

Damage assessment for two Icelandic earthquakes

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ABSTRACT: The seismicity of Iceland is introduced followed by a discussion of the traditional Icelandic building types. The damage caused by two destructive earthquakes in Iceland, in 1934 and 1976, is documented. The damage factors for the different building types are assessed, for each of the earthquakes. A comparison is made to other studies and vulnerability data from the literature.

1 INTRODUCTION

In order to predict damage to buildings in future earthquakes and to develop reasonable seismic design and retrofitting criteria, knowledge of the effect of earthquake induced ground motion on the buildings is essential.

This paper deals with damage to buildings in two Icelandic earthquakes in this century. First, the seismicity of Iceland is discussed. Then the building types are reviewed and the damage in each of the earthquakes is documented. Finally, a comparison is made between the two earthquakes and the Icelandic experience is compared to foreign studies.

2 THE SEISMICITY OF ICELAND

Iceland is located on the Mid-Atlantic Ridge, the spreading center between the North American plate and the Eurasian plate. Figure 1 shows the location of the spreading axes, as well as the major seismic zones (shaded areas). The most of the volcanic activity of Iceland is confined to the central spreading axis, while the major earthquakes originate in the fracture zones to the north and south of it (Einarsson, 1991; Björnsson and Einarsson, 1981; Tryggvason, 1973).

In the 20th century, two earthquakes have caused considerable damage in Iceland (see figure 2). Both originated in the northern zone. The first one was a magnitude 6.3 event. It occurred on June 2nd 1934. The epicenter was in Eyjafjörður, central North-

Iceland, 2 to 3 km outside a small fishing village named Dalvík. The second one occurred on January 13 1976. It was a magnitude 6.5 event, located approximately 6 km west of an even smaller fishing village called Kópasker in Öxarfjörður, Northeast Iceland.

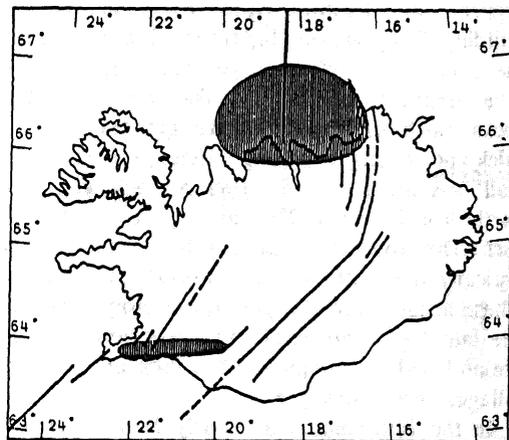


Figure 1. The tectonics and seismicity of Iceland. Heavy lines represent spreading axes, shaded regions the major seismic zones

3 THE ICELANDIC BUILDINGS

Iceland is not rich of natural building material there are no iron mines or forests. Consequently, the traditional Icelandic house is made of the only

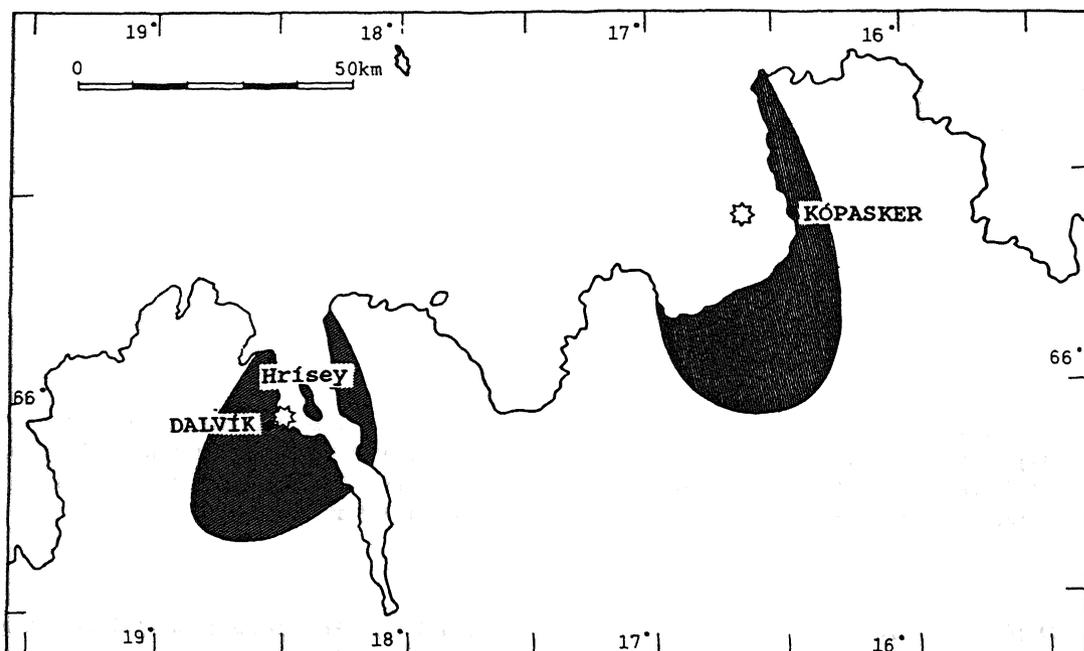


Figure 2. The epicenters of the earthquakes in this study (stars) and the areas where damage occurred to buildings (shaded).

domestic building materials: stone, turf and earthfill. Figures 3 and 4 show a typical traditional Icelandic building. They varied slightly in different parts of the country at different periods, but the basic structure remained the same. The walls are made of rocks, earth and turf. They are approximately 1 m thick and roughly 1.5 m high. Often, the base of the wall was made of two rows of rock with some earthfill in between. The upper part was made of turf. The roof is supported by a wood frame, typically made of two sandwiched layers of turf. These houses were always only one story high. Until the late 19th century, almost every house in rural Iceland and the majority of houses in the fishing villages were of this type.

In the 19th century and early 20th, some wood frame houses were built, mainly in the fast growing villages at the seaside. Most of these houses were imported from Norway and assembled on site. They were hardly ever more than 2 stories high, but often there was a basement underneath. Many of these houses were covered with sheets made of corrugated iron to protect the wood from rain and fire.

The third and last type of houses discussed here is the far most common nowadays. It is a cast-in-place concrete building with concrete shear walls and slabs. In the early 19 hundreds and even until

the 1970's the shear walls were lightly or practically not reinforced with steel bars except around openings such as doors and windows. The slabs, however, were reinforced. The majority of these houses are single family, one or two stories.

As a rule, Icelandic buildings are founded on bedrock.



Figure 3. A typical 19th century Icelandic farmhouse

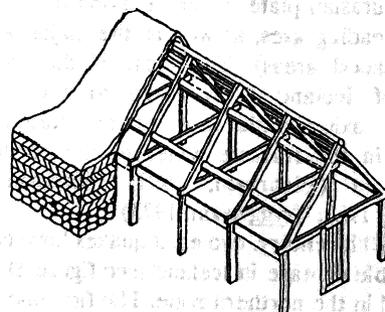


Figure 4. The structure of a typical, traditional Icelandic house

4 THE 1934 DALVÍK EARTHQUAKE

The hardest hit areas were the fishing villages of Dalvík and Hrísey with epicentral distances of 2.5 and 5 km respectively. There, the majority of the houses were wood frame or concrete shear wall buildings with concrete slabs. There were also many farms affected, and the vast majority of the farmhouses were of the traditional Icelandic type.

The damage in this earthquake is documented in Figures 5 to 9. The damage factor is defined as the ratio between the damage and the replacing cost. Each column represents a 0.1 wide range in the damage factor - except the one to the left of 0.0 - which represents no reported damage. The estimates of the ground motion intensity are taken from Thórarinsson, 1937.

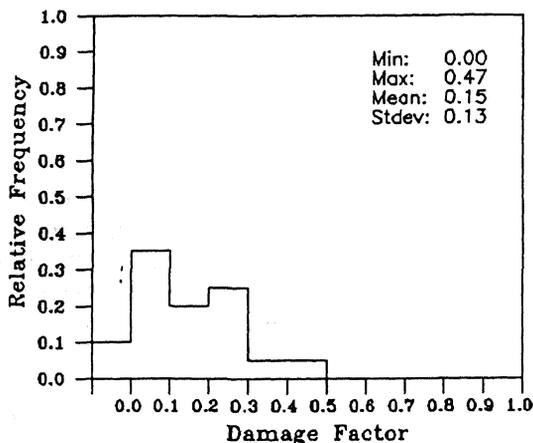


Figure 5. Damage in the 1934 Dalvík earthquake. Wood frame buildings. MMI = IX

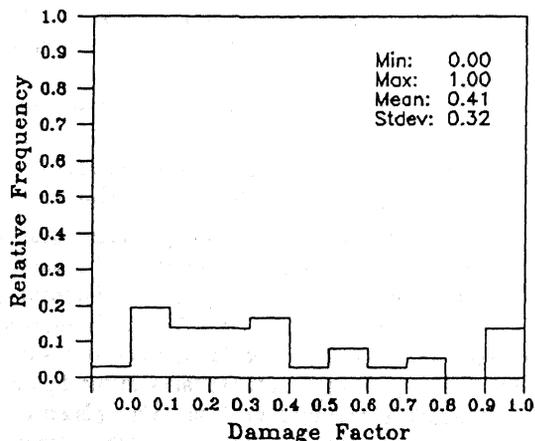


Figure 6. Damage in the 1934 Dalvík earthquake. Concrete shear wall buildings. MMI = IX

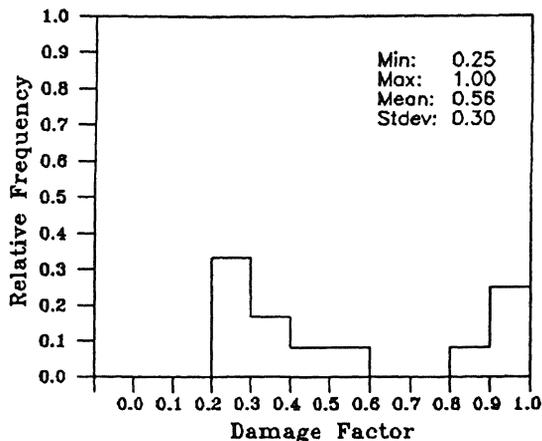


Figure 7. Damage in the 1934 Dalvík earthquake. Traditional Icelandic buildings. MMI = IX

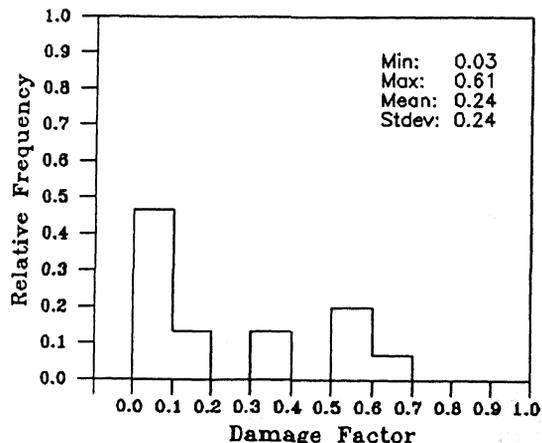


Figure 8. Damage in the 1934 Dalvík earthquake. Concrete shear wall buildings. MMI = VIII

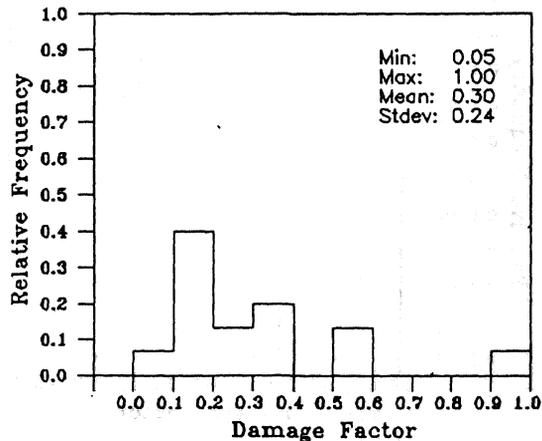


Figure 9. Damage in the 1934 Dalvík earthquake. Traditional Icelandic buildings. MMI = VIII

5 THE 1976 KÓPASKER EARTHQUAKE

The fishing village of Kópasker, approximately 6 km from the epicenter, was hardest hit. Also affected were the farms in the neighbouring communities of Núpasveit, Öxarfjörður and Kelduhverfi. The vast majority of the houses were lightly reinforced cast-in-place concrete shear wall and slab buildings.

The damage is shown in Figures 10 to 12. No strong ground motion recordings exist from this earthquake, but the intensities have been estimated.

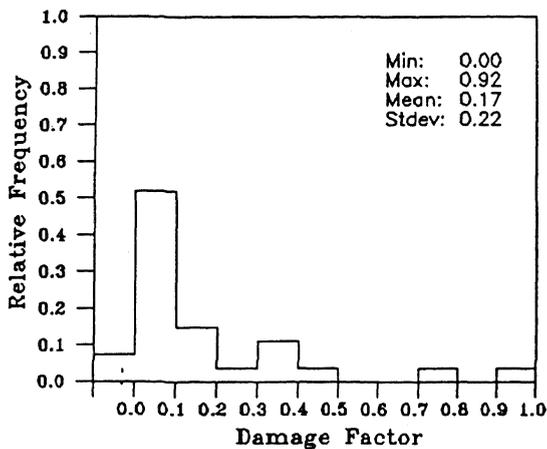


Figure 10. Damage in the 1976 Kópasker earthquake. Concrete shear wall buildings. MMI = VIII

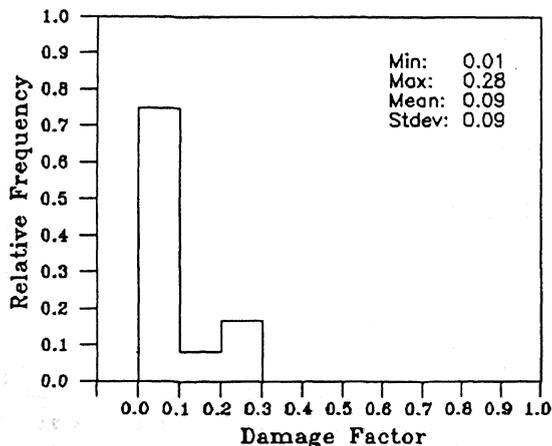


Figure 11. Damage in the 1976 Kópasker earthquake. Concrete shear wall buildings. MMI = VII

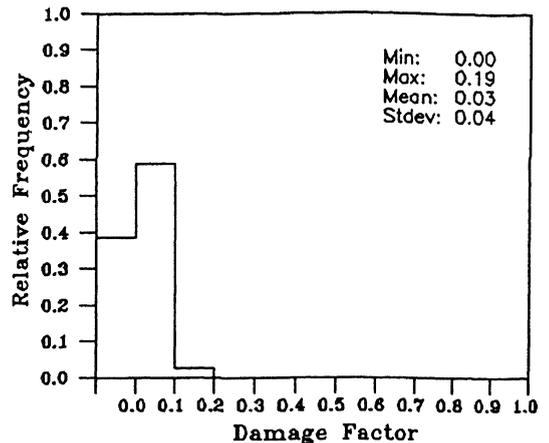


Figure 12. Damage in the 1976 Kópasker earthquake. Concrete shear wall buildings. MMI = VI

6 DISCUSSION AND CONCLUSION

Figures 8 and 10 show striking similarities, which indicates that the seismic resistant of concrete shear wall buildings was almost the same in 1976 as it was in 1934. This is, however, not very surprising because most of the houses struck by the 1976 earthquake were built before 1960 and had hardly any steel reinforcement in the walls. In the following, therefore, all the concrete shear wall buildings are grouped into one group.

A summary of the findings for the concrete buildings is given in figure 13. The minimum, the mean, the mean plus one standard deviation, and the maximum damage factors are plotted against the ground motion intensity. It is worth noting, that for every level of ground motion intensity, some buildings exist which suffer hardly any or even no damage.

The mean damage factor for each intensity level is compared to some foreign studies in figure 14. Sauter and Shah (1978) estimated damage of 10 building classes in Costa Rica. The crosses (-x-) represent unreinforced masonry, low quality buildings, and the pluses (-+-) reinforced masonry, medium quality, no seismic design. It is interesting to note how closely the curve for the reinforced masonry matches the curve for the concrete shear wall buildings in this study (squares in the figure). The triangle curve is taken from Algermissen and Steinbrugge (1984), building class "mixed construction, unreinforced masonry". These are the damage factors used by the USGS in USA.

Compared to this study on Icelandic, unreinforced concrete buildings, the American damage factors would overestimate the damage for low intensities, and underestimate it for high intensities.

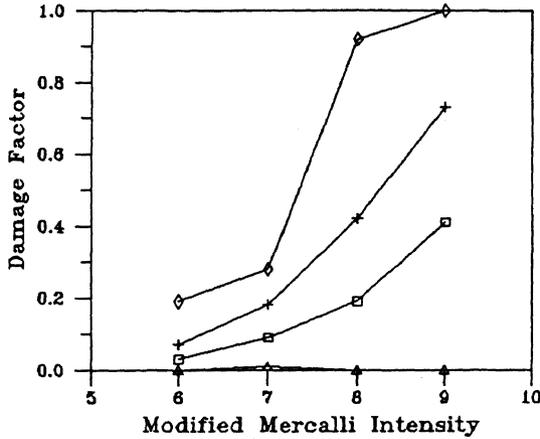


Figure 13. Damage of concrete shear wall buildings in the 1934 Dalvík and 1976 Kópasker earthquakes. Triangles: minimum; squares: mean; pluses: mean plus one standard deviation; diamonds: maximum

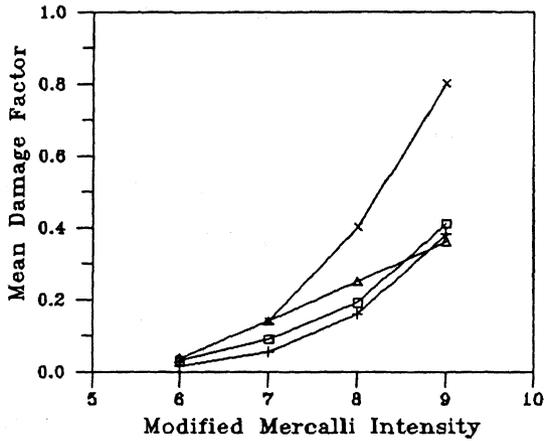


Figure 14. Comparison of mean damage factors obtained from different studies. Squares: concrete shear wall (this study); triangles: unreinforced masonry (Algermissen and Steinbrugge 1984); pluses: reinforced masonry (Sauter and Shah 1978); crosses: unreinforced masonry (S & S 1978)

This study is compared to the damage probability matrixes given by ATC-13 (1985) in figures 15 to 19. In all of the figures, the Icelandic experience is represented by the dashed lines. The earthquake engineering facility classes used for the comparison

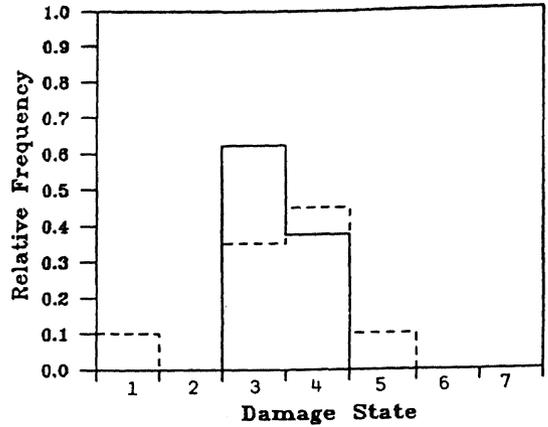


Figure 15. Relative frequencies of damage states. Wood frame buildings. MMI = IX. Solid: ATC-13; dashed: this study

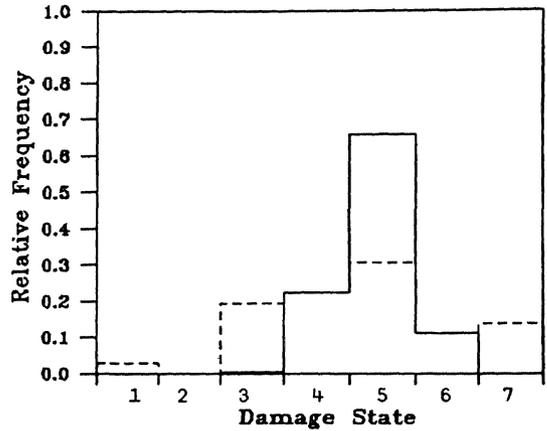


Figure 16. Relative frequencies of damage states. MMI = IX. Solid: ATC-13, URM, low rise; dashed: this study, concrete shear wall

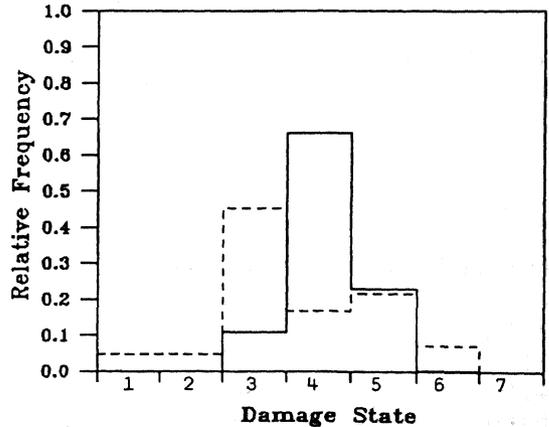


Figure 17. Relative frequencies of damage states. MMI = VIII. Solid: ATC-13, URM, low rise; dashed: this study, concrete shear wall

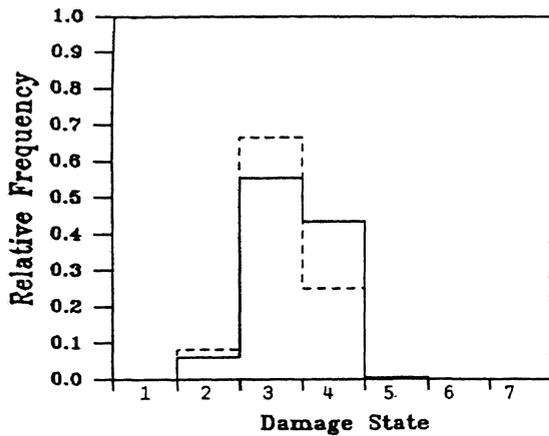


Figure 18. Relative frequencies of damage states. MMI = VII. Solid: ATC-13, URM, low rise; dashed: this study, concrete shear wall

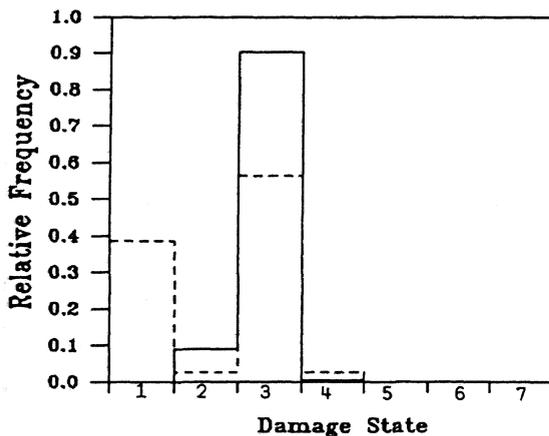


Figure 19. Relative frequencies of damage states. MMI = VI. Solid: ATC-13, URM, low rise; dashed: this study, concrete shear wall

are number 1 (wood frame, low rise) and number 75 (unreinforced masonry, bearing wall, low rise). The damage states used by ATC-13 are tabulated in table 1.

Table 1. Damage states used by ATC-13

Damage state	Damage factor
1 None	0.00
2 Slight	0.00 - 0.01
3 Light	0.01 - 0.10
4 Moderate	0.10 - 0.30
5 Heavy	0.30 - 0.60
6 Major	0.60 - 1.00
7 Destroyed	1.00

It can be seen, that the observed damage in the two Icelandic earthquakes usually has a wider range than predicted by ATC-13, and the ATC-13 damage probability matrixes would consistently underestimate the number of buildings which sustained light or none damage. It should be noted that ATC's damage probability matrixes for earthquake engineering facility class number 9 (reinforced masonry shear wall without moment resisting frame, low rise) did not compare well with the Icelandic unreinforced concrete shear wall buildings.

The results presented in this paper are only preliminary, the work is still in progress. Furthermore, the Modified Mercalli intensity scale has not been properly adjusted to Icelandic conditions and there may exist some discrepancies in the intensity estimates. Hence, these results cannot be used directly to predict damage in future earthquakes in Iceland. They can, however, and will be used to develop such a methodology in the future.

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