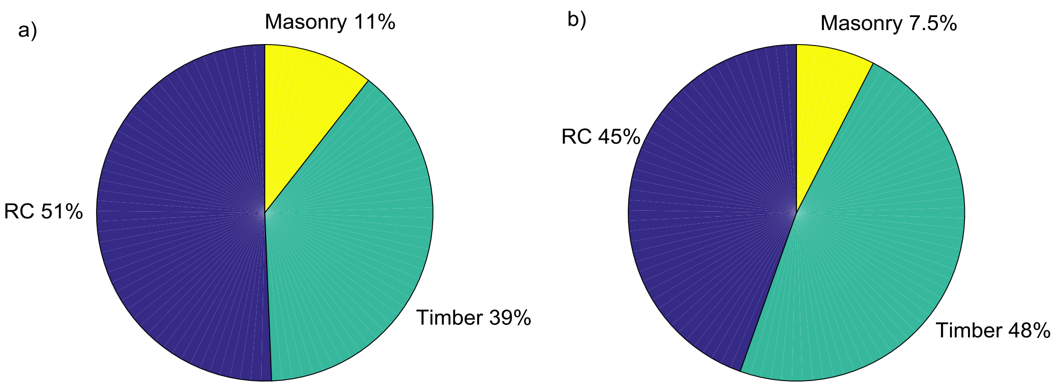

Figure 2-3. Distribution of low-rise residential building types in South Iceland Lowland prior to the South Iceland earthquakes a) in June 2000 and b) in May 2008.

Furthermore, the building stock is relatively young compared to construction age of buildings in Southern Europe. No buildings are built before 1870 and most of them are built after 1940 (Fig. 2-4). The main reason for this is that before say 1900 turf and stone buildings where quite common and the durability of such buildings is limited. In addition, there was an earthquake sequence in the SISZ in 1896 consisting of five earthquakes greater than six in two weeks which hit badly the existing turf and stone buildings in the area as well as other building typologies. Another destructive earthquake hit in 1912 (M_L=7.0) which also destroyed number of old buildings. Severe damaged turf buildings were in most cases not rebuilt after these events.

Figure 2-4. Storey distribution of low-rise residential building in South Iceland Lowland.

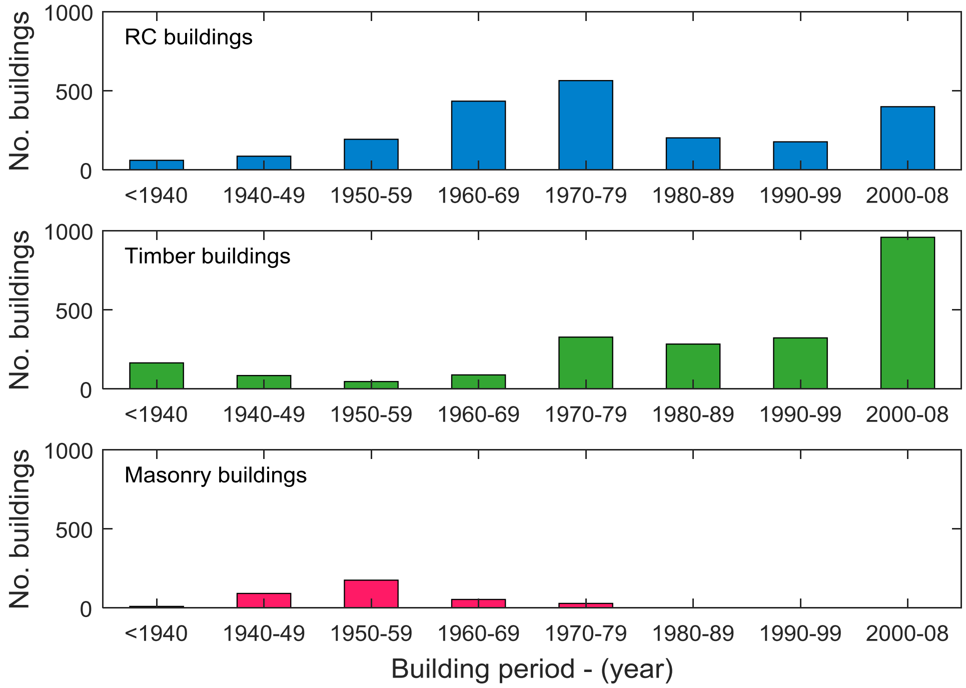

Figure 2-5. Construction year distribution of residential buildings in the South Iceland Lowland.

2.4 Ground Motion Prediction Model

When working with the two data sets it is necessary to have a ground motion intensity measure that can be correlated with the observed damage. In the analytical vulnerability literature, most recent studies consider spectral acceleration or spectral displacement at representative structural periods to be the most effective intensity measures for vulnerability assessment as well as inter-storey drift ratios. It is also known that damage of structural elements and non-structural components depends on combination of high amplitude action effect and repeated reversals of significant ground motion and floor motion amplitudes (see for instance Park & Ang, 1984). High frequency peak values of accelerations and short period spectral acceleration can be observed in low magnitude earthquakes but duration of significant intensive ground motion is more correlated to magnitude.

No site-specific ground motion prediction equations (GMPE) are yet available to predict duration of significant ground motion intensity in the SISZ. On the other hand, few GMPE models exist for PGA and spectral ordinates which are based on Icelandic strong motion data. In current study the affected buildings are low-rise, stiff and with low natural periods and therefore the ground motion intensity was expressed in terms of the PGA which is representative for the short period part of a response spectrum. Two different GPME for PGS have been used in recent studies of the Icelandic loss data. In analysis of loss data from the May 2008 earthquake presented in Bessason et al. (2012) and (2014) a simplified version of GPME developed by Ólafsson and Sigbjörnsson was used (Ólafsson, 1999; Ólafsson & Sigbjörnsson, 2002). The formula is valid for rock sites and is based on using epicentral distance. In a recent vulnerability analysis of the loss data from the June 2000 earthquakes (Bessason & Bjarnason, 2016) a GMPE of Rupakhety and Sigbjörnsson (2009) was adopted. This model will here be used for the EERC data set as well when intensity estimates are required. It is given as:

$$\log_{10}(PGA) = -1.038 + 0.387 \cdot \mathrm{M_w} - 1.159 \cdot \log_{10}\left(\sqrt{\mathrm{H}^2 + 2.6^2}\right) + 0.123 \cdot S + \varepsilon \cdot 0.287 \quad (1)$$

where H is the distance to surface trace of the fault in km, S is a site factor which takes the value 0 for rock sites and 1 for stiff soil sites. The last term is an error/scatter term where ε follows a standard normal distribution, i.e. $\varepsilon \sim \mathrm{N}(0,1)$. The unit of PGA is in m/s^2. Following common practice, the PGA level at a given site was estimated as the median *PGA* from Eq.(1) ignoring the error term. Geological map of South Iceland, was used to determine the soil conditions at each building site (Jóhannesson et al., 1992). The adopted GMPE is based on using both the horizontal peak components from each station. Most of the strong motion recordings used in constructing Eq.(1) were from Icelandic earthquakes but the data was augmented by records from continental Europe and the Middle East. The main characteristic of GMPE given by Eq.(1) is that it predicts a relatively high PGA in the near fault area whilst the attenuation with distance is more than generally found in well-known GMPE of similar form. This higher attenuation with distance in Iceland compared to other seismic regions has been explained by the existence of young, fissured and low quality rock in the seismic source area that damp the propagating seismic waves faster than in more solid rock (Sigbjörnsson et al. 2009; Ólafsson 2013).

2.5 Damage and disruption descriptions

Damage is often characterized by two factors, the Damage Ratio (DR), which is the ratio of the number of buildings damage to the total number of buildings, and Damage Factor (DF), expressed in Eq.(2).

$$DF = \frac{\text{Estimated loss}}{\text{Replacement value}} \quad (2)$$

A damage state (DS) is also a characterization of damage. A set of damage states is used to describe all levels of damage from none to complete. The number of damage states used to cover all damage varies. Damage states are usually characterized by a name, a range of DFs, and a short damage description. For example, ATC (1985) uses seven damage states to describe possible damages to building (see Table 2-1). The Damage Factor ranges for the ATC Damage States vary from 1% in DS Slight (0-1%) up to 40% in DS Major (60-100%). Damage States are therefore not necessarily of equal size.

Table 2-1. Damage states defined in ATC (1985)

Name of DS	DF Range	Damage Description
None	0	No damage
Slight	0-1	Limited localized minor damage not requiring repair
Light	1-10	Significant localized damage of some components generally not requiring repair
Moderate	10-30	Significant localized damage of many components warranting repair
Heavy	30-60	Extensive damage requiring major repairs
Major	60-100	Major widespread damage; facility demolished or repaired
Destroyed	100	Total destruction of the majority of the facility.

The number of DSs, the DF range, and the damage descriptions used may vary from study to study depending on issues such as the scope of the study or the data size used for the analysis. Examples of other formats include a descriptive damage index using four DSs, *none*, *slight*, *significant*, and *collapse* by Colombi et al. (2008), and seven DSs, like ATC but with refined names, *none*, *slight*, *light*, *moderate*, *extensive*, *partial collapse* and *collapse* by Rossetto and Elnashai (2003). Each format will provide their own Damage State DF range and description. For instance, Rossetto and Elnashai (2003) associate "slight" with "fine cracks in plaster partitions /infills", whereas Dolce et al. (2006) associate the damage state "*slight damage*" with DF in the range 0–5%, and "*moderate damage"* is associated to the DF in the range 5–20%.

Usually damage states refer to structural components and fixed non-structural components but exclude household content. However, as the importance of NSC to the operations of a facility or the loss to the stakeholder has become more apparent, researchers are beginning to develop damage states for content. The notion of disruption is important to this context looking at broader consequence than only physical damages. For example, Pujols and Ryan (2016) used motion (sliding, rocking, toppling, and falling) of different types of items to define five states of disruption for content (see Table 2-2 and Fig. 2-6). Rocking is different from the other categories of motion since it can only be detected during the earthquake. By the time damage and disruption is assessed, either the object is back to where it was, has slid, toppled or fallen.

Table 2-2. Distribution rating criteria (Pujols & Ryan, 2016).

Distribution Rating	Evaluation Criteria
No Disruption	• Generally, no items fall off from storage carts, bookcases, or desks. • Isolated instances of light items falling may be observed, but falling is inconsequential • Loosely packed books in bookcases may topple. • Gentle, non-disruptive movement of items on wheels occur • No rocking of items is observed
Minimal Disruption	• Light items topple • Minimum falling or isolated instances of falling among lighter items may be observed (falling is inconsequential) • Items or wheels roll with gentle non-disruptive movement (up to 30 cm) • Small bookcases rock gently (no overturning). • Rocking of items (e.g. monitors, bookcases, CPUs) is minimal or absent.

	• Copier door may open
Mild Disruption	• Desk chairs roll back and forth mildly (up to 30 cm) • Light items topple • CPUs and/or monitors rock without falling. Monitors may topple on desk • Some light to medium items fall (e.g. books, binders, kitchen items) • Bookcases rock (no overturning). Copier/bed rock mildly • Desk slides moderately (up to 30 cm). • Items on wheels move with higher amplitudes, higher frequency that could result in damage during collisions
Moderate – Large Disruption	• Heavier items rock. CPUs and/or monitors on desks may topple or fall. Speakers on desk fall. • Items on wheels roll with greater overall movement. • Up to ½ items on bookcases and up to ¼ items on storage carts fall off. • Bookcases rock (overturning may occur). • Desk slides up to 30-60 cm • Floor lamp may overturn • Copier stands on support for extended periods of time
Extensive Disruption	• Items slide with higher amplitude • More than ½ items on bookcases and more than ¼ items on storage carts fall off • CPUs and/or monitors fall from desk • Bookcases overturn. Floor lamp overturns • Heavier items rock (e.g. bed rocks up on its wheels); bedside cart or desk chairs exit the room or topple. • Heavier boxes on hospital room table my fall.

(a) (b) (c) (d)

Figure 4-2. Four variations of distribution states examples: (a) Minimal disruption, (b) Mild disruption, (c) Moderate-Large disruption, and (d) Extensive disruption (Pujols & Ryan, 2016).

3 Insurance loss data set

3.1 Compulsory catastrophe insurance and loss data

Fire insurance of buildings is mandatory in Iceland. The fire insurance valuation of all buildings is assessed by the Iceland Property Registry. The fire valuation is based on replacement cost, less the depreciation of building materials, age, and upkeep. The valuation for fire insurance also provides the basis for compulsory catastrophe insurance against earthquakes, volcanic eruptions, floods, and landslides, which is managed by a public company, Iceland Catastrophe Insurance (2017). Therefore, in the wake of a natural disaster, all damage (if any) in every estate is collected and 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 (US$560), so that should not dissuade owners from reporting damage.

By combining the estimated repair cost for insurance purposes for each estate with the official inventory a detailed and complete loss database can be obtained for the whole region. Finally, the estimated losses in each building can be linked to estimated ground motion intensity at the site by using appropriate GMPE (see as example Eq.(1)).

Two loss datasets exist, one collected after the South Iceland earthquakes of June 2000 and another after the May 2008 earthquake. In Bessason et al. (2016) the loss dataset for the two June 2000 earthquakes was split in two parts one for all buildings to the east of the 17 June earthquake fault rupture and one for all buildings west of the 21 June earthquake fault rupture (Fig. 2-2). Buildings located in the area between the two events were excluded since they were expected to have obtained accumulated damage as they were affected by strong motion from two events.

In the following the term ‘Eq1’ will be used for the 17 June earthquake, ‘Eq2’ for the 21 June 2000 earthquake and ‘Eq3’ for the 29 May 2008 earthquake (Fig. 3-1). Since geographical coordinates are known for each affected building it is possible to compute the shortest distance to the fault rupture for each dataset (Bessason et al. 2016)

The database for buildings affected by Eq1 includes the fewest buildings. For Eq2 most of the buildings are in the distance bins 10-20km and 20-35km. The largest contribution of buildings in these bins was from the small towns Selfoss and Hveragerdi (Fig. 2-2). For Eq3 most of the buildings were in the distance bin 0-5km again due to clusters of buildings in Hvergerdi and Selfoss. Since the loss data is complete and includes both undamaged and damaged buildings it is possible to see the proportions of buildings with “No loss”, “Loss” and “Total Loss” with respect to the distance bins (Fig. 3-2). In general, it can be concluded that when the site distance to the fault rupture is greater than 10km then the great majority of the buildings got not losses. When studying the losses, it is informative to relate them to the damage factor (DF) as defined in Eq.(2).

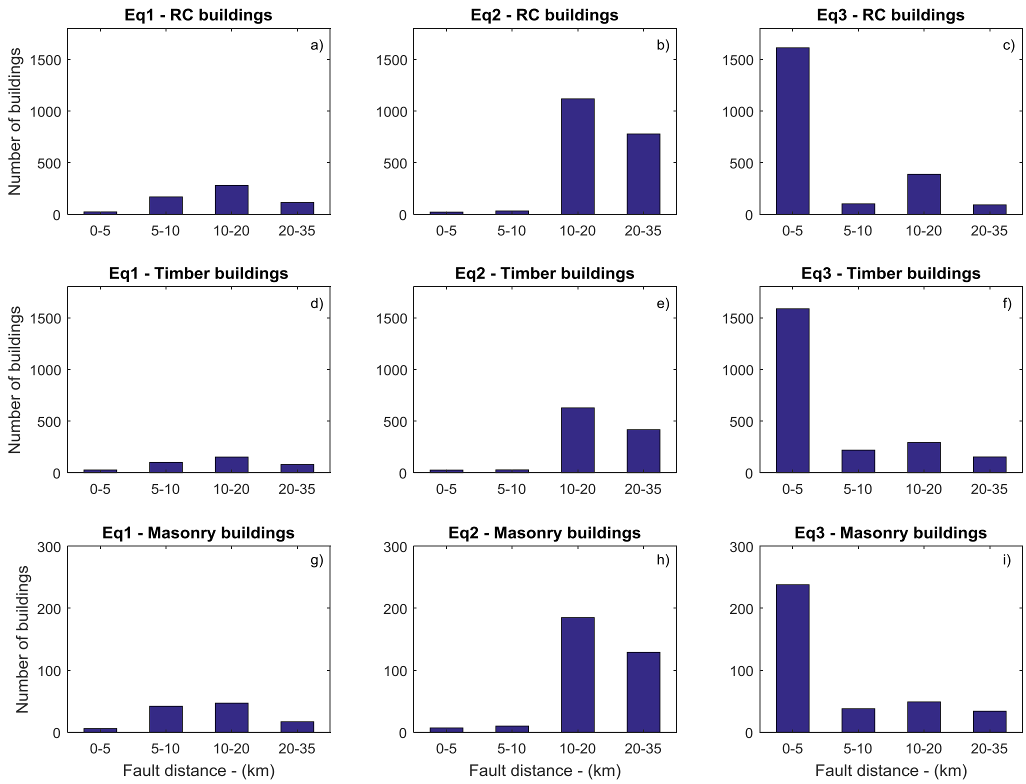

Figure 3-1. Shortest distance to fault rupture for buildings affected by Eq1, Eq2 and Eq3 (Fig. 2-1). Note that the scale of the y-axis is different for the masonry buildings.

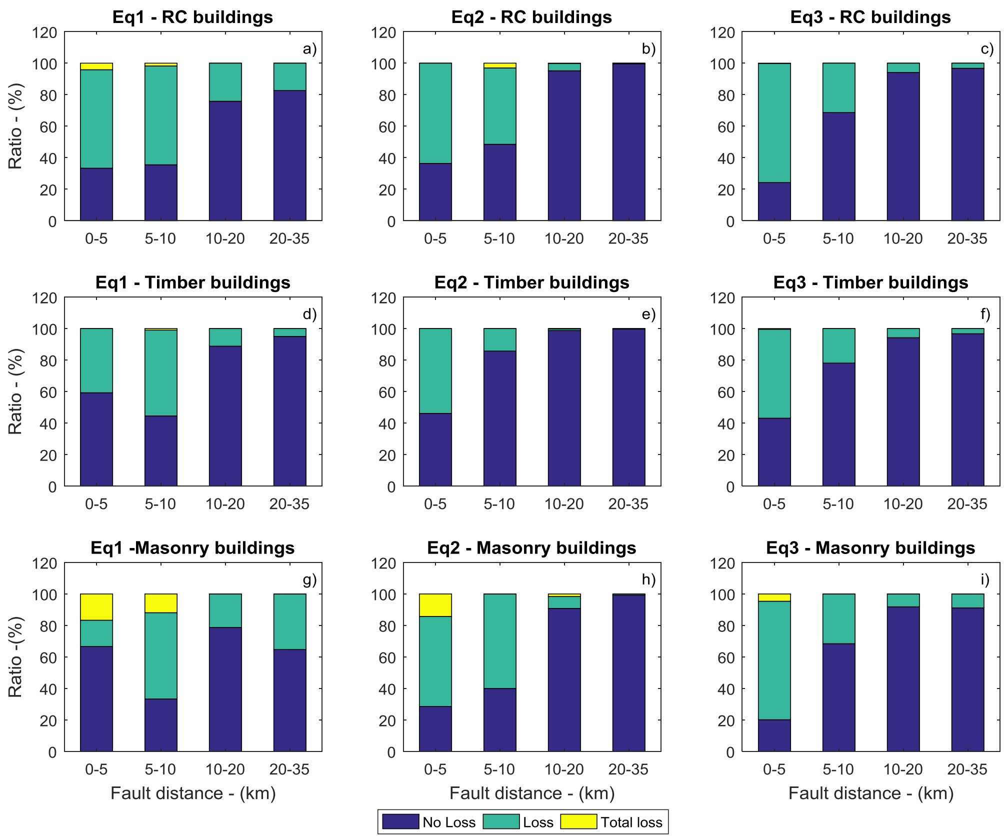

Figure 3-2. Distribution of No loss, Loss and Total loss for the three different building typologies in the two June 2000 earthquakes (Eq1 and Eq2) and the May 2008 earthquake (Eq3).

In the fault area where the ground motion intensity is highest the mean damage factor was low and in general below 10% for both in RC and Timber buildings. For Masonry buildings it was higher and up to 25% (Bessason et al. 2016). It must be underlined that no residential buildings collapsed in the June 2000 earthquake and the May 2008 earthquake and luckily there were no fatalities or serious injuries. Evaluated fragility curves show that the probability of exceeding the moderate damages stage (DF in the range 5-20%) is below 10% for both RC and Timber buildings at all intensity levels but up to 25% for Masonry buildings (Fig. 3-3), (Bessason et al. 2016).

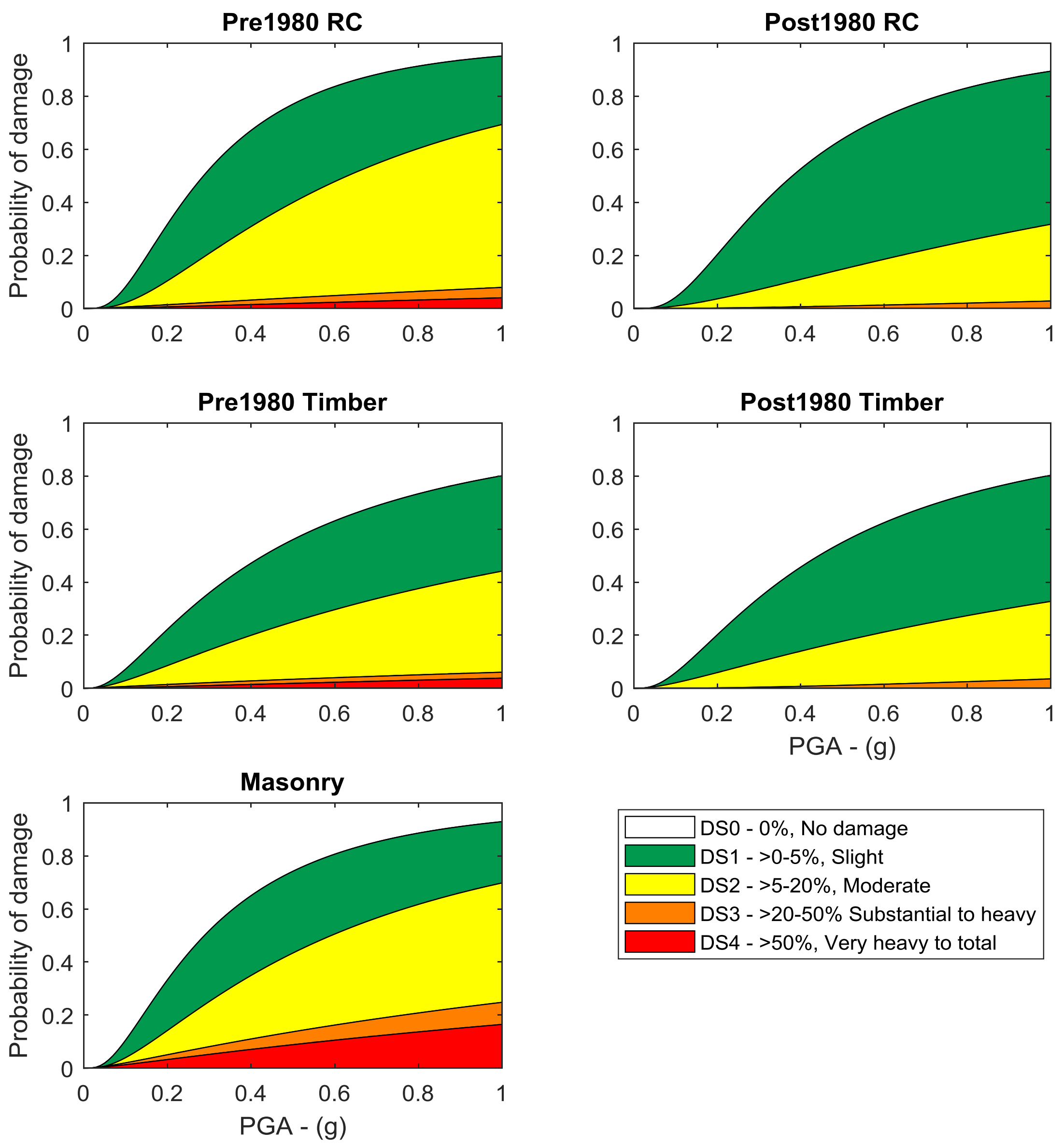

Figure 3-3. Fragility curves for Pre-1980 RC buildings, Post-1980 RC buildings, Pre-1980 Timber, Post-1980 Timber and Masonry buildings (Bessason & Bjarnason, 2016).

3.2 Non-structural damage

Although the insurance loss data set does not include losses from loose household content, like furniture, electronics, loose articles etc. it includes valuable information about other types of non-structural loss of different category (Bessason et al. 2014;

Bessason & Bjarnason, 2016). The loss data from the two June 2000 earthquakes was classified into the five subclasses given in Table 3-1. The loss data from the May 2008 event was on the other hand classified more detailed in 10 subclasses and further in 62 sub-subclasses (Table 3-2). By combining subcategories 1 and 2; subcategories 3, 4 and 5; subcategory 6; subcategories 7, 8 and 9; and finally, subcategory 10 in Table 3-2 into subcategory 1, 2, 3, 4, and 5 in Table 3-1, the data from the two June 2000 earthquakes and the May 2008 earthquakes are comparable.

Table 3-1. Subcategories of losses used in the survey after the 2000 earthquakes (Eq1 and Eq2).

Category	No.	Subcategory
Structural damage	1	Excavation, foundations and bottom slab
	2	Interior and exterior supporting structure (walls, columns, beams, roofs)
Non-structural damage	3	Interior finishing work (partition walls, mortar, suspended ceilings, cladding)
	4	Interior fixtures, paintwork, flooring, wall tiles, windows, doors, etc.
	5	Plumbing (cold water, hot water and sewer pipes), radiators, electrical installations

Table 3-2. Subcategories of losses used in the survey after the 2008 earthquake (Eq3).

Category	No.	Subcategory
Structural damage	1	Excavation, fill and earthwork
	2	Foundations and bottom slab
	3	Exterior supporting structure (walls, columns, beams, stairways)
	4	Roof structure
	5	Interior supporting structure (walls, columns, beams, slabs, stairways)
Non-structural damage	6	Interior finishing work (partition walls, mortar, ceiling cladding)
	7	Interior fixtures, incl. kitchen and bathrooms, doors, flooring, wall tiles, etc.
	8	Windows, glass, exterior doors, wall cladding etc.
	9	Paintwork outdoors and indoors, including crack filling and surface treatment
	10	Plumbing (cold water, hot water and sewer pipes), radiators, electrical installations

Based on data presented by Bessason and Bjarnason (2016) the loss for each damaged building was split proportionally between the five subcategories such that the total sum is 100%. From these proportional values it is possible to find average proportional values for each subclass for given earthquake and given building typology (Fig. 3-4). Only damaged buildings contributed to the results and buildings at all distances are assembled. For all the cases losses due to interior fixtures, paintwork, flooring, wall-tiles, windows, doors, etc. has the highest prevalence, i.e. subcategory 4. Losses in this subcategory are highest for buildings affect by the May 2008 earthquake (Fig. 3-4c, 3-4f and 3-4i). On the other hand, damage due pluming, radiators and electrical installations are low in all cases.

In Figure 3-5 the ratio of non-structural damage (sum of losses in subcategories 3, 4 and 5) to total damage is given for the three building typologies and the three eartquakes (Eq1, Eq2 and Eq3). On the condition that a building is damaged during one of the three earthquakes the non- structural damage is on average above 60% of the total damage in all cases and for the May 2008 it is over 80% in all cases. Here it is important to point out that the magnitude of the May 2008 earthquake was 6.3(Mw) whilst the magnitudes of both the June 2000 earthquakes were 6.5(Mw). The energy release difference between these two magnitude levels is twofold.

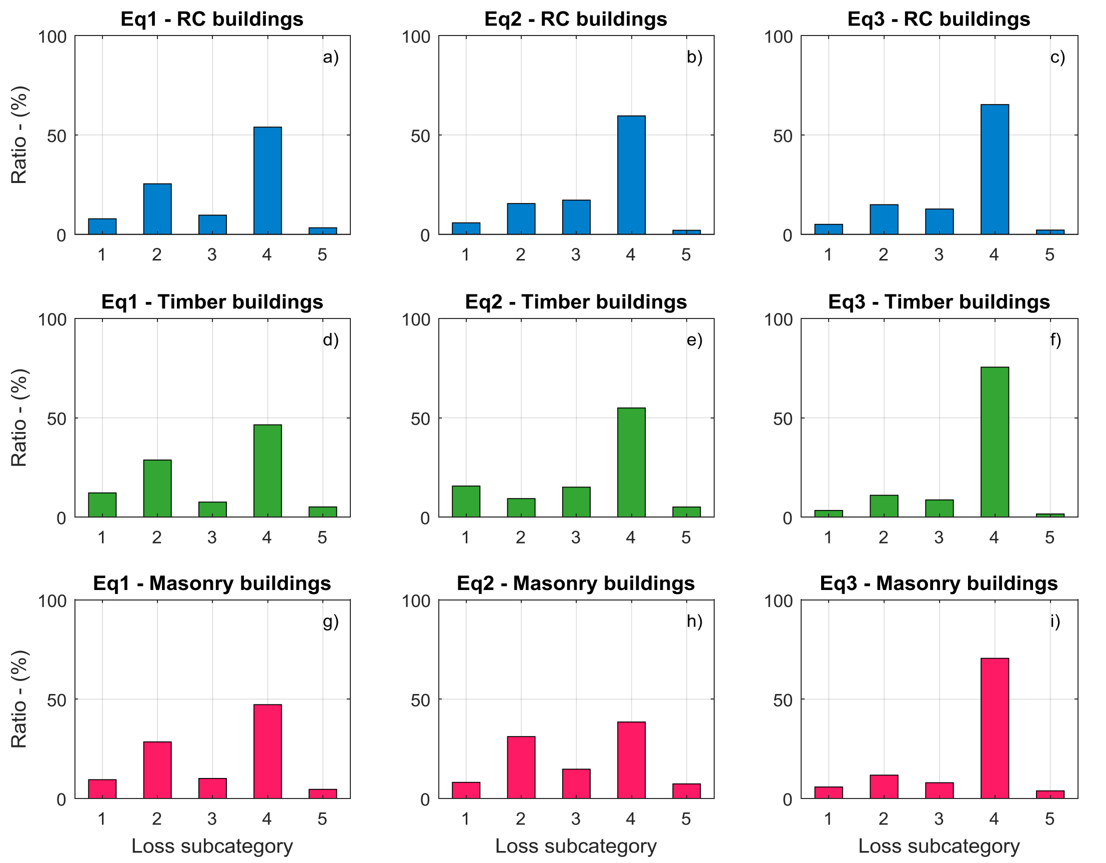

Figure 3-4. Distribution of loss in different loss subcategories (Table 3-1) for the three different building typologies in the two June 2000 earthquakes (Eq1 and Eq2) and the May 2008 earthquake (Eq3).

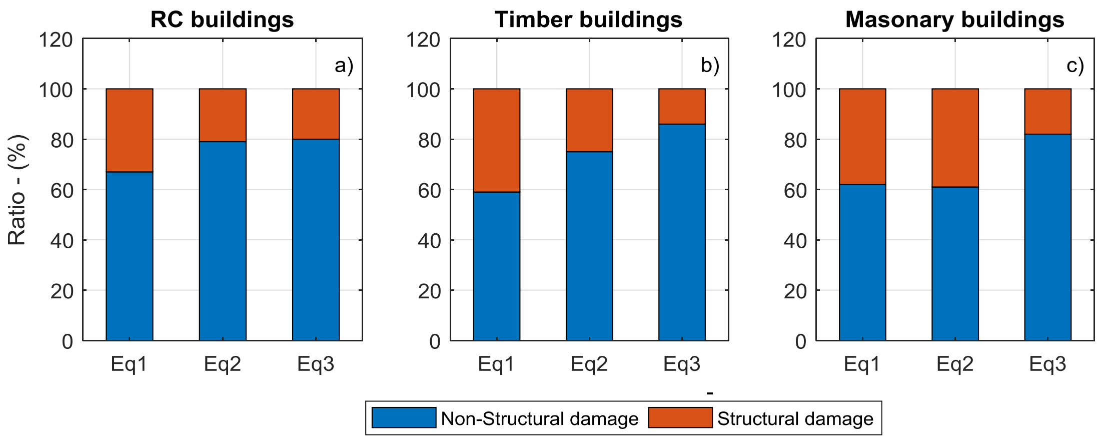

Figure 3-5. Ratio of non-structural damage for the three different building typologies in the two June 2000 earthquakes (Eq1 and Eq2) and the May 2008 earthquake (Eq3).

The loss database for the May 2008 earthquake is more detailed than for the June 2000 earthquakes (Bessason et al., 2014). The subcategories are ten and it is possible to look in more details how for instance the losses in subcategory 4 are split (Fig. 3-6). The highest losses now belong to subcategory 7 and 9 (Table 3-2) whilst losses due to damage of window glasses, exterior doors and wall cladding is low. In subcategory 7 cosmetic damage of flooring is dominating in most cases caused by falling objects and rolling furniture like bookshelves etc. In subcatgory 9 most of the damage was related to cosmetic damage of interior walls that required crack filling and inndoor paintwork (Bessason et al. 2014).

The presented results are expected to give good damage estimates when the earthquake magnitude is similar or less than 6.5. At larger magnitudes higher losses can be expected and different damage pattern. The PGA may not necessarily become much larger in bigger events but the overall ground motion intensity will increase with more significant load cycles and longer duration. On the other hand, the model is believed to give a conservative loss estimates for lower magnitude earthquakes (Mw<6.5).

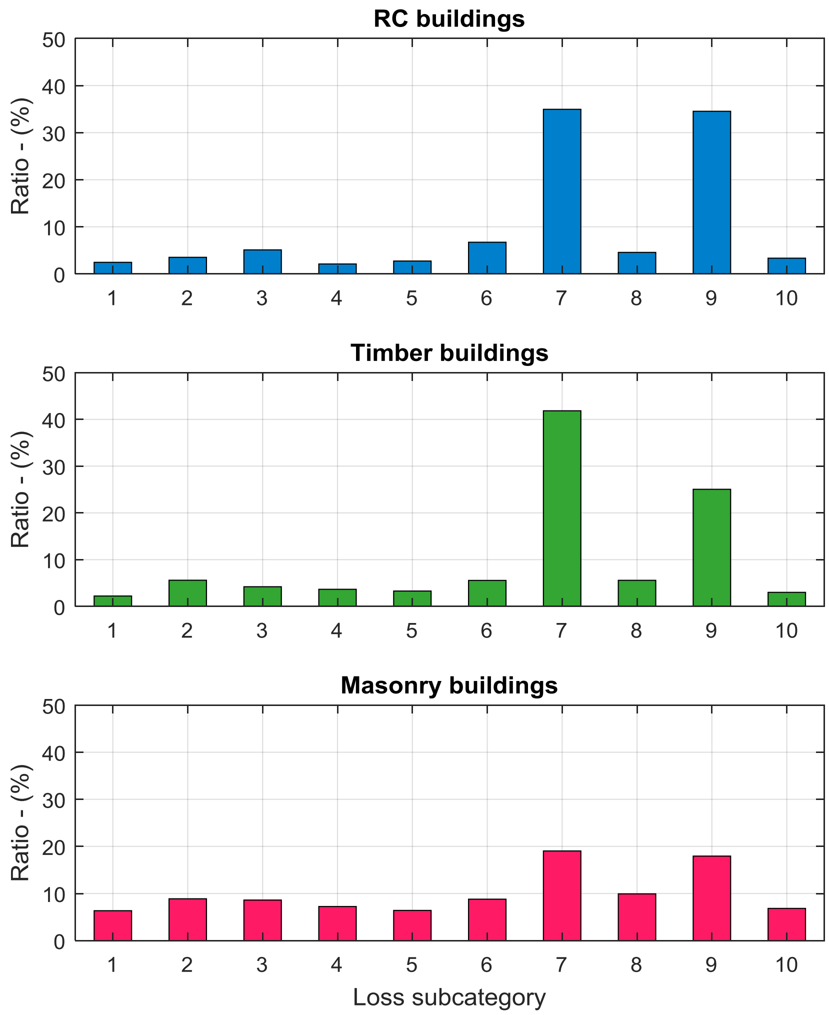

Figure 3-6. Distribution of loss in different loss subcategories (Table 3-2) for the May 2008 earthquake (Eq3).

4 EERC data set

4.1 The data

The Earthquake Engineering Research Centre (EERC) data set was collected via site visits and telephone interviews in the wake of the 2000 and 2008 earthquakes. It consists of digital data, photographs and completed questionnaires in paper form (see Figure 4-1). Most of the data is from single-family dwellings. The interviewees were usually both the owners and occupants of the buildings. The interviews took place in the period 2000-2004 for the 2000 earthquakes, and in 2008 for the 2008 earthquake. The dataset for the 2000 is considerably larger and is separated for the 2000 17th June and the 21st June earthquakes.

The questionnaire is mainly divided into four parts:

a. How the interviews experience the earthquake
b. Movement of building content
c. Damages to the building, both structural and no-structural
d. Damages outside the building

At the time of the 2000 earthquakes, approximate 5,000 houses and 15,000 people lived in the two counties of study area, Árnessýsla and Rangárvallasýsla. It was estimated that the main impact area affected 2,400 houses and 5,000 people. The survey covered 168 houses and 180 people (sometimes more than one person from the household was interviewed). The 168 houses were chosen to include a wide distribution in geographical location, age, and material and construction type

A few houses were included due to closeness to the epicentre or causative fault and because they housed the EERC strong motion accelerometers.

In this study special attention was placed on analysing data on building content using the photos in the EERC data set. The objective of the analysis was to identify typical building content in residential buildings in the study area in South Iceland and categorize the items based on possible damage due to motion, mitigation options, disaster activities and preparedness activities for the disaster activities, for risk management purposes. This approach was used to gain an understanding of the most vulnerable NSC.

Figure 4-1 EERC Damage Data Set

An investigation of the EERC dataset led to a set of photographs of 24 buildings from 17 sites: 16 sites that were damaged during the 2000 earthquake, and 1 site from the 2008 earthquakes that were usable for the analysis (Table 4-1).

Most of the buildings were permanent homes and five were summerhouses. The sites of the photographed building are listed in Table 4-, along with shortest distance to fault and computed PGA based on Eq. (1). Thirteen sites out of seventeen were located where the fault distance was less than 5 km. When compared to Fig 3-1 it is clear that the sets were not randomly picked. They were generally from buildings where the disruption was extensive, and the owner wanting to photograph it. On the contrary, in cases where the damage was limited the owners usually had no desire to take photographs. This means that the photos are greatly biased and cannot be used to make any damage statistics. They are nevertheless informative as they show the type of NSC damage and disruption that occurred during the earthquakes.

Table 4-1. Site and building information where photographs were taken.

Site Id	Year	Material	Soil Class	Fault distance (km)	PGA (g)
1	1975	RC	A	1.5	0.85
2	1997	Timber	A	4.8	0.43
	1958	Masonry	A	4.9	0.42
3	1959	RC	A	3.1	0.61
	1999	Timber	A	3.1	0.61
4	1970	?	A	12.4	0.16
5	1978	RC	A	6.3	0.33
	1996	Timber	A	6.2	0.34
6	1956	RC	A	4.3	0.47
	1986	Timber	A	4.3	0.47
7	1966	RC	A	1.3	0.89
8	1991	Timber	A	5.2	0.40
9	1976	RC	A	3.1	0.60
10	1946	RC	B	8.0	0.34
11	1958	RC	A	1.1	0.92
12	1930	RC	A	1.1	0.92
	1981	Timber	A	1.1	0.92
13	1960	RC	A	1.8	0.80
	1995	Timber	A	1.8	0.80
14	1960	RC	A	0.1	1.01
15	1950	RC	A	0.6	0.98
	1961	RC	A	0.7	0.97
16	1981	Timber	A	0.3	1.00
	1991	Timber	A	0.8	0.96
17	1990	Timber	A	0.90	0.95
	1984	Timber	A	0.99	0.93

While the photos cannot be used for statistical analyses, they do provide examples of what damage can occur in similar magnitude earthquakes and ground motion intensity. In that context they are educational for owners and residents who have not experienced intense ground motion of what may happen. Finally, the photos are useful to characterise the damage and to use as a basis of discussion which NSC are the most vulnerable items. The general opinion of the residents was that most of the damages occurred in the kitchen.

A total of 309 photos were analysed that covered 138 rooms where there use could be identified, along with 7 unidentifiable rooms that were not used in the analysis. The photos did not cover every room in every house. Most of the pictures are from living rooms, kitchens, and bedroom/offices (Table 4-2). In Annex 1 there is an example of one photograph set from a building located close to a fault.

Table 4-2. Distribution of room types covered by photos used in the analysis

Name	Rooms
Living room	22
Kitchen	21
Bedroom/office	20
Children´s bedrooms	15
Larder and laundry	13
Corridor and TV room	13
Bathroom	13
Garage	11
Master bedrooms	10
Total	138

4.2 Analytical steps

The analysis involved filling in the 17 columns of Table 4-3 for each room type listed in Table 4-2. The completed Excel files are in: EERC–C2–analysis_2017.xlsx

Table 4-3. Table layout for analysing items (see also excel file: EERC–C2–analysis_2017.xlsx)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
ITEMS	MOTION			PHYSICAL DAMAGE		CONSEQUENCES				SECONDARY IMPACT TO OTHER ITEMS AND PEOPLE	MITIGATION CATEGORY	MITIGATION ACTION	DISASTER ACTIVITIES REQUIRED, if no mitigation action is performed			
	Slide	Topple	Fall	RC	Functionality	Human	Natural	Economic	Social				Impact	Rescue	Relief	Recovery
Subcat																
											SECURE					
											PROTECT					
											MOVE					
											Nothing					
Subcat																

Column 1: Items typically found in room type

Typical building content for each room in the study area was identified from the photos and listed on an item list. (see Annex 2). The “items” can be a single item (e.g., a sofa), a group of similar items (e.g., dishes), or components of an item (e.g., doors, shelves, draws and boxes that together make a cabinet). Not every house had all items, but the list was compiled to provide an overview of typical items in a home. The items in each room were then divided into subcategories (3 to 7 depending on the number of items in the room), based on similar functions or similar expected behavior, and thus similar mitigation measures for the sake of grouping (simplifying) mitigation measures.

Items found in a summerhouse that are typically found in homes were not listed as special items. However, items that are not common in homes, but are common in summerhouses were listed as "Summerhouse extras".

A total of 196 item types were identified, divided into 7 rooms (Table 4-4). Most of the items were found in the kitchen and in general the photos show most of the disruption is usually associated with that room. It became apparent that the level of damage and disruption observed is in proportion with the number of items in the room. Figure 4-1 shows examples of extensive disruption in kitchens after the South Iceland earthquakes of June 2000 and May 2008. All the buildings are at sites close to the fault rupture and consequently with high PGA.

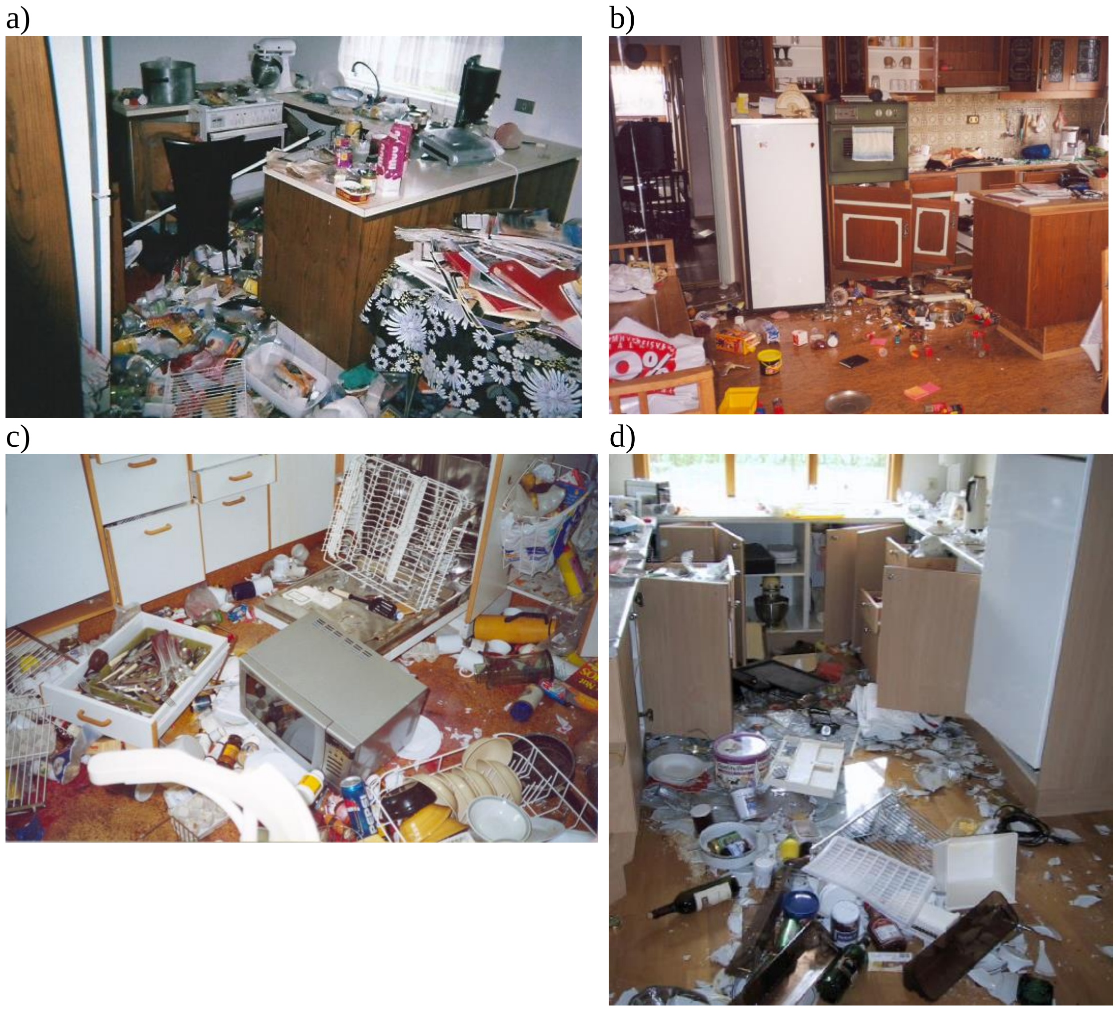

Figure 4-1. Damage in kitchen in four different buildings during the South Iceland earthquakes of June 2000 and 2008; a) Site x b) Site 9, c) Site 11, d) Site 13 (EERC data set).

Table 4-4. Item types in each room.

Room	Items
Kitchen	41
Larder and laundry	20
Corridor and TV room	30
Bedroom and office	41
Garage/Storage	13
Bathroom	15
Living room	31
Summerhouse extra	5
Total	196

Columns 2-4: Motion of items

Each item can move to a final state of damage according to three degrees of freedom:

- Slide (horizontal): this includes doors attached at hinges
- Topple (rotational): falling over
- Falling (vertical): this requires sliding or toppling to happen first. Also, the item has to be located above the floor.

The header Motion in Table 4-2 was split into the three sub-headers: slide, topple, and fall. This field is marked 1 for yes, and 0 for no, based on an analysis of the photos. If an item could in *any* home sustain sliding, toppling, or falling motion then the field was marked "yes", even though it was not the case in all homes. Thus, the table represents what could happen based on these photos, not what did happen. For example, tables and chairs were only marked as able to slide, as they cannot fall (are already on the floor), and none of the photos showed overturned chairs. This does not mean that chairs have not experienced toppling in other earthquakes.

Columns 5-6: Physical damage

The column for physical damage is divided into two parts:

- Percentage of replacement cost
    - In this study, the replacement cost of items was not considered.
- Reduced functionality
    - The tables show the functionality of the item
    - Function level (Full function, Reduced function, Destroyed with no remaining function)

The photos do not always give complete information on damage. For example, a toaster that fell on the floor may or may not be still useable.

Columns 7-10: Consequences

Four types of consequence categories were taken into account, based on the asset categories used in the Livelihood Sustainable Framework (DFID, 1999):

- Human
    - Blocked passages hindering access
    - Injury due to being hit by projectiles
    - Cuts due to walking on broken items
- Natural
    - No photo showed harmful impact on the natural environment, therefore not included in this study
- Economical
    - Estimated low for each individual item, and therefore not considered in the study
- Social value
    - Practical (Cabinets, toasters, tables, and chairs)
    - Emotional (Photos, memorabilia)
    - Essential (Food, toilet)
    - Choice (Spices)

Column 11: Secondary impact

Two types of secondary impact were taken into account

- Damage that items cause to other items
- Injury that items inflict on people

Secondary damages and injuries highlight how objects that are projected across a room can damage other items that they land on, such as floor covering and kitchen benches. Food and wine can leave stains on furniture, and shattered glass can scratch items and cut people who are cleaning up the debris.

Column 12: Mitigation Category

The mitigation categories are as follows:

- Secure
- Protect
- Move
- Nothing

The first three mitigation categories used in this study are those used in the KNOWRISK Practical Guide. A fourth category, "do nothing", was added after studying the photos, as it seemed obvious that some items will not be secured, protected, or moved, they will simply be placed in a room where it is best suited, such as a kitchen table, a sofa, or a lamp. It is important to be aware of the items that are loose.

Also, the definition of the Move category was expanded to mean not only move once permanently, as used in the KNOWRISK Practical Guide, but to move it after use to a secure location, e.g., placing kitchen items in a cupboard with secured doors.

Column 13: Mitigation Action

The mitigation actions used to fill in Table 4-2 were determined from analysing the photos and the information the columns, for example the type of motion the item could sustain. As mitigation actions were decided and written into the Excel file: EERC–C2–analysis_2017.xlsx, a pattern began to develop of similar actions. The items in the column were then standardized to the extent possible to allow for a summary of mitigation actions.

Columns 14—17: Disaster activities required when mitigation is performed

Preparedness activities are preparations *before* the disaster in order to be well prepared to take action *during* the disaster. To know what activities to take to prepare, one needs to know what could happen and what activities to take during an action. There are four key disaster operations, or disaster actions. The term disaster actions may be more appropriate for homeowners (Thorvaldsdóttir and Sigbjörnsson, 2014):

- *Impact actions*: actions taken due to the earthquake shaking, the damaging processes, and any consequences causing damages needed to be addressed immediately.
- *Rescue actions*: lifesaving actions, including immediate first aid.
- *Relief actions*: temporary actions taken to bridge the gap and relieve suffering until recovery actions are complete
- *Recovery actions*: actions taken to restore life back to normalcy.

4.3 Key summaries

4.3.1 Mitigation

Table 4-5 shows what type of mitigation action is recommended for all the items within each room. The table shows that in most cases, 160 out of 196, it is possible to perform some actions to reduce risk. The most common option is to protect an item. Most objects are found in the kitchen, so most of the mitigation can take place there.

Table 4-5. Mitigation type for the items in each room category

	MOVE	PROTECT	SECURE	NOTHING	Total
Kitchen	17	12	6	6	41
Larder and laundry	9	5	6	0	20
Corridor and TV room	0	16	5	9	30
Bedroom and office	9	19	5	8	41
Garage	2	10	1	0	13
Bathroom	3	5	3	4	15
Living room	3	15	6	7	31
Summerhouse	1	0	2	2	5
TOTAL	44	82	34	36	196

Table 4-6 shows a summary of the type of mitigation actions identified as appropriate for each item. The most logical option is also the most common, to prevent the object from moving. This implies a free-standing object. The second most common is to prevent from opening, implying a cabinet of some sort. The first most common is to put in a secure place when not in use. It is likely that this is the most difficult to sustain as it involves a repeated action opposed to for example fixing a bookshelf to a wall once. No action at all is the second largest category. This is an important result, as it emphasizes the importance of preparedness since not all risk can, or will be, mitigated.

Table 4-6. Categories and frequency of mitigation

#	Mitigation Action	Frequency
1	Prevent movement during earthquake	65
2	Prevent opening during earthquake	25
3	Put in secure place when not in use, draws behind baby locked cabinet draws	22
4	Move loose items to a secured storage container	21
5	Prevent from loosening or falling during earthquake	14
6	Prevent sliding during earthquake	5
7	Make sure cannot come off wall	2
8	Place baby locks on doors	2
9	Prevent sliding and falling during earthquake	2
10	Keep closed when not being used	1
11	Shelves usually stay in cabinet, but make sure they do	1
	Subtotal	160
12	No action	36
	Total	196

A summary of mitigation actions per room is given in Table 4-7. Note that the actions are not mutually exclusive. For example, #3 is placing items behind baby locked doors, while #8 is to baby lock doors.

Table 4-7. Item Mitigation Category Summary

Room	Action	No.
Kitchen	Keep closed when not being used	1
	Make sure cannot come off wall	1
	Place baby locks on doors	1
	Prevent from loosening or falling during earthquake	5
	Prevent movement during earthquake	5
	Prevent sliding and falling during earthquake	2
	Prevent sliding during earthquake	3
	Put in secure place when not in use: in draws behind baby locked cabinet draws	16
	Shelves usually stay in cabinet, but make sure they do	1
	Total	35
	Nothing	6
Larder - Laundry	Move loose items to a secured storage container	9
	Prevent loosening and falling during earthquake	2
	Prevent movement during earthquake	9
	Total	20
	Nothing	0
Corridor – TV room	Prevent from loosening or falling during earthquake	2
	Prevent movement during earthquake	17
	Prevent opening during earthquake	1
	Prevent sliding during earthquake	1
	Total	21
	Nothing	9
Bedroom	Make sure cannot come off wall	1
	Move loose items to a secured storage container	9
	Place baby locks on doors	1
	Prevent from loosening or falling during earthquake	3
	Prevent movement during earthquake	18
	Prevent sliding during earthquake	1
	Total	33
	Nothing	8
Garage	Move loose items to a secured storage container	2

	Prevent movement during earthquake	11
	Total	13
	Nothing	0
Bathroom	Prevent movement during earthquake	1
	Prevent opening during earthquake	6
	Prevent from loosening or falling during earthquake	1
	Put in secure place when not in use: in draws behind baby locked cabinet draws	3
	Total	11
	Nothing	4
Living room	Prevent movement during earthquake	2
	Prevent opening during earthquake	18
	Prevent loosening and falling during earthquake	1
	Put in secure place when not in use, draws behind baby locked cabinet draws	3
	Total	24
	Nothing	7
Summerhouse extras	Move loose items to a secured storage container	1
	Prevent movement during earthquake	2
	Total	3
	Nothing	2

4.3.2 Disaster activities

Disaster activities (impact, rescue, relief, and recovery) involve reacting to issues listed in the following columns:

- Reduced functionality (column 6)
- Consequences of reduced functionality (columns 7-10)
- Secondary impact to other items and people (column 11).

A summary of disaster activities determined based on the content of the above columns for all room types is listed in Table 4-8.

Table 4-8. List of disaster activities

Impact Activities	Rescue Activities	Relief Activities	Recovery Activities
Avoid projectiles (move to safe or safer location, duck, cover, and hold on). Stop water leaks from heaters, tanks, washing machine, and dishwasher. Stop chemical leaks, e.g., paint. Stop chemical leak from washing powder/liquids	Rescue people that are trapped under fallen objectives. Address injuries, send to hospital if needed, otherwise administer first aid.	Emotional relief Temp arrangements for the following: Baby eating/seating Bedding arrangement Body washing Cleaning Clothing Cloths drying Cloths washing Cold storage Communication Cooking Curtains Doors for privacy Drinking Eating Food storage Food supply Heating Heat water Ironing Lighting Make coffee Seating	Clean-up due to chemical damage Clean-up due to water damage Clean-up: General Irreplaceable - emotional recovery Purchase normal food Repair repairable items Replace irreparable items

		Storage Table Toilet Water/drainage (sink)	

4.3.3 Disaster Preparedness

As stated before, preparedness activities are taken before the earthquake, alongside mitigation actions, in order to be prepared for disaster actions if and when they are required. Disaster preparedness actions are grouped in the same way as disaster activities:

1. Impact preparedness
2. Rescue preparedness
3. Relief preparedness
4. Recovery preparedness

Preparedness activities were not identified for every item in the table, instead a summary was created to give a general overview. The summary is presented below.

Impact preparedness

- Ponder what building content could become projectiles and where to go in an earthquake to avoid being hit my them (for each room)
- How to stop water and chemical leaks. What tools are needed?
- Is it likely that there will be a need from official fire services to stop leaks? Do you know how to call for their help?

Rescue preparedness

- One's ability to rescue people from under heavy fallen objects? What items are needed?
- One's ability to address injuries? Prepare a first aid kit and take a course.
- Is it likely that there will be a need from official rescue services to stop leaks? Do you know how to call for their help?

Relief preparedness

- Does one have the ability to provide own temp arrangements? Is it necessary to buy simple items for temporary use, e.g. plastic cutlery, dishes, containers, chairs, tables, washing clothes by hand, and other items that are unlikely to be damaged during an earthquake to use for temporary arrangements? Could these items be the camping gear?
- Be prepared to quickly judge whether the family can stay in the house or whether the state of the house is such that you need to move out. Have a few ideas of where to move to. Know where your mass care shelter is located.
- Consider possibilities if temporary relocation is required during repair and replacement work during recovery.
- Know how to call for assistance from relief services.

Recovery preparedness

- One's ability to provide own recovery arrangements? What is needed for clean-up? Cleaning equipment, shoes, etc.
- One's likely needs from official recovery services?
- Know whom to contact for recovery assistance.

- Consider the time it may take to recover from the event.
- Consider financial cost of recovery.
- Consider emotional recovery: be prepared for losses of items of emotional value.

Additional issues to be considered when preparing for a disaster are, first of all, being prepared to support others, but through direct impact, rescue, relief, and recovery actions, and also through emotional support. Also, it is important to be aware of the level of assistance needed in the community? When will help come to you? Could it be immediately or in 1-2 days?

4.4 Damage and disruption state characteristics

A study of the results leads to suggestions for criteria for developing damage and disruption state for household content. Key criteria are: Motion (number of items of sliding, toppling and/or falling; note the more items in the room, the more quantity of items can move); Level of reduced functionality; Level of blocked passageways; and Time period for recovery. Table 4-9 outlines how these four types of criteria can be distributed over four increasing levels of damage/disruption states.

Table 4-9. Damage states for content

Damage/Disruption State	Motion	Functionality	Passageway	Recovery time
No disruption	Isolated, non-disruptive, inconsequential sliding, toppling, and/or falling.	All items are fully functional	Passageway is clear	Recovery is complete within 1 hour by straightening up or picking things off the floor and
Minimum/Mild	Tall and slender (less stable) items topple and may suffer damages.	Most items are fully functional	A few items are in passageway, but easily avoidable	Recovery takes less than 1 day
Moderate	Many items sustain motion and damage	Many items suffer reduced functionality	Many items affect passageway, need to walk carefully	Recovery takes less then 1 week
Extensive	Most items sustain motion and damage	Most items have reduced function	Passageways are blocked	Recovery takes more than 1 week, especially the replacement of practical items and repairs

5 Discussion

Understanding vulnerability of individual building content items includes understanding how items can be damaged (the motion), the physical damage (replacement cost and reduced functionality), the human, natural, environmental, and social consequences, and secondary impact (damages to other items and injury).

The level of vulnerability is highly dependent on circumstance. Motion depends on earthquake magnitude, fault mechanics, geographical location of building with respect to fault rupture, soil conditions, dynamic characteristic of building etc. Physical vulnerability needs to be seen in context with overall damage. For example, even though the microwave is destroyed, one can still cook using the oven and stove to cook food. However, if all three are destroyed the ability to cook food is significantly reduced. Replacement cost of a few items is most likely not going to be high, but if all items need to be replaced, the total cost can be significant to an individual. The human impact is random; where are people sitting/standing/lying/walking when the earthquake takes place. How will individuals behave during and immediately after the event: Will they run over broken glass? It is unlikely that damage to building content will have an impact on the environment. In comparison to damage cost of structural components, the economic loss of individual items is low. It will also depend on the value of the items in the home. Some homes have expensive items, such as expensive paintings that can fall down, while other homes have the bear minimum leading to much less economic loss.

The categories of social consequences used in this study were practical, emotional, essential, and one case of choice. Essential items include those that allow people to eat and go to the toilet. Practical items include a dishwasher, but if it breaks, one can wash dishes by hand. Ruined photo albums or broken vintage crystals may lead to an emotional response to the individual who own them, but no one else. Those who choose to have spices in their food may be upset if all the spice bottle break, but others may choose to not to spice their food therefore are not affected by broken spice bottles.

These variations reduce the ability to estimate vulnerability of building content in homes. However, understanding damage and consequences to this level of detail and explaining to people what can happen is a significant guide to people who live in earthquake prone areas. By explaining to people what can happen and what options they have to mitigate their risk, or what to do to prepare for unmitigated risk, gives people choices. Also, importantly, it removes the surprise of “what just happened” following an earthquake. Educating people on what can happen to building content is an important aspect of pre-disaster activities. People realize when looking at their broken crystal that they only have themselves to blame.

The question arises whether the important question is about the vulnerability of an item or whether it is about the consequences of the item being damaged. For example, the fact that all the dishes broke may not be a big deal in itself, dishes are cheap and replaceable, but the risk of injury from broken dishes and the need to find something else to eat off is more of an issue.

The above discussion leads to the following question: what is the purpose of an estimation of building content vulnerability?

- For insurance purposes?
- For home owners (get paid from insurance companies)?
- For emergency services (do people need to move out during repairs? Can they get assistance)?
- Usability of homes, what will be needed in regards of relief?
- Recovery needs?

The level of detail addressed in this study is important from the perspective of individual homes in order for them to mitigate and prepare future response activities. However, this level of detail is too high for disaster loss estimation.

Homeowners need to balance the cost and benefits of mitigation in context with the cost and benefits of disaster preparedness. This should be done for each room separately. One might take less risk in rooms where people sleep and more risk in a kitchen, where people are always (hopefully) awake in and have a plan to get up and move to a secure location as soon as they feel P-waves arriving.

Even if a building does not collapse or is not severely damaged, a high level of building content damage can significantly affect people´s home life and business life.

Task C1 of the KNOWRISK project led to Table 5-1 for homeowners on what action to take regarding earthquakes (section 3.4.2 in C1 report).

Table 5-1. Exposure examples, DS, Disaster Scenario, Mitigation, Preparedness

<table>
<tr><td>Exposure (examples)</td><td colspan="3">• Food, drinks, place to cook, cooking utensils, cookers
• Bed clothes
• Toilet, bath/shower, cleaning utensils (toothbrush, towels)
• Washing machine, dryer
• Furniture, TV, radios
• Office supplies, work documents not backed up
• Car, car-keys may be somewhere else.
• Routers
• Memorabilia
• Walls, locks on doors/windows</td></tr>
<tr><td>DS</td><td>1. Minor DS</td><td>2. Moderate DS</td><td>3. Severe DS</td></tr>
<tr><td>Disaster scenario</td><td>Describe minor damages to the exposure, and the consequences, from a home perspective, based on the following:
• No deaths
• Non-fatal injuries that do not require hospital visits
• Continued functionality
• Repair cost within deductible level</td><td>Describe damages to the exposure, and the consequences, from a home perspective, based on the following:
• No deaths
• Non-fatal injuries that require outpatient visits to hospitals
• Continued functionality, but living arrangements need to be made
• Repair cost above deductible level</td><td>Describe damages to the exposure, and the consequences, from a home perspective, based on the following:
• Deaths
• Non-fatal injuries that require hospitalization
• Need to move out while repairs are made or find new location
• Repair cost above deductible level</td></tr>
<tr><td>Mitigation</td><td>Implement the following based on the disaster scenario for minor damage states
a. Identify mitigation options
b. Analyse options
c. Compare and choose
d. Implement</td><td>Implement the following based on the disaster scenario for moderate damage states
a. Identify mitigation options
b. Analyse options
c. Compare and choose
d. Implement</td><td>Implement the following based on the disaster scenario for severe damage states
a. Identify mitigation options
b. Analyse options
c. Compare and choose
d. Implement</td></tr>
</table>

Preparedness	Implement the following based on the disaster scenario for minor damage states, and home perspective, taking into consideration any mitigation measures that are to be implemented: a. Procedures for assessing the situation b. Facilities, communication, and equipment c. Contingency plans d. Training and testing plans	Implement the following based on the disaster scenario for moderate damage states, and home perspective, taking into consideration any mitigation measures that are to be implemented: a. Procedures for assessing the situation b. Facilities, communication, and equipment c. Contingency plans d. Training and testing plans	Implement the following based on the disaster scenario for severe damage states, and home perspective, taking into consideration any mitigation measures that are to be implemented: a. Procedures for assessing the situation b. Facilities, communication, and equipment c. Contingency plans d. Training and testing plans

The information presented in Task C2 provides further detailed information for homeowners to perform disaster risk management, and can be considered as an extension of Table 5-1. An explanation of how the information presented in C2 is an extension of C1 is listed below:

Exposure: C1 provides a general exposure list generated randomly by the author, who is a homeowner. The C2 exposure list (Annex 2) is generated from damage photos taken in homes after an earthquake.

Disaster Scenario: C1 mentions deaths, injuries, level of functionality and repair cost as issues to be taken into, without going into further detail. Columns 2 – 11 in Table 4-3 (motion, physical damage, consequences, secondary impact) provide more detailed information on possible damages and consequences that define a scenario (see Table 4-4).

Mitigation: C1 lists the four steps of mitigation: identify options, analyse them, compare and choose, and finally, implement. C2 provides a detailed list of the first step, options, which are ready for further analysis by a homeowner within a given context.

Preparedness: C1 lists four key steps to be completed to be ready for an earthquake: have a plan for assessing the situation make sure that any facilities, communication equipment and other equipment is packed and available, ready to be used, have a plan on how to perform impact, rescue, relief, and recovery activities, and finally, test and train plans and equipment. The results in C2 (section 4.3 Key summaries), provide detailed information for homeowners to develop their preparedness plans, decide what equipment might be necessary (shoes under the bed)

6 Conclusions and Closing Remarks

This report focuses on observed damage of non-structural components in low-rise residential buildings from three major earthquakes in the study area in South Iceland, and along with an overview of structural damage to place the NSC into context of damage in the study area. The two earthquakes in June 2000 were of the same magnitude, i.e. Mw6.5, whereas the third one from May 2008 was of Mw6.3. All three events affected the same building typologies. In total 9500 residential buildings were affected (PGA > ~5%) and of these approximately 3200 buildings were damaged, a Damage Ratio of 34%. The study is based on two datasets: A detailed and complete loss data set based on insurance claims; and secondly on photos of damage of NSC in residential buildings from selected building sites mainly in the near-fault area damage in one of these three events. The buildings were categorized into three typologies referring to the main building material, RC, Timber and Masonry. In some cases, the RC and Timber buildings were split in two categories, i.e. those built before and after 1980 (Pre1980 and Post1980). Great majority of the buildings are RC or Timber buildings whilst Masonry buildings are only around 10% or less and are now longer built.

A number of information and conclusions can be drawn from the damage data in the study area from the three events. The main findings are shown below:

- **Human impact:** No one was killed or badly injured in these earthquakes. Minor injuries for fewer than 10 people were reported in total for all three events.
- **Collapse:** No residential buildings had total collapse or local collapse in these three earthquakes. However, a few buildings (<0.5% of affected buildings) were so heavily damaged that they were classified as totally damaged.
- **Distance from epicentre:** Most of the losses and the highest damage factors (DF) were observed in the near-fault area in all three earthquakes or more specifically at a 0-10 km distance from fault rupture. Beyond 10 km the losses were significantly reduced and more than 75% of all dwellings at that distances had no losses.
- **Probability of structural damage:** Evaluated fragility curves show that the probability of exceeding a Moderate Damage State with a DF range of 5-20% is less than 10% for both RC and Timber buildings, but as high as 25% for Masonry buildings at the highest ground motion intensity in the near-fault area. The fact that only a few buildings were extensively damaged or totally damaged means that it is difficult to compute reliable fragility curves for the higher damage states based on existing data. The data indicated that new and after-code buildings (Post1980) were significantly less damaged than older buildings built before the implementation of seismic codes in Iceland. The strict requirements of minimum reinforcement according to codes for new reinforced concrete buildings increased concrete strength (not related to seismic design), as well as the improved finish of foundations for both concrete and timber buildings were probably the main reasons for this rather than advanced seismic design.
- **Ratio of non-structural to structural damage:** The insurance loss data showed that non-structural damage dominated the overall damage for all the building typologies and all three earthquakes. For the M_w6.5 June 2000 events

the ratio of non-structural damage to total damage was typically in the range of 60-70%, whereas it was in the range of 80-90% for the M_w6.3 May 2008 event. Here it must be underlined that the insurance loss data does not include losses of loose household content.

- **Type of NSC damaged:** The insurance loss data also showed that most of the damage was related to interior fixtures, paintwork, flooring, wall tiles, windows, doors, etc. On the other hand interior finishing work (partition walls, mortar, suspended ceilings, cladding) as well as plumbing (cold water, hot water and sewer pipes), radiators, electrical installations showed in general good resistance against the seismic action.
- **Disruption from NSC:** Photos from the EERC data showed that although the building and fixtures behaved satisfactory there were number of cases with extensive disruption of household content. Most of the disruption was generally found in the kitchen where most of loose items are usually located. In general, the disruption was proportional to number of loose items in a given room. Nevertheless no statistic is available of content losses during the June 2000 and May 2008 earthquakes.
- **NSC motion and mitigation:** Damages and the threat of damage to household items is related to their ability to move; slide, topple and fall. In most cases it is possible to perform some type of mitigation action (secure, protect and/or move items) to increase the indoor safety and to reduce the content losses. In some cases it may be impractical to take actions, such as fastening sofas and dining room tables, and kitchen items that are frequently used.

From a structural perspective, these findings are quite encouraging and indicate that low-rise residential buildings in seismic zones in Iceland behave satisfactorily in earthquakes of magnitudes 6.5 or less. This is especially true for new building typologies introduced after seismic building codes were implemented in Iceland in 1976. The low-rise residential buildings in the study area are primarily of stiff shear wall type, responding elastically, and it seems that a stronger earthquake is needed to really challenge the bearing capacity of them. Despite the low structural damage, this study shows that extensive disruption of household content can be expected most likely in all houses in the near-fault area but this damage can be reduced by simple and inexpensive mitigation actions.

Finally, we address the question of defining the most vulnerable NSC in South Iceland. The study shows that the answer involves many complicating factors:

- **Vulnerability; susceptibility to damage.** The vast number of items in this study of different shape, size, and location makes it impossible to group and judge which items are more susceptible to damage than others.
- **Vulnerability expressed as losses.** Vulnerability can be expressed in terms of financial loss, functional loss, and emotional “loss” of irreplaceable items. The variability of items in this study leads to a high variability in losses and makes comparison of which objects lead to the most losses impossible.
- **Unknown mitigation efforts**. The fact that the data did not supply information on the amount of mitigation measures performed prior to the earthquakes make comparison of the damage difficult.
- **Balance between mitigation and preparedness**. Even though an item sustains damage during an event, it may be more practical for the owner to simply replace a damaged item than to take impractical mitigation measures.

The loss therefore becomes disproportional to damage and distorts any comparison of vulnerability of items.

- **The number of items in a room**. The number of items in a room will influence how people observe the amount of damage and disruption. The more items that more the damage and disruption is likely to be.

We conclude by stating that asking what is the *most vulnerable* NSC is not the appropriate question, and suggest instead the three following statements:

1. From a pure functional perspective, the kitchen and bathroom are the most critical room types in a home, and from that perspective the most vulnerable rooms of a home, and should be given priority regarding mitigation measures. Also, the number of items in a kitchen is relatively high compared to other rooms which may result in observed damage and disruption being seemingly high.
2. Vulnerability of NSC found in residential buildings is characterized by monitory losses, functional losses, and emotional losses, which in turn should be characterized by activities needed to mitigate the risk of these losses, and the preparedness activities required if no mitigation action is taken. The mitigation and preparedness efforts are good measures of vulnerability; the more effort is needed the more vulnerable is the home.
3. The owner of the items will make judgment on which items are *most vulnerable*.

A fundamental conclusion is that vulnerability of NSC cannot be addressed in the same way as SC. First of all, NSC are many and diverse, even when only considering residential buildings. Secondly, consequences may be more related to disruption of the functionality of an item than the physical damage or financial losses, since the item could be easily thrown away.

Future research could develop a stronger statistical overview of content damage and link it to ground motion intensity in recent earthquakes. This could be done by collaboration with insurance companies. To improve databases researchers need be prepared with data collection after an earthquake and have ready questionnaires for such purposes. In such study it is important to sample data from buildings experience all levels of damage, i.e. from none to extensive disruption and work with different source-to-site distances. Further work is also needed on developing criteria for Damage and Disruption States for Non-Structural Components.

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Annexes 1 Example photos

An example of photographic data from the EERC dataset is given in the following figures. The photos are from the same building, a SFD in a high-ground motion region, but are from separate rooms in the house.

Figure 0-1 NSC in the 2000 earthquake, (a and b) master bedroom with cot and televisions, (c) hall (d) kitchen, (e) living room, and (f) washroom

(a)

(b)

(c)

(d)

(e)

(f)

Annex 2 Item per categories and sub-categories

KITCHEN ITEMS (41)	LARDER_LAUNDRY ITEMS (20)	CORRIDOR_TV ROOM ITEMS (30)	BEDROOM AND OFFICE ITEMS (41)
Appliances in cabinet	**Appliances**	**Fixtures**	**Fixtures**
Oven	Washing machine	Lightfixtures on walls	Cupboard boxes
Microwave	Dryer	heaters on walls	Shelves, wooden
Fridge	Freezer	Mirror	Curtain rods
Dishwasher	**Fixtures**	Curtain rods	Cupboards doors
Stove	Fixed shelves	**Furniture**	Lightfixtures
Fixtures	Water tank	Cupboard boxes	Door
Cabinet box	Light fixtures	Bookshelves	Cabinet draws
Cabient shelves	**Content, mostly on shelves or in cabien**	Chest of draws	**Appliances**
Cabinet doors, pull	Fire exstinguishers	Tables on wheels	TV
Curtain rods	Toolbox	Doors on cupboards	Computers, monitors, laptops
Cabinet doors, slide	Storage boxes	Chairs	Keyboard, speakers
Cabinet draws	Paint	Sofa	Printers
Sink	Ice chests	Sofa table	Stereo
Fans over stove	**Content on shelves or in cabients, sma**	Table	Video player
Hanging objects	Food	Benches	Record player turntable
Pictures	Breakables	**Appliances**	Sewing machine
Clocks	Winebottles	TV	Lamps
Heater	Baskets	Telephone	**Content, should be protected**
Lightfixtures	Washing powder/liquid	Fax machine	Boxes
Heavy content not in cabinet	Shoes	Lamps	Statues, memorabilia
Flower pots	Umbrella	**Hanging items**	Items hanging on walls
Wine bottles racks	Overcoats	Hanging lights	Ceramic items
Knife racks	Folders/Papers	Pictures	Breakables
Medicine cabinet		Memorabilia	Flower pots
Fishbowl		**Content**	Musical instruments and cases
Appliances Loose		Clocks	Tables on wheels
Kettle		Books	Cupboards
Coffeemaker		Candlesticks	Bookshelves
Toaster		Vases	Shelves
Mixer		Flower pots	Tables on wheels
Blender		Ceramic items	Beds
Content in cabinet, fridge, dishwasher		Drinking glasses	Sofas
Food		Shoes	Tables
Cutlery		Ironing board	Chairs
Pots and pans			Desks
Tupperware			**Content, that is generally loose**
Rubbish in bins			Wine bottles
Content, Breakables			Books, folders, papers
Dishes and bowls			Bottle top collection
Mugs, Cups, Glasses			CDs, casettes, videos
Jars, Bottles			Suitcases
Ceramic objects			Records
Eye glasses			Photo albums
Spice bottles			Toys
Furniture			Clothes
Tables			
Chairs			
Highchair			

GARAGE AMD STORAGE ITEMS (13)	BATHROOM ITEMS (15)	LIVINGROOM ITEMS (31)	SUMMERHOUSE EXTRA ITEMS (5)
Maintenance	**Fixtures**	**Fixtures**	**Additational items**
Cupboards	Cupboard boxes	Lightfixtures on walls	Kamina/fire place
Gym equipment	heaters on walls	heaters on walls	Parafin oil stove
Boxes storing household items	Doors on cupboards	Individal shelves	Wood for burning
Empty bottles	Mirror	Cupboard boxes	Bench
Household items in storage	Curtain rods	Doors on cupboards	Rocking chair
Outdoor equipment	Cupboards draws	**Furniture**	
Tools	Toilet	Piano	
Tool boxes	Bathtub	Bookshelves	
Generator	Glass shower curtain	Sofa	
Oils and chemicals	**Appliance**	Sofa chairs	
Wheel barrow	Washing machine	Dining room table	
Boxes	**Content, loose**	Sofa table	
BBQ equipment	Flower pots	Dining room chairs	
Camping equipment	Ceramic items	**Appliances Loose**	
Skis	Toiletries/Make up	TV	
	Cleaning chemicals	Stereo/speakers	
	Mugs, Cups, Glasses	Video	
		Table lamps	
		Floor lamps	
		Hanging objects	
		Hanging lights	
		Glass pictureframes	
		Content on shelves or tables	
		Candlesticks	
		Statues	
		Flower pots	
		Memorabilia	
		Books	
		Silver items	
		Clocks	
		Content, breakables	
		Vases	
		Glass frames	
		Nice coffee set	
		Nice dishes, bowls	
		Nice wine glasses	