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QUICK DISASTER ESTIMATION

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ABSTRACT

Since stronger earthquakes are monitored worldwide, the fundamental question often arises, whether or not a certain earthquake, which has been recorded and - roughly - located, might have caused a disaster. The presented method utilizes frequency-magnitude and frequency-intensity distributions of a certain region, to enable the operator of a seismic network - or a computer algorithm - to estimate the chance of a particular seismic event to have caused a catastrophe.

KEYWORDS

Intensities, magnitudes, b-value, disaster estimation

INTRODUCTION

Shortly after an earthquake has occurred, seismologists are normally faced with the problem to estimate whether or not this particular earthquake has caused widespread damage to dwellings - which, during the course of the event, collapsed and might have trapped the inhabitants. Coburn (1992) showed, that building collapse is responsible for 75 % of earthquake fatalities - and that people seldomly survive more than four days when trapped in a collapsed building. Therefore, the success of international relief operations relies basically on the response time, hence time is of essence. If a disaster strikes and local authorities are seeking for additional assistance, sometimes other countries are asked to deploy rescue teams. Under normal circumstances, these teams will only be prepared in order to reach their point of destination with a minimum loss of time, if they have been informed prior to the international call for help. Here, a quick estimate of a possible disaster situation becomes very important for reducing the response time.

The following paragraphs present a simple method, based on seismicity data, to calculate the chance of an earthquake to cause a certain macroseismic intensity in terms of the European Macroseismic Scale 1992 'EMS-92' (Grünthal, 1993). This approach enables us to estimate quickly a damage scenario for a specific earthquake, based on preliminary seismic data only.

METHOD

The method is based on the frequency-distribution of magnitudes and intensities of a particular region (Ishimoto and Ida, 1939, Gutenberg and Richter, 1949). As preliminary epicentre determinations of earthquakes are normally rather poor - e.g. epicentre-determinations of several seismological agencies differed for some hours by more than 500 km after the Cairo-earthquake (Egypt) in October 1992 -, we consider a whole country as a region for the sake of this exercise. Although this simplification might sound inappropriate - especially for large countries such as the USA -, it meets European conditions. Further, it can be used as a quick reference once - according to the first epicentre determinations - just the country is known, where the earthquake occurred.
The cumulative frequencies 'N' of earthquake magnitudes 'M' from time window 'T_1' and inten-sities ' I ' from time window 'T_2' obey the laws of

$$\log (N[>M]/T_1) = a_1 - b_1 * M, \tag{1}$$

$$\log (N[>I]/T_2) = a_2 - b_2 * I \tag{2}$$

which is valid between

- a threshold magnitude or intensity (normally due to technical constraints or varying population densities),
- and a maximum magnitude, which represents a regional seismo-tectonic limit.

Thus, the constant 'a' constitutes a measure of the regional seismicity in events per year, and 'b' represents the relationship between larger and smaller seismic events. The formulae can be extended to incorporate the converging influence of the maximum magnitude or intensity. But for this approach, the formulae stated above will be sufficient, for we are not interested in an extreme magnitude estimate but rather in the relation between magnitudes and intensities to be able to determine the chance of a certain magnitude 'M' to cause an intensity of degree ' I '.

Both statistics - those dealing with magnitudes and those which use intensities - are based on two kinds of earthquake catalogues. In seismology, magnitude data or intensity data are often evaluated seperately to describe the seismicity of a region. The selection, which data set is actually used, depends mainly on the amount of available data in each category: intensity or magnitude. In this approach, the availability of both data sets - which is made possible nowadays by international and local data bases - is utilized.

One catalogue can be considered as the complete one for a specific region. It will be used to determine the annual frequency-distribution of magnitudes in terms of the constants 'a_1' and 'b_1'. The second catalogue contains only information of *true* damaging earthquakes of the same region and therefore excludes on purpose all *estimated* intensities of earthquakes which have occurred in mountainous areas or offshore of the selected region. As this information also depicts regional focal depth distributions, local building conditions and the distribution of the population, there is no need to consider these factors any further. The constants 'a_2' and 'b_2' of the intensity-distribution will be calculated from the latter data set.

Combining both cumulative frequency distributions, we find

$$\log(N[>I]/T_2) - \log(N[>M]/T_1) = a_2 - a_1 + b_1 * M - b_2 * I \tag{3}$$

The left hand side of the equation represents the chance 'C' , that an intensity ' I ' is exceeded by an earthquake of magnitude 'M' in the selected region. The chance 'C' can therefore be expressed as

$$C = 100 * 10^{(a_2 - a_1 + b_1 * M - b_2 * I)} \tag{4}$$

in percent, whereas 'C' must not exceed the value of 100. Larger values would simply mean, that an event of magnitude 'M' has a longer average return period than intensity ' I '. Therefore, 'C' needs to be curtailed at 100 %.

Throughout this approach, a very important assumption has been made: Both time windows ('T_1' and 'T_2')- need to be representative, although they might differ in their length. In general, one would select T_1 to be larger than T_2 to counteract effects due to changes in the population density and building types, which inherently influence the number of true damaging earthquakes.

Besides, instrumental earthquake data are available only since approximately 90 years ('T_1') - whereas the information regarding intensity data can cover a few hundred years or even more ('T_2') in Europe.

Depending on these factors, one has to choose representative time spans in order to establish the chance of an earthquake to cause a disaster.

APPLICATION

The following example shall demonstrate the practical advantages of a quick disaster estimate.

Austria

Seismicity in Austria can be considered as moderate - similar to Switzerland, as most of its seismicity results from the ongoing tectonic processes which led to the creation of the Central and Eastern Alps. Since the turn of century, social habits have not changed and the population growth and density have remained static, hence $T_1 = T_2 = 1994 - 1900 + 1$. For this region we find the frequency distribution of magnitudes (in this context, the magnitude 'M' is to be understood as local magnitude) follows the relationship:

$$\log(N[>M]/\text{year}) = 3{,}16 - 0{,}86 * M \quad (5)$$

(linear between $2{,}5 < M < 5{,}3$)

and for intensities (Fig.1):

$$\log(N[>I]/\text{year}) = 3{,}99 - 0{,}73 * I \quad (6)$$

(linear between $4 < I < 8$)

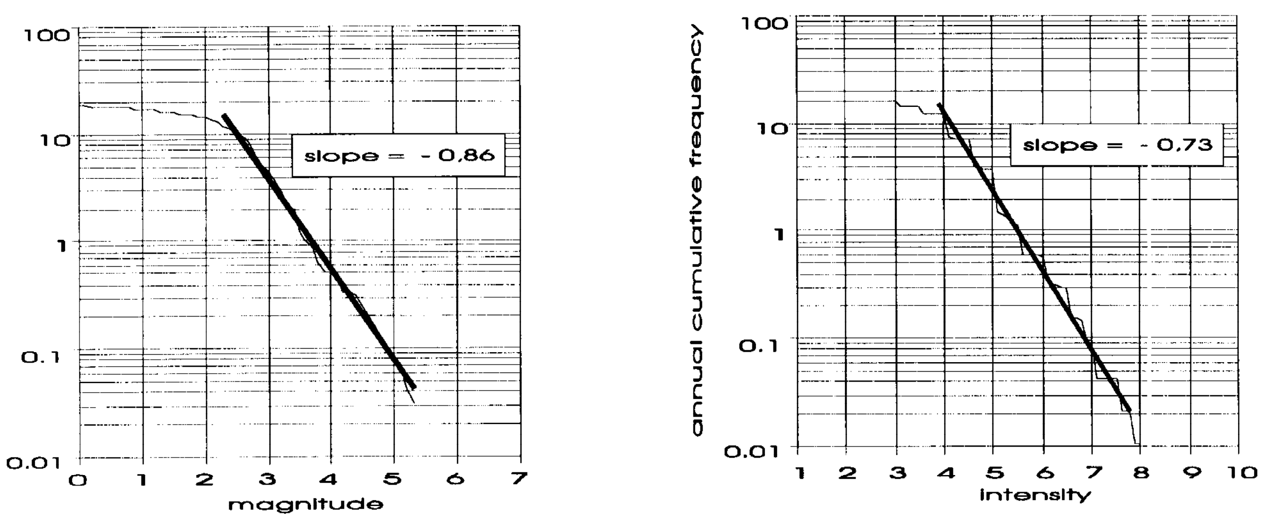

Fig. 1. Cumulative frequency-distributions magnitudes and intensities in Austria

and therefore

$$C = 100 * 10^{(0{,}83 + 0{,}86 * M - 0{,}73 * I)} \quad (7)$$

Hence, earthquakes of magnitude M ≥ 5 occur 0,071-times per year - or in other terms, every 14 years on average. Intensities ' I ' of degree ≥ 7 occur every 13 years, however. Already from this information, we can deduce, that a magnitude M5 creates in any case an intensity of degree 7, for the magnitude recurrence period is larger than the intensity recurrence time span ('C' > 100 %, but is limited to 100 % for the reason stated above, see also Tab.1). However, an intensity of degree ≥ 8 occurs only 0,014-times a year - or every 71 years on average. This means, that an earthquake of magnitude M5 causes damage of intensity 8 in 19 % of the cases. In comparison, events of magnitude M4 cause intensities of degree 6 in 78 % of the cases, and degree ' I ' = 7 with a probability of 14 %.

The chance of a catastrophe in terms of ' I ' = 10 in connection with a magnitude M6, which is considered as the upper limit in Austria, amounts to 5 %, whereas the chance for ' I ' = 9 is 26 % for the same magnitude. An intensity of ' I ' = 8 will be reached in any case.

Table 1. Expectancies of intensities in Austria, derived from magnitudes

	⇐	Magnitude	⇒
Intensity ⇓	4	5	6
6	78 %	100 %	100 %
7	14 %	100 %	100 %
8	3 %	19 %	100 %
9	<1 %	4 %	26 %
10	<< 1%	< 1 %	5 %

Seismic regions in Austria

The presented approach can be applied to subregions of Austria, which exhibit different seismicity levels and population densities themselves(Fig.2).

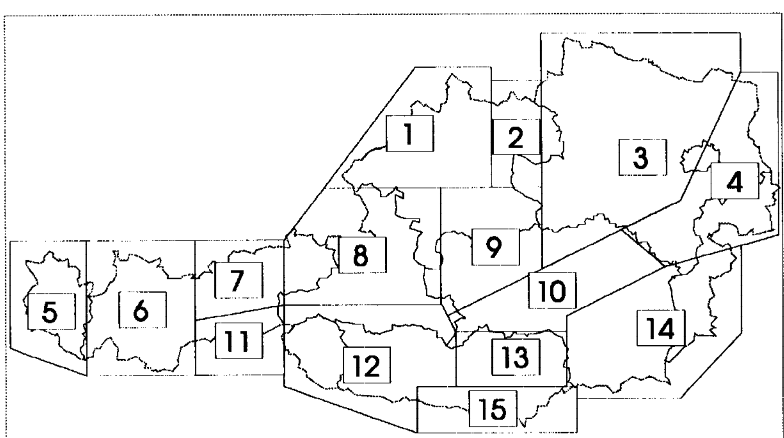

Fig. 2. Seismic regions in Austria. Numbers refer to Table 2 (Lenhardt, 1995)

From each region we can determine the constants a_1, a_2, b_1 and b_2 (Tab.2). Additionally, we can calculate a specific magnitude 'M_{I6}' for each region, which causes in any case intensities of degree 6. This can be accomplished by setting 'C'=100 and selecting ' I ' = 6 in the above stated formula, thus

$$M_{I6} = (a_1 - a_2 + b_2 * 6) / b_1 \tag{8}$$

From this specific magnitude we find, that the chance experiencing an earthquake of intensity degree ' I ' = 6, which can already cause minor damage to buildings, varies across Austria between M3,2 (region 1) and M4,3 (region 12), hence more than a unit of magnitude. This difference can be explained by the local topography and the distribution of the population: region 1 can be described as flat and evenly populated, whereas region 12 is moutainous and only sparsly populated in places. On average, a magnitude of M3,8 will be experienced by the population with an intensity of degree 6 in Austria.

As another example, we can calculate for each region the probability 'C' of an intensity - e.g. degree 7 - due to an earthquake of e.g. magnitude M4. Here again, we find massive discrepancies between different seismic regions in Austria.

Table 2. Regional variations of seismicity in Austria

Region	a_1	b_1	a_2	b_2	M_{I6}	C (%) M4, I7
1	0,43	0,79	1,14	0,54	**3,2**	100
2	-0,10	0,48	1,13	0,47	3,3	72
3	1,68	1,00	3,71	0,92	3,5	39
4	1,81	0,63	2,47	0,55	4,2	21
5	1,65	0,92	2,20	0,65	3,6	48
6	2,24	0,85	2,47	0,62	4,1	19
7	2,18	0,88	3,00	0,72	4,0	20
8	2,89	1,09	3,08	0,78	4,1	12
9	2,35	0,97	4,20	0,98	4,2	7
10	2,50	0,86	2,82	0,63	4,0	22
11	2,09	1,20	1,76	0,70	3,8	37
12	1,94	0,90	2,51	0,74	**4,3**	10
13	1,01	0,64	1,72	0,56	4,1	22
14	1,55	0,89	1,04	0,48	3,8	49
15	3,20	1,34	3,44	0,92	3,9	14

DISCUSSION

As it was shown before, the chance 'C', that an earthquake results in a certain intensity in terms of the EMS-92, can differ substantially when different regions are compared. We notice, that topographical and population-distributions dominate the chance of experiencing an earthquake of a given magnitude with a specific intensity. When comparing these results with those from other countries, one might find, that differences in the intensity-exposure can also reflect different building conditions.

Further reasons for deviations from a general empirical magnitude-intensity relationship can be attributed, first of all, to the tectonic setting and the focal depth distribution of earthquakes. Additional effects due to the geographical, social, industrial and cultural situation certainly add to a disaster szenario, although their complicated interrelation may remain unknown in this context as they are already inherently present in the curtailed intensity data set.

Figure 3 shows an example of a *quick disaster estimate*-graph of a region of relative high seismicity with the constants $a_1 = 4{,}00$, $b_1 = 0{,}67$, $a_2 = 3{,}08$ and $b_2 = 0{,}39$. If an earthquake of magnitude M5 would occur in this region, we can read from the graph, that the probability of slight damage to buildings (' I ' = 7) in the epicentre would not exceed 50 %. Heavier damage to buildings (' I ' = 8) is very unlikely, for the probability reaches just 20 %. A disaster in terms of ' I ' = 10 has chance of less than 5 %. However, a magnitude M6,2 would cause damage in terms of ' I ' = 8 in any case, and extreme damage to houses (' I ' = 9) with a probability of almost 50 %.

Hence, a stand-by request of rescue teams after an M5-earthquake in this region would not be necessary, whereas a M6,2-earthquake would justify such measures. Immediately after the earthquake has been located and the magnitude has been determined, seismological and other official agencies could estimate from the magnitude and the quick disaster estimate-graph of the affected region, whether or not a stand-by request to potential rescue teams should be released.

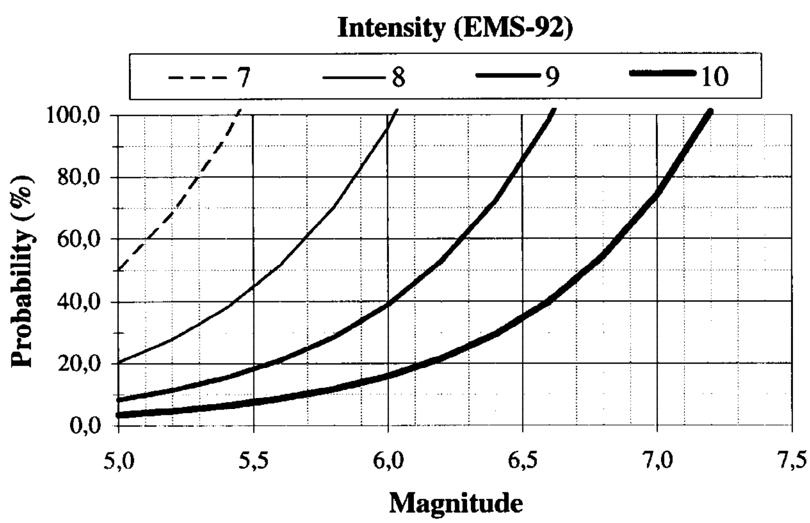

Fig. 3. Example of a 'quick disaster estimate', which allows to estimate the probability of an intensity for a specified region from an earthquake magnitude alone.

Problems, which may arise when calculating a 'quick disaster estimate'-graph, are the following:

- The data catalogue is not complete or contains multiple entries of the same earthquake.
- The retrieval of *true* damaging events from the earthquake catalogue can be cumbersome.
- The distribution of the population and their density can be the subject to changes on a national - or regional - level. Hence, care must be taken, when the time span 'T_2' is chosen, so as the statistics for intensities remain representative for the selected region. Besides, short term population density changes require normally too many earthquakes of reasonable size (' I ' > 8) within the appropriate period to be accounted for in a statistical meaningful way.

- The definition of the border of the region under consideration can be difficult.
- A possible migration of seismicity across borders of the defined region is not considered. This factor, however, plays a minor role, as such processes involve centuries rather than decades. The available data are based on the latter.

The advantages of a 'quick disaster estimate' are:

- The method is relatively stable, for inaccuracies in epicentral coordinates, intensities and magnitudes play only a subordinate part and can be discarded in general, as long as the definition of the employed magnitude is adhered to.
- It is easy to implement this method into automatic warning systems, once the constants 'a_1', 'a_2', and the slopes 'b_1' and 'b_2' for several regions have been established.
- The method can be applied to any region and comparisons can be carried out.
- The method is not limited to earthquake studies, but can be employed for other natural hazard assessments.
- Dividing a region in sub-regions and calculating the required coefficients, allows to map the probabilities of certain intensities, thus creating a risk map.

The procedure for calculating the two statistics consists of six steps:

1. define region and representative time windows
2. select earthquakes from catalogue
3. calculate logN-M statistic
4. discard earthquakes in the catalogue, which did not cause damage to buildings in the epicentre
5. calculate logN-I statistic
6. establish formulae to calculate 'C'

When extending this approach to the assessment of risks or the likelihood of a rescue team-deployment, issues such as social habits (e.g. occupants per household) and international relationships need to be considered of course.

SUMMARY

Two frequency distributions - one of which is based on the magnitude, whereas the other one utilizes intensity data - are used to assess the probability of an earthquake disaster from a magnitude information and a crude epicentre determination only.

Having world-wide access to the constants a_1, a_2, b_1, b_2 of each seismo-active region - or country - would permit every other country to judge whether or not a disaster has occured in another part of the world.

The presented method can easily be incorporated into automatic earthquake evaluation routines - which enables seismological agencies not only to release seismological parameters shortly after an earthquake, but also to add a disaster scenario in terms of probability.

Even when considering the limitations of this method, it enables seismological centres to inform rescue teams whether or not their help might be requested by international or national authorities. Besides, the presented approach of comparing a complete data set with a subset of its data set, can be applied to other natural disasters as long as they occur on a frequent basis in a certain time span and adhere to log-log distributions (note: magnitudes or intensities are themselves logarithmic expressions of energies or ground motions).

REFERENCES

Coburn, A. (1992). Factors determining human casualty levels in earthquakes: Mortality prediction in building collapse. In Proc. *10th World Conference on Earthquake Engineering*, Balkema, 5989-5994.

Grünthal, G. (1993). European Macroseismic Scale 1992 (up-dated MSK-scale). Conseil de l'Europe, *Cahiers du Centre Européen de Géodynamique et de Séismologie*, Volume 7.

Gutenberg, B. and C.F. Richter (1949). Seismicity of the Earth and Associated Phenomena. Princeton University Press.

Ishimoto, M. and K. Ida (1939). Observations sur les seisms enregitres par le microseismograph construit dernierement (I). *Bull.Earthqu.Res.* 17 , 443-478.

Lenhardt, W.A. (1995). Regional earthquake hazard in Austria. In Proc. *10th European Conference on Earthquake Engineering*, Balkema, 63-68.