Quake risk model

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- Introduction: models and parameters
- Algorithm of the quake simulator
- Some simulation results
  - Effect of the most important settings
  - The most dangerous areas

Intensity

- It is widely used for modelling the destruction capability of an earthquake. It is convenient to use it on a continuous scale, but its definition is based on a discrete scale.
- **III.** Many people indoors feel movement. Hanging objects swing back and forth.
- **IV.** Most people indoors feel movement. Hanging objects swing. Dishes, windows, and doors rattle. The earthquake feels like a heavy truck hitting the walls.
- **V.** Almost everyone feels movement. Sleeping people are awakened. Doors swing open or close. Dishes are broken. Pictures on the wall move.
- **VI.** Everyone feels movement. People have trouble walking. Objects fall from shelves. Plaster in walls might crack. Damage is slight in poorly built buildings.
- **VII.** People have difficulty standing. Loose bricks fall from buildings. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.
- **VIII.** Drivers have trouble steering. Houses that are not bolted down might shift on their foundations. Tall structures such as towers and chimneys might twist and fall. Well-built buildings suffer slight damage. Poorly built structures suffer severe damage.
- **IX.** Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

Magnitude

- It is directly related to the energy of the quake. It is calculated on a logarithmic scale, so a magnitude-increase by 1 means an energy-increase by $10^{1.5}$, approximately a factor of 31.6.
- We have used the following formula for the epicentral intensity i_0:
  $m=a\,i_0+b\log10(h)+c$
  where m is the epicentral magnitude and h is the depth of the quake. The estimated value of the constants for Hungary are
  a=0.68, b=0.96, c=-0.91.

The quake-attenuation

- The following formula by Kövesligethy was used:
  $$i_r = i_0 - 3\log(\sqrt{r^2+h^2}/h) - 3\alpha\log(e)(\sqrt{r^2+h^2}-h)$$
- i_r is the intensity at the distance of r from the epicentre
- h is the depth
- α is the absorption coefficient

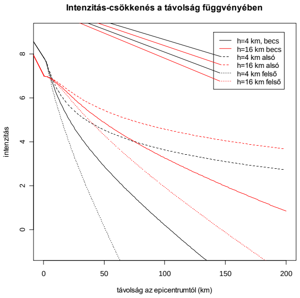
The coefficient α

- α depends on the epicentral depth as follows:

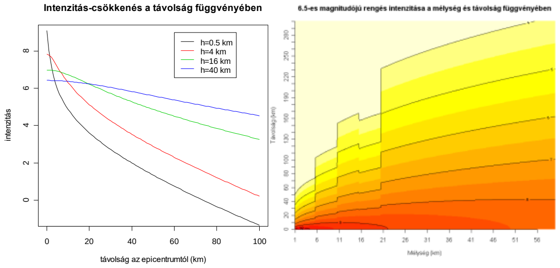
h (km)	Absorption coefficient α
1-5	0.0275±0.0457
6-10	0.0161±0.0241
11-15	0.0106±0.0120
16-20	0.0119±0.0120
21-60	0.0068±0.0049

The effect of the estimation error

- As we saw, there is a substantial vagueness in the estimation of α
- Its effect is also important
- However, our simulation showed that we get at least the observed losses, so we do not suggest to use a more pessimistic version

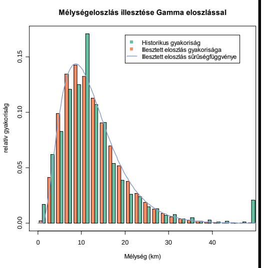


Effect of depth and distance



Depth distribution

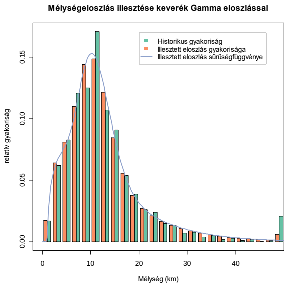
h (km)	prob	h (km)	prob
0-2	0.02	24-26	0.02
2-4	0.06	26-28	0.01
4-6	0.08	28-30	0.01
6-8	0.12	30-32	0.01
8-10	0.13	32-34	0.00
10-12	0.17	34-36	0.01
12-14	0.11	36-38	0.00
14-16	0.09	38-40	0.00
16-18	0.05	40-42	0.00
18-20	0.04	42-44	0.00
20-22	0.03	44-46	0.00
22-24	0.02	46-48	0.00
		48-	0.02



For the simulation, we needed a continuous distribution. First try: Gamma.

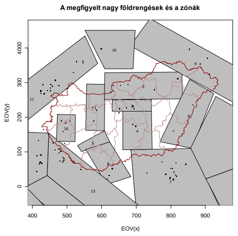
Modification

- Better fit was achieved through the mixture of two Gamma distributions:



The seismically active zones

- The figure shows the zones and the quakes from the last 100 years, with $m>4$.



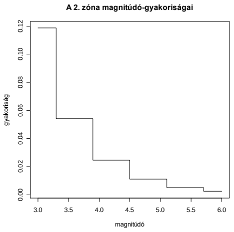
The parameters of the zones

number of zone	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
max. magnitude	6.2	6	5.8	6	5.4	5.8	6	6.2	5.8	5.8
freq (1/1000 y)	2.4	2.3	1	1.9	2.6	2.4	4.6	2	0.7	2
number of zone	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	
max. magnitude	6.2	6.5	6.2	6.2	6.2	5.4	6.5	5.6	6.2	
freq (1/1000 y)	2.5	5.2	2.6	1.5	0.9	5.6	1.1	1.4	3.6	

Zone 2 is the most dangerous, as Budapest belongs to it. We investigate the magnitude distribution in it in some detail. The other zones behave similarly, so there is no need to repeat the procedure for all zones.

Magnitude distribution

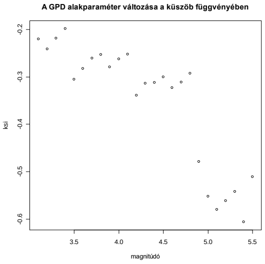
- The original distribution is shown on the figure. It is uniform over the intervals and the probability of the largest (half) interval looks too large.
- Modification is done by the extreme value theory (GPD).



Magnitude distribution for zone 2, given by the seismologists

Estimation method

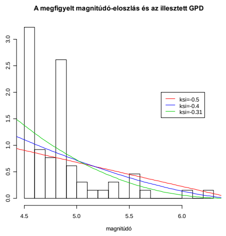
- We assume that there is a single shape parameter for all zones
- Usual maximum likelihood is very unstable (too few large observations)
- The possible maximum of magnitudes (given by the seismologists) can be considered as fixed, thus only the scale parameter has to be estimated.
- Threshold selection is crucial



The change of the GPD shape parameter, as a function of the threshold

Possible shape parameters

- The threshold of 4.4 magnitude looks reasonable (in this case the frequency of 4 full intervals can be estimated by the GPD)
- Different, possible distributions are shown on the figure
- ξ=-0.4 was chosen



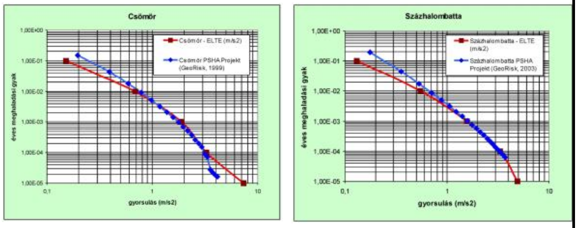
Observed magnitude distribution and different GPD densities

The frequencies for zone 2

- The end point and the shape uniquely determines the distribution
- ξ=-0.4 gave a good fit

interval	5.7-6	5.1-5.7	4.5-5.1	3.9-4.5
original estimate	0.0023	0.0051	0.0112	0.0246
ξ =-0.31	8.12E-05	0.0027	0.0118	0.0286
ξ =-0.4	3.33E-04	0.0049	0.0134	0.0246
ξ =-0.5	0.0009	0.0071	0.0141	0.0212
observed	0	0.004	0.0127	0.03
length of the observed time period		500	200	200

Checking the results



We simulated quakes in zone 2 by the model above, and compared it to the seismologist’s calculations

Historical earthquakes

- We chose the largest intensity quakes from the cathalogue

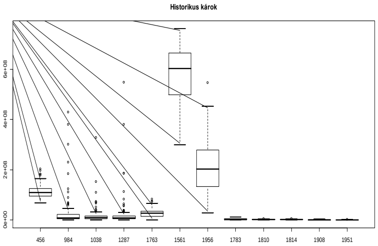
Year	Month	Day	Latitude	Longitude	Depth	Magn.	Intens.	Error code
456	9	7	47.24	16.62	-1	6.3	9	X
984	-1	-1	47	19	-1	5.6	8	E
1038	8	15	47	19	-1	5.6	8	E
1287	6	23	47	19	-1	5.6	8	E
1763	6	28	47.76	18.12	-1	6.3	9	C
1561	2	12	47.5	19.05	-1	5.6	8	X
1956	1	12	47.37	19.07	14	5.6	8	B
1783	4	22	47.76	18.12	-1	5.2	7.5	C
1810	5	27	47.38	18.21	-1	4.9	7	B
1814	5	10	47.38	18.21	-1	4.9	7	B
1908	5	28	46.96	19.57	12	4.4	6.5	C
1951	2	20	47.97	19.11	15	4.7	6.5	B

Historical simulations: methodology

- The magnitude, depth and location were random, within the given error. The code gives the possible location error, ranging from 2 km (X) to over 50 km (E). The magnitude has an error margin of ±1, or even more for the older ones.
- 100 simulations were carried out for each quake
- Loss was generated by the algorithm above

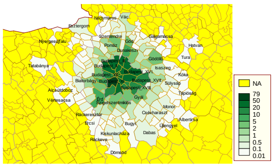
Historical simulations: results

We see the results of the simulations (losses in thousands of HUF) in the figure. The quakes, possibly affecting Budapest, gave the highest values.



Highest simulated losses at the 1561 earthquake

- The losses grouped by settlements
- Quantitative results for the 3 highest simulations:



Settlement	1	2	3
Budapest_XI.	78.66	81.95	94.36
Budapest_VII.	48.67	40.71	50.26
Budapest_XIV.	47.73	44.92	43.54
Budapest_XIII.	43.88	44.95	37.9

By settlement

Building losses (Thousands of Millions of HUF)	Content losses (Thousands of Millions of HUF)
761.7	84.63
750.1	82.46
746.1	85.3

Total

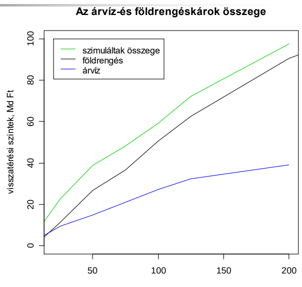
Quantile calculations by the historical simulations

- The difference in the observed period should be taken into account: having *T* years for a given quake-size, we chose 2000**n*/*T* such quakes into the bootstrap sample.
- The results are in Thousands of Millions HUF.
- These simulations resulted in slightly smaller values that the seismic models.

Mean	2.9
Variance	762
50% quantile (median)	0.03
75% quantile	0.22
90% quantile	1.17
95% quantile	4.62
97.5% quantile	11.9
99% quantile	47.7
99.5% quantile	69
99.6% quantile	114
99.8% quantile	376
Maximum	735

Convolution of the flood and the quake losses

- The simplest, and also the most accurate method was the simulation. The flood results are calculated for the wet years, including the effect of the climate changes.



10	25	50	100	200	year
9.38	22.55	38.40	57.66	93.84	return level (thousands of M HUF)