13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2333

RESIDENTIAL SECURITY AS RELATED TO PERCEIVED AND ASSESSED EFFECTS TO STRONG GROUND MOTION RECORDINGS

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SUMMARY

A case study of the perceived effects of earthquakes and their relation to strong motion recordings, with regard to human security inside residential houses, is presented. The cases considered are the South Iceland Earthquakes on the 17th and 21st of June 2000. The highest recorded ground accelerations in these events are respectively 64% g ($M_w = 6.6$) and 84% g ($M_w = 6.5$), and the highest assessed intensities are, respectively, MMI XI and IX. Dwellings and inhabitants in the epicentral areas were chosen for the study. The data on perceived effects were obtained through field surveys, using standardised questionnaires as well as personal in-depth interviews. Detailed descriptions of the behaviour of the people experiencing the earthquakes are given. This includes accounts of both psychological and physical effects. In all cases the dwellings are low-rise, single-family farmhouses located in a rural area. The structural material is cast-in-situ concrete, timber, and 'masonry'. Altogether 168 dwellings, housing approximately 600 people, are considered. The analysis of the collected data is both qualitative and quantitative. Intensity assessments, using the MMI-scale were obtained for all the strong motion stations in the Icelandic Strong Motion Network in South Iceland as well as for every farm in the sample. The interpretation and analysis of the collected data are still going on.

INTRODUCTION

This paper deals with a case study of perceived effects and their relation to strong motion recordings with regard to human security inside residential houses. The case considered is the South Iceland earthquake sequence in 2000, especially the events on 17 and 21 June. The highest recorded ground accelerations in these events are 64% g ($M_w = 6.6$), and 85% g ($M_w = 6.5$) [1], and the highest assessed intensities are, respectively, MMI XI and IX [2, 3]. The objective of the study is to analyse inside-security problems surfacing in the wake of the earthquakes and suggest possible preventive remedies regarding future earthquakes. With regard to the objective, we have focused on structural damage to selected houses – including the fact that no houses collapsed - and, at the same time, we approached the people living in them. In this paper, we deal with the structural as well as social impact, including the people's emotional and physical reactions to the earthquakes. Hence, attempts to seek security inside residential houses, and

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supposedly fortunate circumstances are analysed, which we also attempt to relate to MMI-assessments. In two graphs, attempts are made to map the relation between assessed Modified Mercalli intensities versus peak ground accelerations and Arias intensities. The main focus of the present paper is on a study area in the countryside within 20 km of the causative faults for the June 17th and June 21st events. Social research methods (i.e., participant observations and in-depth interviews) are applied in this research project.

METHODOLOGY

Research area and sample selection

The random sample of 168 residential houses - also applied as the main approach to 160 victim-residents (informants) - relies upon a previous research sample [7]. The number of residential houses is around 5,100, with some 15,000 inhabitants in the South Iceland Lowlands. The sample was selected for detailed investigation in an area of 1700 km² with about 2,400 residential houses and a population of 5,000. The sample of houses was also selected to ensure that it would reflect fundamental geographical and structural qualities with regard to the nature of earthquakes: (1) geographical distribution, (2) age distribution, and (3) distribution of building types and building material. However, we added to the sample a few other residential houses of interest [see also 2, 3]: (1) houses, very close either to the epicentres or causative faults, and (2) houses equipped with strong motion stations. We deem these additions desirable with regard to the objective of this paper, i.e., study of the effects perceived by victims and the relationship of the perceptions to structural and non-structural damage: The social effects then are related to the recorded physical qualities.

Survey

The qualitative methodology produces descriptive data: people’s own written or spoken words and observable behaviour, focusing on concepts, insights, and understanding from patterns in the data, rather than collecting data to assess preconceived models, hypotheses or theories. The research design is flexible, with only vaguely formulated research questions, looking at settings and people holistically. The quantitative methodology relies upon the use of recorded data and questionnaires. To some extent the questionnaires were predefined, and they grew in part out of the data obtained with the qualitative methods [8, 9].

Ethical problems

Survey research involving people raises delicate ethical questions. The problems that may arise are extremely sensitive when employing social research methods to collect source material, such as participant observation and in-depth interviewing, i.e., sharing and observing the informants’ everyday life over an extended period. In this type of research ethical problems must be dealt with as an immanent element. Therefore, in this project, serious attempts have been made to practice the following ethical research policy: (1) The researcher shall approach and deal with the informant and his/her physical property with respect, fairness and delicacy. (2) No one shall be “pressured” or tricked into participating, and no one shall be shamed for not doing so. (3) Those agreeing to participate shall know from the very beginning that they can rely on confidentiality and remaining anonymous. (4) The informants shall always be informed of the real aim of the research at the first meeting. (5) The informants will be neither asked nor tricked into saying or doing anything that can harm their self-respect and interests or that of others. (6) Personal quotations, photos of people, their property and other intimate documentary source material will be neither distributed nor published without formal permission from the informants. (7) The informants’ property is dealt with as an extension of their self-image. In addition, we always try to convey our gratitude to informants and explain the applied value of their contribution to the project [3, 4, 5, 6, 7].

RESULTS

Fortunate timing and circumstances

According to the results of the 1996-1999 preventive SEISMIS research project in South Iceland [7], the greatest hazard to people is said to be loose household articles inside residential houses, even a potential cause of serious physical injury to people, as well as potential emotional and economic loss of intimate property (i.e., different household articles). According to [1, 11] none died, and only five injuries were recorded in the South Iceland 2000 earthquakes. However, enormous structural damage has been recorded [1, 2, 3, 12, 13], as well as major damage to potentially life-endangering heavy, loose household articles, flung onto floors inside many residential houses in the earthquake area [2, 3]. Many sample victims claimed that some of the loose articles inside their homes might - or would definitely - have caused serious injury (even death to people), if the June 17th 2000 earthquake had struck when most of the inhabitants were at home, i.e., inside their houses.

June 17th is the National Day of Iceland, a day of celebration, when the great majority of the Icelanders have the day off. The earthquake struck at 15:41 in the afternoon, during calm and sunny weather [1]. Hence most of the people living in the study area were celebrating, either out in the open or inside well-built meetinghouses [2, 3]. Therefore, the informants were asked what they thought would have happened if the June 17th earthquake had struck when most of them were at home, i.e., inside their houses, when, for instance, kids were playing/crawling on the floors, and weaker, elderly people were walking around. Many of the victims thought that many more serious injuries, even death, would have then occurred. With regard to these victims' views in connection with our observations and the recorded huge damage to loose household articles flung onto floors inside many houses whose occupants were celebrating outside [2, 3], it can be claimed that considerably more people would have been seriously injured physically, and lives even lost, if the earthquake on June 17th had, for instance, struck during the victims' usual inside-time at home.

A survey analysis two and a half years after the events, i.e., in late 2002, indicates that there is a significant relation between the victims' geographical distance from the June 17th 2000 causative fault, along with assessed intensity (MMI), and their point of view that the fortunate circumstances saved many victims from injury, or even death: the closer the victims were to the causative fault, along with higher intensity (MMI), the more of them claimed that the fortunate circumstances saved people. According to the survey analysis ($p < 0.05$) 73.7% of the victims in the whole research area (i.e., 87 of 118 sample-victims) thought that the fortunate circumstances of the June 17th 2000 earthquake probably, or definitely, saved many victims from injury (alleged potential death in two recorded comments, see below) (see Figure 1).

Several comments from the sample victims were also recorded besides their answers to the alternative questions. Generally, descriptive comments of those who thought that the fortunate circumstances probably or definitely saved many victims from serious physical injury (MMI VI-XI) appear to be answers like "it might have occurred [at home]", "might have happened in my kitchen", "would have been a great danger -concrete dust, and things spread all over [at home], "no doubt [at home]", "definitely", and "I am definitely sure. If the old married couple in [the farm] had been at home they might have injured themselves." However, more striking comments were recorded on potential injuries, and casualties, like the following two comments from Hella Village: "What blind luck that people were not at home. The electricity and the telephone went out, pieces of glass were all over, and shelves fell down. Any other time, many people would have lost their lives", and "surely accidents would have occurred involving people - casualties."

With regard to the above analysis it can be stated that the fortunate circumstances, i.e., the fortunate timing of the June 17th earthquake, definitely saved many earthquake-victims from injury, possibly death in some cases.

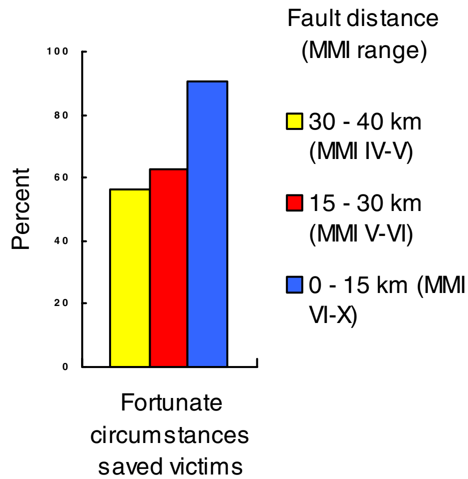

Figure 1: A survey analysis: χ^2 (2, N = 118) = 15.199, $p < 0.05$, indicates that 90.7% of the victims (i.e., 49 of 54 sample victims), within MMI-range VI-X (distance to the June 17th causative fault 0-15 km), deemed that the fortunate circumstances of the earthquake probably, or definitely, saved many victims from injury, even death, 62.5% (i.e., 20 of 32 victims) within MMI-range V-VI (15-30 km from the fault) thought this, and 56.3% (i.e., 18 of 32 victims) within MMI-range IV-V (30-40 km from the causative fault).

The victims' perceived impossibility of seeking security inside houses

In spite of the fact that most of the June 17th earthquake (sample) victims were celebrating the National Day of Iceland, either out in the open or inside well-built meetinghouses when the earthquake struck, quite a few of them were at home, inside their residences. Two informants (sample victims), both positioned inside the residence with strong motion station no. 103 think that it probably would have been impossible for them to move from their position during the June 17th (MMI IX) and June 21st (MMI IX) earthquakes. They were both lying in bed during the latter earthquake. They then made the hasty decision to remain there, since they assumed that it could be physically dangerous to try escaping to security. When the former earthquake struck (MMI IX), Informant 2 was resting (lying down) on a sofa in the living room. He stated: "I had to hold" onto the sofa, "it was the only thing I was capable of doing, holding on." Informant 1 was sitting in a chair at the kitchen table. He described his attempt to get up: "I intended to get up to close the refrigerator, which had opened, but then I just plumped down on the chair again."

Another victim stated, when asked whether he could have moved to a more secure position inside (MMI VIII-) said: "No, it was totally impossible." (See the victim's position on Photo B in Figure 2). At another farm, located on the June 17th earthquake's epicentre (MMI X, X+, XI-, i.e., a bit under XI), an Informant outdoors on a moor, fell to his knees (MMI X): "I fell ... thought I could stand up, but I didn't, I was on my knees in a moment." One informant, who was standing on the wooden terrace of a summerhouse, approximately 500 meters away, described his experience (MMI X). He said that the first earthquake shock had come from beneath, i.e., he found himself standing right above the earthquake focus. He was thrown off the terrace, though without causing any physical injury to him. He stated: “There is no handrail” on the terrace “and then in a moment I found myself off it…I tried to grasp something…I never got the feeling that I was flying in the air, but suddenly I was down.” This informant tried to bend and hold with his hands onto the planking of the terrace, but it didn’t help, he was thrown off all the same. Results, based on analyses of in-depth interviews and field notes, indicate that physical movement of people and their escape from inside houses to some kind of security (getting out, holding on, going under tables, getting in corners of rooms and doorframes, according to authoritative preventive advice) were perceived as dangerous or impossible at intensities passing MMI VIII. However, survey analyses ($p < 0.05$) two and a half years after the events (in late 2002) indicate a lower MMI, i.e., MMI VII (see Figure 3).

Figure 2: An earthquake-resistant residential building in the June 17th 2000 earthquake area (distance to fault 3,4 km). Photo A: The residential building from outside. Photo B: The victim’s position inside (inserted figure) during the earthquake (MMI VIII). Photo C: A bookcase had fallen on the bed when the resident was absent (same building).

A questionnaire survey analysis ($p < 0.05$) indicates that there is a significant relationship between the victims' MMI assessments (related to geographical distance from the June 17th 2000 causative fault), and their perception that they couldn't move to some kind of security (for instance, seeking security under tables, in doorframes, and corners inside houses, according to authoritative preventive advice): The higher the MMI assessments of the victims (and consequently the closer to the causative fault), the more who claimed that they could not move to some kind of security inside their houses. According to the survey analysis ($p < 0.05$) 28.4% of the sample victims in the whole area (i.e., 25 of 88 sample victims) claimed that they did not dare or could not move to some kind of security inside their houses (see Figure 3).

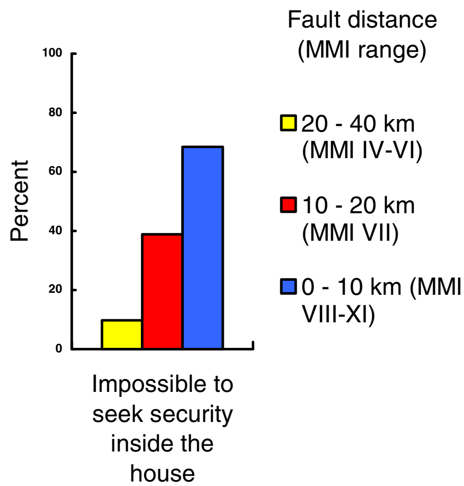

Figure 3: A survey analysis: χ^2 (4, N = 88) = 31.983, $p < 0.05$, indicates that 9.8% of the victims (5 of 51 sample victims) within MMI-range IV-VI (distance to fault 20-40 km) claimed (perceived) that they did not dare or could not move to some kind of security inside their houses, 38.9% (7 of 18 victims) within MMI VII (approximate distance to fault 10-20 km) claimed this, and 68.4% (13 of 19 victims) within MMI-range VIII-XI (approximate distance to fault 0-10 km).

On the basis of the above analysis, it can be claimed that seeking security inside houses at intensities approaching MMI VII is frequently perceived as dangerous or impossible, and this perception spreads and heightens, as the MMI assessments heighten (consequently when getting closer to the causative fault): MMI VII appears to be a turning-point, or in other words, a boundary between a rather rare and quite common perception. However, the survey analysis also indicates that quite a few victims succeeded in seeking security inside their homes as the earthquakes struck. Reconsideration of advisories on seeking security inside houses is recommended. However, taking into consideration the potential danger of "flying" loose household articles, and that quite a few victims succeeded in seeking security inside their homes as the earthquakes struck, it can be stated that the authoritative advisories indeed remain high in value as a public preventive measures. Therefore inhabitants in earthquake-prone areas, and this applies to inhabitants in the South Iceland Lowlands, should always keep these advisories in mind as these advisories might indeed provide the only way to avoid inside danger, and thus help an earthquake-harassed victim to avoid injury or even death during the "seconds" the earthquake is striking and threatening.

Relation between perceived intensities and recorded strong ground motion
As mentioned in the Introduction, the Modified Mercalli intensity (MMI) was obtained for all the strong motion stations in South Iceland. An attempt was made to correlate these values with recorded strong ground motion. First, the MMI was related to the peak ground acceleration as recorded on 17 and 21 June, respectively. As the Mercalli intensity describes the holistic effects of the earthquake, it is necessary to relate it to a measure representing the overall recorded ground acceleration. It is suggested that the application of the SRSS (square root of the sum of the squares) peak ground acceleration is defined as:

$$R_{srss} = \sqrt{X_{pga}^2 + Y_{pga}^2 + Z_{pga}^2} \quad (1)$$

Here, X_{pga}, Y_{pga} and Z_{pga} are the peak ground acceleration components, respectively, two horizontal components and one vertical. The data obtained are displayed in Figure 4 along with the following regression curve:

$$Y = \alpha X^{\beta} \quad (2)$$

Here, X refers to the srss-values (see Eq. (1)), Y to the MMI-values; furthermore, $\alpha = 3.0841$ and $\beta = 0.2130$ are regression parameters obtained by linear regression after transforming the data in accordance with Eq. (2). The fit is seen to be fair with a coefficient of determination equal to 0.74. It is seen that the data tend towards zero in the lower end and approach MMI = XII in the upper end, which inevitably leads to a non-linear relationship, as indicated by the regression curve. It should be noted that the duration is not reflected in the srss peak ground acceleration. On the other hand, the Arias intensity does account for the duration. The definition is as follows [2, 15]:

$$I_{ij} = \frac{\pi}{2g} \int_0^T a_i(t) a_j(t) dt \quad (3)$$

where $a_i(t)$ is the i-component of the ground acceleration as a function of time; T is the duration of the recordings, and g is the acceleration of gravity. The trace of the intensity tensor, which constitutes the 'first' invariant of the tensor, is suggested as a representative measure of the strong ground motion in this context. That is:

$$I_1 = I_{xx} + I_{yy} + I_{zz} \quad (4)$$

where the indices x, y and z refer to two horizontal components of acceleration and one vertical component. Figure 5 shows the available data along with a regression curve based on Eq. (2), with the following parameters: $\alpha = 3.5285$ and $\beta = 0.1404$. The coefficient of determination turned out to be 0.72, or slightly lower than in the above-mentioned case using the srss peak ground acceleration. It can be clearly seen that the non-linear behaviour of the regression curve, the rapid increase in MMI-values at low Arias intensities, followed by a much slower increase rate at higher Arias intensities, tends towards the upper-bound, MMI = XII.

The graphs in Figures 4 and 5 represent an attempt to provide a graph interrelating seismic measurements (strong ground motion) to individually perceived, scaled assessments (MMI assessments). However, it should be stressed that the data used in the analysis applied for this purpose are very limited. Therefore, a general conclusion can only be drawn cautiously, and any generalisation should be avoided. It is worth underlining that some authors have come to the conclusion that the spreading in data collected during different events is too great to allow the assumption of any correlation between intensity and acceleration [2, 15]. However, the graphs can be cautiously applied to assess the "likely" intensity in both ways, for instance on the basis of the outstanding recorded descriptions of historical earthquakes [3, 17], which in many cases provide for MMI assessments, and then consequently a "likely" SPSS Peak Ground Acceleration (see Figure 4) or Arias intensity (see Figure 5). However, EMS (European Macroseismic Scale, [18]) assessments, made for at least every sample farm in research area 1 and every strong-motion station, is of additional value, i.e., assessments according to the EMS, by taking into consideration the sketches, notes, and photographs on structural and environmental damages, disturbance of loose household articles, and the informants' descriptions of the impact of the earthquake [2, 3, 11, 17].

The research presented in this paper gives an overview of the societal effects of the June 2000 earthquakes. However, further research is necessary to broaden perspective on the impact and to conduct more in-depth analysis of specific topics, for instance, regarding the social impact of structural damage, related to the June 2000 South Iceland earthquakes.

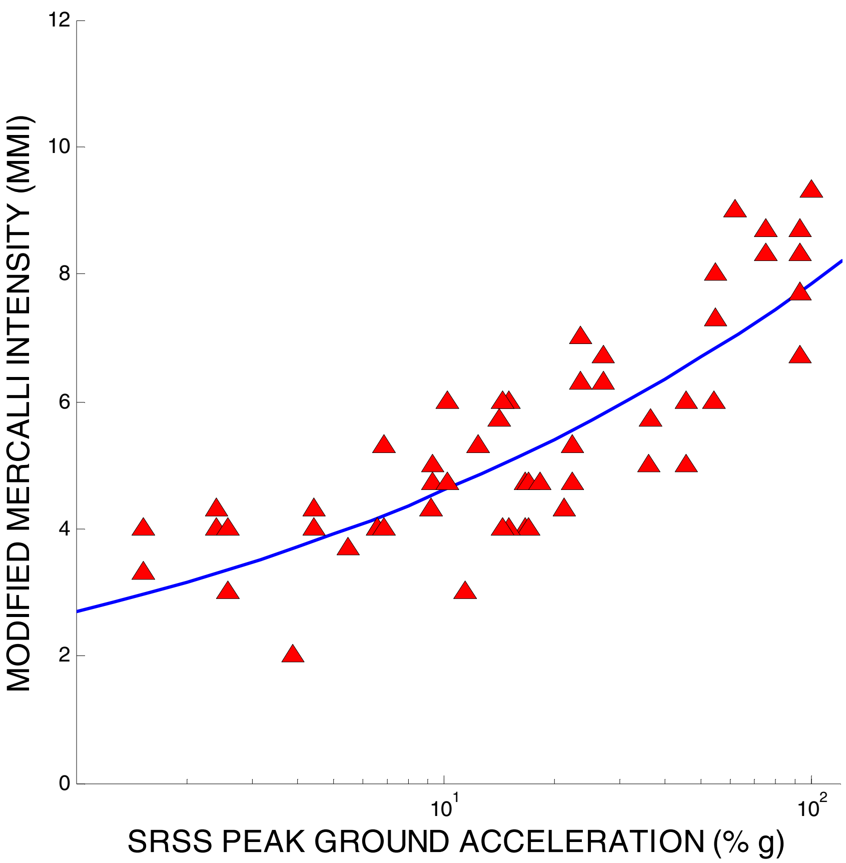

Figure 4: Modified Mercalli intensity as a function of srss peak ground acceleration. The triangles represent data from the earthquakes on 17 and 21 June 2000. The blue curve is obtained by linear regression analysis after transformation of the data.

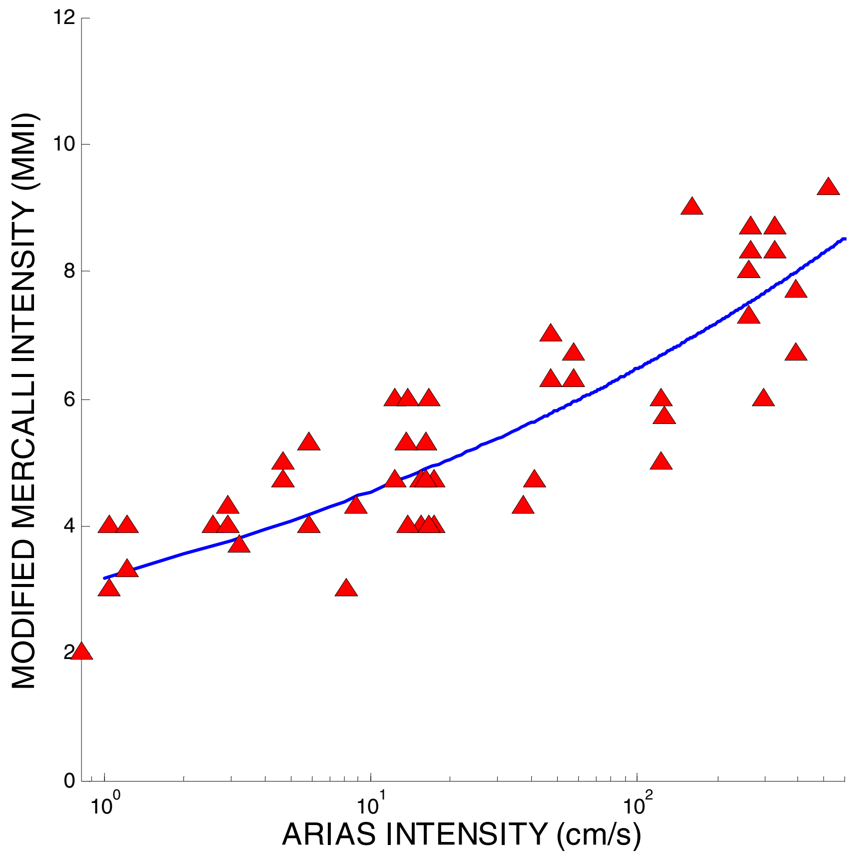

Figure 5: Modified Mercalli intensity [2, 15] as a function of Arias intensity, represented by the first invariant of the Arias intensity tensor. The triangles represent data from the earthquakes on 17 and 21 June 2000. The blue curve is obtained by linear regression analysis after transformation of the data.

"Earthquake-secure" community

Fortunately the 2000 South Iceland earthquakes caused no casualties, and only five physical injuries were recorded [1, 2, 3, 11]. However, insurance compensation already paid owing to earthquake-related structural damage to buildings had reached $US 31 million by October 1st 2002 [20]. Observations and a survey [1, 2, 3, 7, 13] indicate that there are two main reasons for the absence of serious injuries or loss of life:

(1) None of the residential buildings exposed to the earthquakes collapsed, although many of them were severely damaged. There are several reasons for this: first, a relatively high percentage of the residential buildings are made of timber, which has proved to be very earthquake resistant. Second, residential buildings of concrete are traditionally cast in-situ, which yields strong and resistant structures, even in the case of limited steel reinforcement. Third, all the buildings in the earthquake area are low-rise, in most cases only one story, where the dimensions of structural elements are not governed by codified strength requirements, the results being buildings with very high specific strength. Finally, a minor fraction of the residential buildings were made of 'masonry' [7, 20].

(2) As discussed and analysed in the above sections, the first high-intensity earthquake struck (at 15:41) on June 17th, which is the National Day of Iceland, a day of celebration, when a great majority of Icelanders have the day off [1, 2, 3]. Hence, most of the earthquake victims were absent from their homes celebrating, either out in the open, or inside well-built meetinghouses, and therefore fortunately avoiding the observed and recorded life-endangering, earthquake-related damage of loose, heavy household articles, flung onto floors inside many residences during the earthquake [1, 2, 3, 7].

With regard to the above reasons for the absence of serious injury or loss of life, it can be stated that at least one of the reasons is proper residential building material and building types (i.e. none of the buildings collapsed). In this sense the inhabited area in The South Iceland Lowlands might be considered as "earthquake secure" or "earthquake resistant". However, (1) life-endangering, non-structural damage from heavy loose household articles flung onto floors was enormous, and (2) with regard to the above discussion of the fortunate circumstances, i.e., the fact that most of the victims were not at home inside their houses when the earthquake struck, definitely saved many victims from injury, or even death. In this sense the inhabited area in the South Iceland Lowlands is non-earthquake secure or non-earthquake resistant. We therefore recommend, as preventive pre- and post-earthquake action, a radical improvement of general societal education about the South Iceland 2000 earthquakes' impact. Insurance auditors should be of special concern. In the post-earthquake societal healing process, the disaster victims should always enjoy some benefit of the doubt.

The fact that it may be "impossible" to move to some kind of security inside a house in an earthquake-prone area while an earthquake is striking stresses the great importance of the pre-earthquake arrangements for loose household articles (e.g., fastening down bookshelves, closets, loose articles, etc.), as it may be the only "available" protection against injury or even death during an earthquake.

DISCUSSION AND CONCLUSIONS

The June 2000 South Iceland earthquakes caused no casualties, and only five physical injuries were recorded as no houses collapsed, and no one was seriously injured by loose household articles. However, the serious danger from heavy, loose household articles flung onto floors inside many houses, whose occupants were celebrating outside, indicates that considerably more people would have been badly injured physically, and lives even lost, if the earthquake on June 17th had, for instance, struck during the victims' usual inside-time at home.

The victims' attempt to seek security inside houses, according to authoritative advisories (e.g. getting out, holding on, going under tables, getting in corners of rooms and doorframes), at intensities approaching MMI VII is frequently perceived as dangerous or impossible, and this perception spreads and heightens, as the MMI assessments heighten: MMI VII appears to be a turning-point, a boundary between a rather rare and quite common perception.

The "fact" that it may be "impossible" to move to some kind of security inside a house in an earthquake-prone area while an earthquake is striking stresses the great importance of pre-earthquake arrangements of loose household articles (e.g., fastening down bookshelves, closets, loose articles, etc.), as it may be the only "available" protection against injury, or even death, during an earthquake.

Reconsideration of advisories on seeking security inside houses is recommended. However, taking into consideration the potential danger of "flying" loose household articles, and the fact that several victims succeeded in moving to some kind of security inside their homes as the earthquakes struck, it can be stated that the authoritative advisories indeed remain of high value as public preventive measures. Therefore, inhabitants in earthquake-prone areas, and this applies to inhabitants in the South Iceland Lowlands, should always keep these advisories in mind as they might indeed provide the only way to avoid actual inside danger and thus help an earthquake-harassed victim avoid injury or even death during the "seconds" the earthquake is striking and endangering the victim.

A statistically significant, non-linear association can be established between earthquake intensity, MMI, and holistic measures of ground acceleration represented by SRSS-peak ground acceleration or Arias intensity for the present earthquakes.

MMI-related, post-earthquake impact research will be difficult or even impossible to utilise for comparative references in corresponding future research without continuing MMI assessment. The data collected are believed to be important for vulnerability and risk analysis, at least for the study area.

ACKNOWLEDGEMENTS

The present work was supported by a grant from the University of Iceland Research Fund. This important support is greatly acknowledged.

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