VEÐURSTOFA ÍSLANDS

Report
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Seismic wave attenuation for earthquakes in SW Iceland

First results

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Contents

ABSTRACT

Earthquakes of local moment magnitude (M_{lw}) 3.5 to 6.5 in SW Iceland were selected from the database of the national seismic network in Iceland, the SIL-network. The attenuation was investigated for peak ground acceleration and velocity. Comparison with formerly derived attenuation formulas for acceleration reveal larger accelerations in large earthquakes for shorter distances than attenuation calculated according to the SIL-catalogue. In smaller earthquakes the accelerations calculated from the SIL-data are smaller. Attenuation formulas for velocity have not been presented before.

INTRODUCTION

This work is a part of the SAFER project that is funded by the EU. The purpose of deriving the relations between magnitude, distance and velocity on one hand and acceleration on the other hand is to make use of them to create shake maps for the south Iceland seismic zone (SISZ) and adjacent areas like the Reykjanes peninsula (RP), areas that are shown on figure 1.

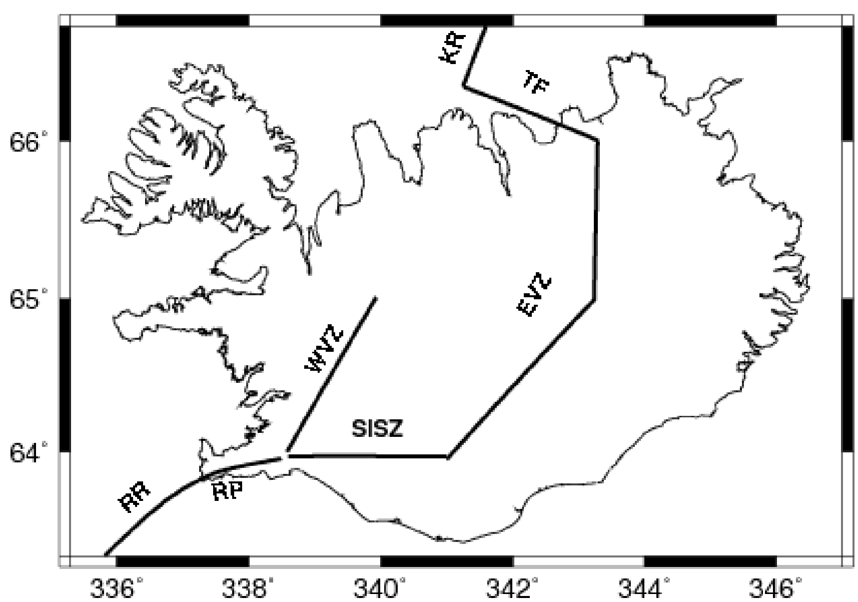

Figure 1. *The main tectonic and volcanic zones in Iceland. The following abbreviations are applied: RR Reykjanes ridge, RP Reykjanes peninsula, WVZ western volcanic zone, SISZ south Iceland seismic zone, EVZ eastern volcanic zone, TF Tjörnes fracture zone, KR Kolbeinsey ridge.*

The Reykjanes peninsula and the south Iceland seismic zone are left lateral shear or transform fracture zones that connect the Reykjanes ridge (RR) and the eastern volcanic zone (EVZ) that runs through central Iceland. The Reykjanes peninsula is an oblique shear zone but the south Iceland seismic zone is close to being a pure shear zone.

In the south Iceland seismic zone the largest earthquakes reach magnitudes around 7. On the Reykjanes peninsula earthquakes reach magnitude 6, possibly 6.5. The largest earthquakes in these zones occur in the eastern part of the south Iceland seismic zone.

The south Iceland seismic zone is a relatively densely populated farming area with several villages. The population that can be directly affected by large earthquakes can amount to 15.000. Vulnerable infrastructures like power lines, telecommunication and roads can also be affected.

These facts demand a rather fast location of damage area and estimate of the degree of damage when an earthquake has occurred to aid rescue teams and planning regarding the disaster management. The shake map is an excellent tool for this purpose (USGS, webpage reference).

In 2003 an attenuation formula for peak ground horizontal acceleration was derived (Halldórsson P. and B. I. Sveinsson, 2003). This formula was derived according to the Eurocode standard. The dataset that the formula is based on are earthquakes of magnitude 4 and larger from the years 1896 to 2000. The dataset consists of 131 observations of horizontal acceleration, mainly from the years 1988, 1999 and 2000 (University of Iceland, webpage reference) and acceleration estimates from the 1896 earthquake sequence.

DATA AND PROCESSING

Earthquakes of local moment magnitude (M_{lw}) larger than 3.5 in the latitude range 63.5 to 64.3 degrees north and longitude range 18 to 23.5 degrees west were selected from the SIL-database. The local moment magnitude is based on the standard fault plane solution of the SIL-system. The data covers the time span from July 1992 to April 2007. The catalogue is more or less complete for earthquakes with magnitude above M_{lw}3.5. Still some events are missing because of the earthquake swarm character of the activity, particularly following large earthquakes. The number of earthquakes with M_{lw} larger than 3.5 is 342. Due to the complex wave trains where several earthquakes are superimposed we selected only 64 earthquakes with "clean" waveforms. Altogether the datasets consist of 1065 velocity triples (peak amplitude of velocity, distance, magnitude) and 1085 of acceleration (peak amplitude of acceleration, distance, magnitude) covering distances from few km to 350 km. The acceleration and velocity values we use are vector sum of both horizontal and vertical components.

Most of the instruments of the SIL system are 5 Hz Lennarz seismometers. Few are 1 Hz and long period instruments. The sampling frequency is 100 Hz.

ANALYSIS OF THE DATA

The data was analyzed by use of the R statistical package (R Development Core Team (2007)).

To investigate the quality of the data we analyzed the relation between peak amplitude and distance from the epicentre in several individual earthquakes to get a measure of the quality of the data (Figures 2 and 3). The attenuation in individual earthquakes follows approximately following relations:

$log10(acceleration) \sim -2.0 * log10(\mathrm{R}) + constant$ $[\mathrm{m/s^2}]$

$log10(velocity) \sim -1.7 * log10(\mathrm{R}) + constant$ $[\mathrm{m/s}]$

where R is the distance in km from the station to epicentre. The *constant* is different for different magnitudes. These relations were well behaved to the extent that following linear models could be analyzed:

$$log10(acceleration) = a * log10(\mathrm{R}) + b * log10(\mathrm{M}) + c$$

$$log10(acceleration) = a * log10(\mathrm{R}) + b * \mathrm{M} + c$$

$$log10(velocity) = a * log10(\mathrm{R}) + b * log10(\mathrm{M}) + c$$

$$log10(velocity) = a * log10(\mathrm{R}) + b * \mathrm{M} + c$$

where M is the local moment magnitude (M_{lw}) and R the distance in km to the epicentre.

RESULTS

The result of the analysis is as follows:

Peak acceleration in m/s^2:

$$log10(acceleration) = -1.95600 * log10(\mathrm{R}) + 9.59878 * log10(\mathrm{M}) - 4.87778$$

$$log10(acceleration) = -1.96297 * log10(\mathrm{R}) + 0.89343 * \mathrm{M} - 2.65660$$

or as proportion of the acceleration of gravity:

$$log10(acc/g) = -1.95600 * log10(\mathrm{R}) + 9.59878 * log10(\mathrm{M}) - 5.8699$$

$$log10(acc/g) = -1.96297 * log10(\mathrm{R}) + 0.89343 * \mathrm{M} - 3.6487$$

Peak velocity in m/s:

*log10(vel) = -1.72016 * log10(*R*) + 11.16768 * log10(*M*) - 7.58101*

*log10(vel) = -1.72828 * log10(*R*) + 1.03113 **M *- 4.96190*

The fit is similar for these regressions and the summary of it is shown in appendix A.

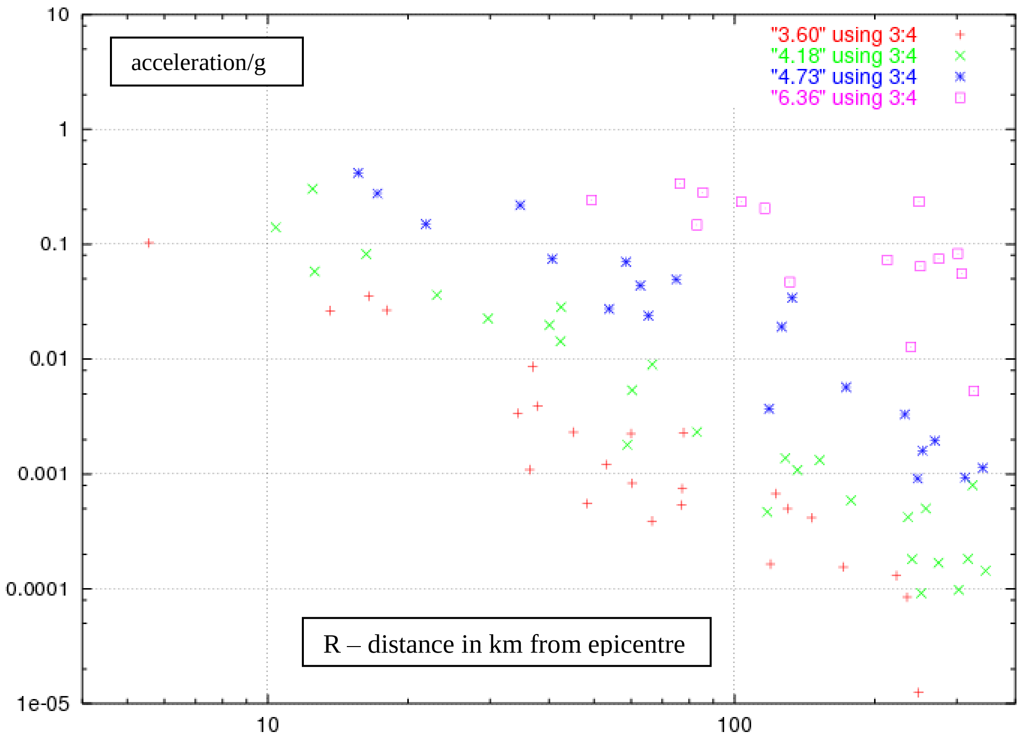

Figure N10. *Attenuation of peak acceleration in 4 earthquakes in SW Iceland.*
Figure 2. *Attenuation of peak acceleration is shown as a fraction of the acceleration of gravity in four earthquakes. The numbers in the upper right corner show the magnitude individual earthquakes and their mark.*

DISCUSSION

The present Eurocode attenuation formula (Halldórsson P. and B. I. Sveinsson, 2003) is:

*log10(acc/g) = -1.49890 * log10(R) + 0.48400 * M - 2.16400*

This formula is mainly based on horizontal acceleration measurements on accelerometers that are operated by the Earthquake Engineering Research Centre of the University of Iceland (webpage reference). Most of the events used were in south Iceland in the years 1998 to 2000. Some acceleration values are based on estimate in the earthquake sequence in south Iceland in 1896.

In the analysis presented here the vertical component of acceleration is included.

Examples of the results for earthquakes of magnitude 3.5 and 6.5 are shown on figures 4 and 5. For the earthquakes of magnitude 6.5 on figure 4, the peak acceleration based on the SIL data is greater for distances shorter than 100 km than the Eurocode model. For the smaller earthquake of magnitude 3.5 in figure 4, the Eurocode estimate is larger.

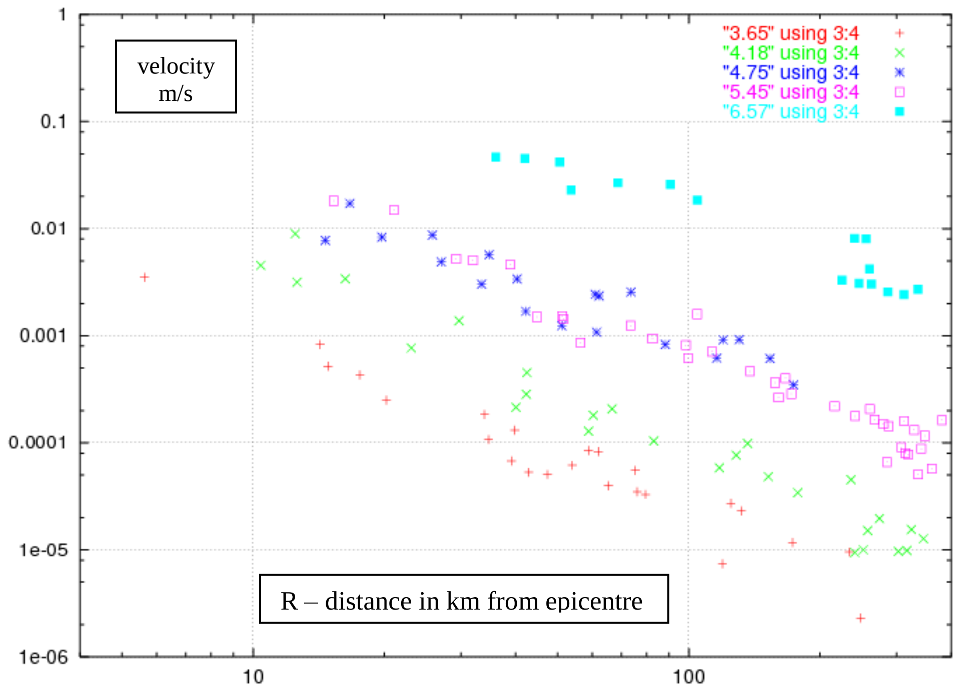

Figure 3. *Attenuation of peak velocity in five earthquakes in SW Iceland. The numbers in the upper right corner show the magnitude of individual earthquakes and their mark.*

The discrepancy between these models in large earthquakes can possibly be explained by that we use also the vertical component of the acceleration. The maximum vertical acceleration is probably larger in comparison to the vertical components close to epicentre but opposite in the far field. In the Eurocode model all earthquakes were of magnitude larger than 4 and therefore little constraint on the relation at small magnitudes. Further, some flaw may be in the magnitude estimate in the SIL system, particularly in large earthquakes.

In conclusion, this dataset gives a reasonably good relation between the parameters that were investigated. Still, a more careful selection and more detailed study of the dataset will improve the relations and possibly make other models more feasible.

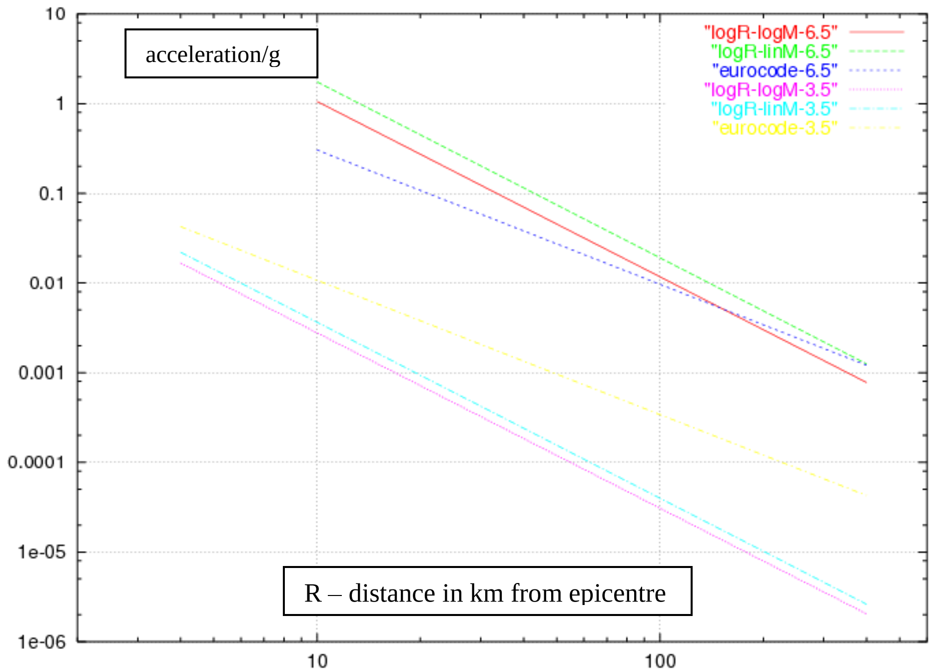

Figure 4. *Peak acceleration as a function of distance to the epicentre. The two models tested (logarithmic and linear in magnitude) are shown as well as the Eurocode model. The examples are for earthquakes of magnitudes 3.5 and 6.5. The acceleration is in fraction of acceleration of gravity g and the distance is in km.*

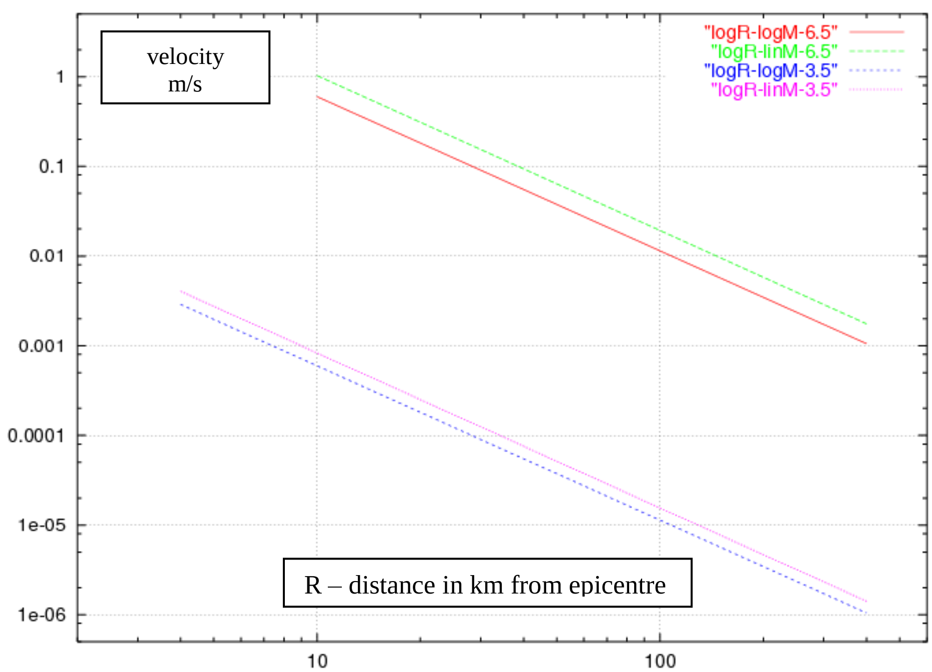

Figure 5. *Peak velocity as a function of distance to the epicentre. The two models tested (logarithmic and linear in magnitude) are shown. The examples are for earthquakes of magnitudes 3.5 and 6.5. The velocity is in m/s and the distance is in km.*

ACKNOWLEDGEMENTS

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Gnuplot: http://www.gnuplot.info/

APPENDIX

Results of the regression analysis. The formulation is according to the syntax of the R package. Units of acceleration are m/s^2 and the velocity in m/s.

```
ACCELERATION = f(log10(R), log10(M)):

lm(formula = log10(z) ~ log10(x) + log10(y))

Residuals:
     Min       1Q   Median       3Q      Max 
-2.23569 -0.26667  0.01741  0.30504  1.41354 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) -4.87778    0.17622  -27.68   <2e-16 ***
log10(x)    -1.95600    0.03409  -57.38   <2e-16 ***
log10(y)     9.59878    0.27229   35.25   <2e-16 ***

Residual standard error: 0.4591 on 1082 degrees of freedom
Multiple R-Squared: 0.7913,     Adjusted R-squared: 0.7909 
F-statistic:  2051 on 2 and 1082 DF,  p-value: < 2.2e-16 

log10(acc)   = -1.95600 * log10(R) + 9.59878 * log10(M) - 4.87778

--------------------------------------------
ACCELERATION = f(log10(R), M):
lm(formula = log10(z) ~ log10(x) + log10(y))

Residuals:
     Min       1Q   Median       3Q      Max 
-2.19752 -0.27723  0.01741  0.29891  1.45765 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) -2.65660    0.12008  -22.12   <2e-16 ***
log10(x)    -1.96297    0.03415  -57.48   <2e-16 ***
y            0.89343    0.02540   35.17   <2e-16 ***

Residual standard error: 0.4596 on 1082 degrees of freedom
Multiple R-Squared: 0.7908,     Adjusted R-squared: 0.7904 
F-statistic:  2045 on 2 and 1082 DF,  p-value: < 2.2e-16 
log10(acc)   = -1.96297 * log10(R) + 0.89343 * M - 2.65660
```

VEOLOCITY = f(log10(R), log10(M)):

```
lm(formula = log10(z) ~ log10(x) + log10(y))

Residuals:
     Min       1Q   Median       3Q      Max
-1.45806 -0.25918  0.01839  0.27182  1.29154

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -7.58101    0.15327  -49.46   <2e-16 ***
log10(x)    -1.72016    0.03063  -56.16   <2e-16 ***
log10(y)    11.16768    0.23714   47.09   <2e-16 ***

Residual standard error: 0.404 on 1062 degrees of freedom
Multiple R-Squared: 0.8169,     Adjusted R-squared: 0.8165
F-statistic:  2369 on 2 and 1062 DF,  p-value: < 2.2e-16
```

log10(vel) = -1.72016 * log10(R) + 11.16768 * log10(M) - 7.58101

VEOLOCITY= f(log10(R), M):

```
 lm(formula = log10(z) ~ log10(x) + y)
Residuals:
      Min        1Q    Median        3Q       Max
-1.483279 -0.248448 -0.006329  0.255229  1.348473

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.96190    0.10550  -47.03   <2e-16 ***
log10(x)    -1.72828    0.03100  -55.76   <2e-16 ***
y            1.03113    0.02226   46.33   <2e-16 ***

Residual standard error: 0.4085 on 1062 degrees of freedom
  (20 observations deleted due to missingness)
Multiple R-Squared: 0.8128,     Adjusted R-squared: 0.8124
F-statistic:  2306 on 2 and 1062 DF,  p-value: < 2.2e-16TY = f(log10(R), M):
```

log10(vel) = -1.72828 * log10(R) + 1.03113 *M - 4.96190