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Problems of seismic hazard assessment for the pleistoseismal area of swarm earthquakes in Western Bohemia and Vogtland

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Abstract

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A detailed study of the 1985–1986 earthquake swarm in Western Bohemia and Vogtland, the historical seismicity and instrumental monitoring of earthquake shocks during the last 25 years have provided the necessary data for seismic hazard assessment of the Pleistoseismal area of the swarm. On the basis of this diverse data, deterministic and probabilistic (seismostatistical) hazard estimates have been made.

The seismic hazard is calculated for a certain site or a certain area usually distant from active earthquake regions. When we established the hazard for a pleistoseismal area of a seismoactive region in which shallow swarm quakes occur, the standard technique could be simplified by skipping any attenuation relationship of seismic effects. Two types of hazard can be determined: (1) the maximum possible hazard for the Pleistoseismal area, and (2) the seismic hazard with respect to the return period of earthquake occurrence.

The former type of seismic hazard coincides with the determination of the maximum possible earthquake of the region, or, more specifically, with the epicentral macroseismic effects and/or strong ground motions, which are expected to result from the maximum possible earthquake. The latter type of seismic hazard can be calculated from the value of the maximum possible earthquake and the recurrence graphs of the studied events by a probabilistic approach. The subject of this paper is the estimation and the discussion of both types of seismic hazard as applied to the focal region of swarm earthquakes in Western Bohemia, Czechoslovakia, and Vogtland, G.D.R. (Fig. 1).

Maximum possible earthquake

To estimate an earthquake of a probable maximum magnitude and/or epicentral intensity the following procedures can generally be used: modification of the observed maximum earthquake, extrapolation of the recurrence graph to higher values of earthquake magnitudes or intensities, the

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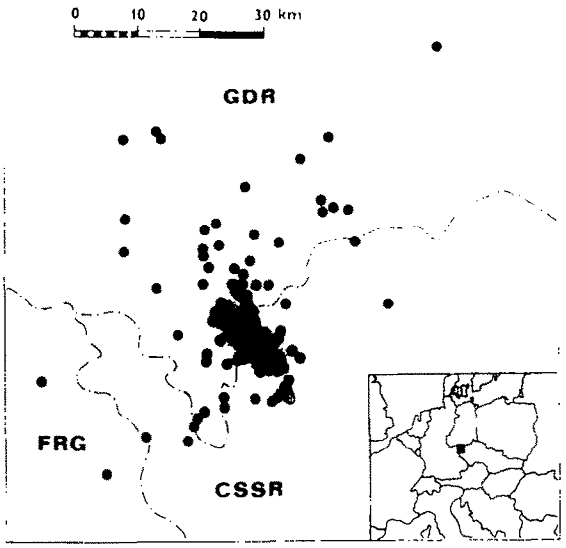

Fig. 1. Map of earthquake epicentres occurring in and around the seismogenic zone in Western Bohemia and Vogtland. Large dots denote instrumentally recorded shocks since 1962, the shaded zone is the focal area of the 1985–1986 swarm (Neunhöfer and Güth, 1988).

theory of extreme values, the seismotectonic analysis of the focal zone, recent crustal movements and their correlation with observed earthquakes, the Benioff strain-release graph, thickness of the seismoactive layer, horizontal gradients of isostatic anomalies, elastic properties and conditions of the rock material, and, of course, various expert systems.

It is obvious that the application of the above-mentioned procedures requires that suitable data are available and knowledge of the relationships between them. We will apply some of these approaches to assess the probable maximum earthquake and its macroseismic effects in the pleistoseismal area of the 1985–1986 Western Bohemia and Vogtland swarm.

Maximum observed earthquake

Historical reports describing macroseismic effects of swarm occurrences in the western part of the Bohemian massif date back to the 16th century. Retrospectively maximum macroseismic intensities of about $6.5 \pm 0.5°$ (MSK scale) were repeatedly observed.

Recent criteria which have been adopted for assessing a probable value of the maximum possible earthquake recommend the addition of a total of only 1° of the macroseismic intensity and half a unit of the earthquake magnitude to the values observed as maximum values (IAEA, 1979). For the two values obtained above it can be decided that the maximum earthquake, the occurrence of which could be found during any swarm sequence in the western part of the Bohemian massif, in the future can attain a maximum I_0 value of 7.5° MSK (i.e., macroseismic magnitude $M = 4.9$) in the pleistoseismal area.

Recurrence graphs of earthquakes

In principle, recurrence graphs can be used to estimate the maximum earthquake. In practice mainly the modified Gutenberg–Richter, the truncated exponential, and the truncated double exponential distributions are applied. In these distributions the estimate of the maximum earthquake ($M_{\max}$, $I_{\max}$) is explicitly introduced and, therefore, can be determined directly from the known data.

In our study the modified Gutenberg–Richter distribution (Utsu, 1974) was calculated. The data describing the last 1985–1986 swarm (Strauch and Wylegalla, 1988) give the relationship:

$$\log N = 1.98 - 0.43M + \log(M_{\max} - M) \qquad (1)$$

where $M_{\max} = 4.71 \pm 0.13$ and using the relationship (Grünthal, 1988)

$$M = 0.66 I_0 - 0.11 \qquad (2)$$

where M is the macroseismic magnitude. For focal depths between 5 and 15 km we can convert the M-value into the $I_{\max}$ value which is then equal to 7.3 ± 0.2 MSK.

Theory of extreme values

In extreme value statistics type III of Gumbel's distribution is especially useful because this type allows us to determine the asymptotical value a value which can never be exceeded. This distribution is given by the relationship:

$$F(x) = \exp\left\{ -\left[(M_{\max} - x) : (M_{\max} - u) \right]^{k} \right\} \qquad (3)$$

where $F(u) = \exp(-1)$, $F(M_{\max}) = 1$, $x \leqslant M_{\max}$, $M_{\max}$ is the asymptotical value ω in Fig. 2 which corresponds to the maximum possible earthquake magnitude, $k > 0$ is the shape parameter of the distribution, and $u < M_{\max}$ is the characteristic largest value.

In contrast to the prerequisite of the applicability of Gumbel statistics, which is based on statistically independent events, we first analyzed the data on the last 1985–1986 swarm separately. Then, all known data were used from the period of observations between 1891 and 1986 in such a way that the maximum shock occurring in a certain time interval could be selected. In the first case we used the obviously too short intervals of 3, 6 and 12 h, 1, 2 and 4 days, and 1 and 2 weeks; in the latter case the more correct intervals according to the extreme value statistics of 2, 4 and 8 yrs were used.

Even though we are aware that extreme value statistics require strictly independent events, we apply it to the data of the last 1985–1986 swarm in order to point out the impossibility of its applicability under such special conditions. The period of the main earthquake activity of the last swarm began on December 4, 1985 and lasted until January 24, 1986. Not unexpectedly the third Gumbel distributions given for the time intervals of hours and days are rather unrealistic, because of the numerous physically dependent events with small magnitudes which cause a shift in the approximation curves towards a range of absurd magnitude values (up to $M = 285$!).

The other set of data used in Gumbel-III statistics consists of the data covering the observation period of 1891–1986. These data allow each strongest event per interval to be managed as an individual event. The asymptotical value resulting from this (ω in Fig. 2), which determines a probable maximum earthquake, is 7.4° MSK.

Benioff strain-release graph

To understand a trend of earthquake activity the Benioff diagram is usually constructed. With long-time observations the upper and lower "envelope" can be drawn on this graph, and the difference between these two envelopes allows us to estimate the probable maximum energy release, which can then be converted into the earthquake magnitude.

We attempted to apply this approach to assessing the maximum possible earthquake using the swarm data from Grünthal's (1988) earthquake catalogue. Reliable observations of the swarm activity in the Western Bohemia and Vogtland area only cover the period of the last 100 years. We can observe (Fig. 3) that great amounts of energy were released at the turn of the century (1897, 1903 and especially 1908), while during the swarms of 1936 and 1962 relatively small amounts of earthquake energy were accumulated in the swarm focal zones. Nevertheless, it is obvious that the standard approach cannot be applied to the swarm data, because the $E_{\max}$ estimate belongs to the maximum value of the total energy release during the whole swarm and does not belong to the strongest event occurring during the swarm. This value gives an overestimated value of the maximum possible earthquake.

If we use the data corresponding to one swarm only (Fig. 3) we can see that it is rather problematic to envelop the Benioff diagram with two reliable curves. From this viewpoint, we did not apply the Benioff strain-release diagrams to the assessment of the maximum possible earthquake.

Probabilistic (seismostatistic) estimation of seismic hazard

The probabilistic calculation of seismic hazard assessment was defined by Cornell (1968) and is based on knowledge of the earthquake regime of a focal zone, the maximum possible earthquake which is expected for this zone, and the attenuation law of seismic vibrations. In our case it is not necessary to introduce attenuation because we are only estimating the seismic hazard for the pleistoseismal area of the focal swarm zone. For this reason the input data consist of (1) parameters of cumulative intensity–frequency distributions and (2) the value of the maximum expected epicentral intensity. This value corresponds to the maximum possible earthquake determined in the previous section and is equal to an intensity of 7.5° MSK.

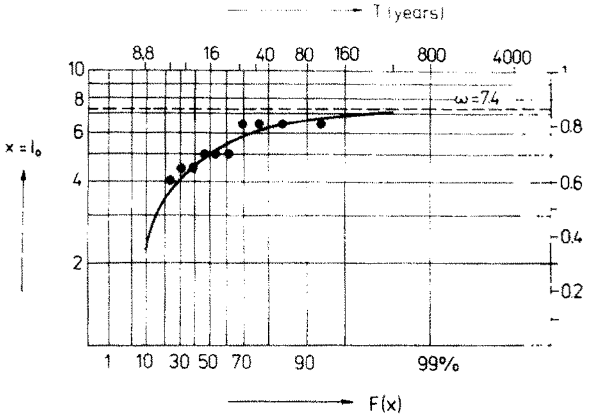

Fig. 2. The third type of Gumbel distribution of epicentral macroseismic intensity I_0 for the interval of 4 yrs.

The probabilistic approach was applied to four cumulative recurrence graphs. The first two were only constructed from (a) the events of the 1985–1986 swarm, which can be written in the form:

$$\log N = 3.22 - 0.45 I_0 \quad (4)$$

where N is the cumulative number of earthquake occurrences observed during the swarm and I_0 is the epicentral intensity of the earthquake, and in the form:

$$\log N_y = 2.44 - 0.45 I_0 \quad (5)$$

where N_y is the cumulative number of annual earthquake occurrences.

The second two cumulative recurrence graphs were determined from (b) all events known for the Western Bohemia and Vogtland region in the form:

$$\log N_y = 3.52 - 0.67 I_0 \quad (6)$$

and (c) all independent events selected from the previous set of earthquakes known for the Western Bohemia and Vogtland region, written in the form:

$$\log N_y = 1.80 - 0.44 I_0 \quad (7)$$

Procedures for separating individual events from the whole dataset were described in Schenk (1988) and Grünthal (1985).

The seismostatistical calculations were performed with the use of the above-discussed data. The results obtained are expressed as maximum expected earthquake effects which will not be exceeded within a given probability in different periods of time (Schenková et al., 1981).

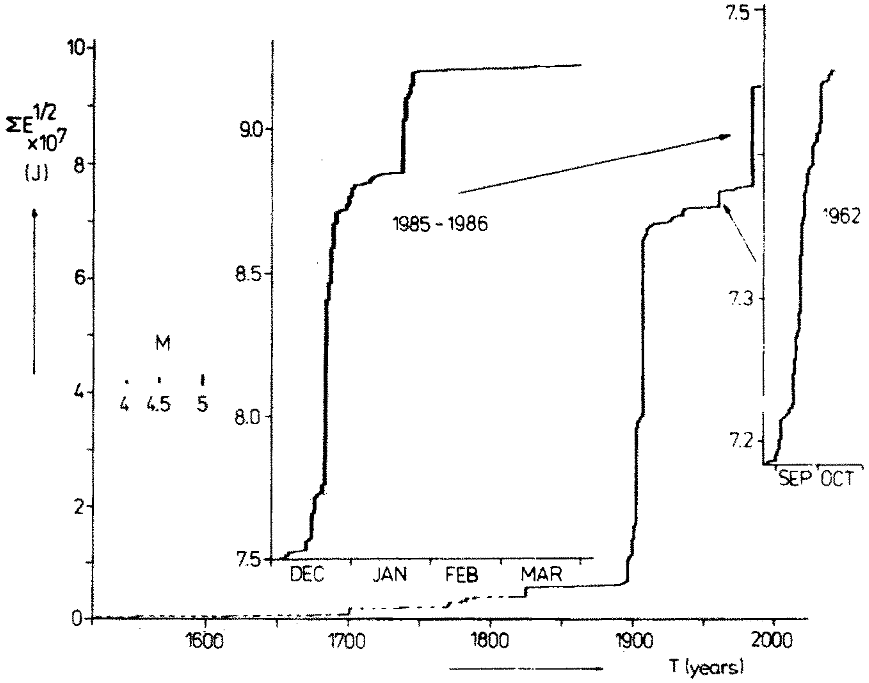

Fig. 3. Benioff strain-release graph of the swarm activity in the Western Bohemia and Vogtland area from the period of 1800–1984 with details of the 1962 and 1985–1986 swarms.

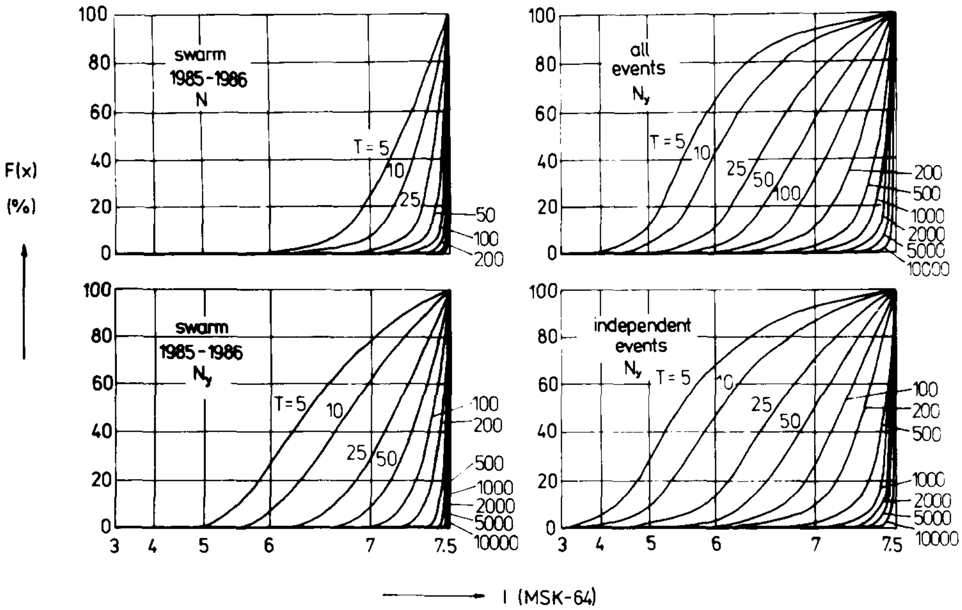

Fig. 4. The maximum expected macroseismic effects I_0 in the epicentral zone which will not be exceeded with a probability $F(x)$ in time periods T (yrs).

A graphical presentation of the results (Fig. 4) shows pronounced differences between the calculations obtained for the 1985–1986 swarm data only and for all data known from the Western Bohemia and Vogtland region. We can see that the probability of an earthquake occurrence during a swarm period is approximately 20 times higher than the mean probability of occurrence of events corresponding to the long time period of observations. Seismic hazard values for all events collectively and for individual events only differ below the intensity level of 6° MSK much more than above this level. This is because of the large number of dependent events in the range up to 6° MSK of macroseismic intensity.

Concluding, we can state that our probabilistic approach to seismic hazard assessment has resulted in a realistic estimate provided that strictly physically independent events were used as required by the underlying statistical theory. The maximum expected value of seismic hazard is fixed by the maximum possible earthquake, in our case at an intensity of 7.5° MSK.

Conclusion

Seismic hazard calculations performed for the pleistoseismal area of the Western Bohemia and Vogtland seismogenetic zone in which shallow earthquake swarms occur show that some of the standard deterministic and probabilistic approaches can be applied without any changes required. Only the attenuation law must be eliminated from the calculation. The maximum macroseismic intensity expected for this area was assessed more-or-less by means of deterministic methods and it attains a value of 7.5° MSK. The seismostatistical approach gives the relationship between macroseismic intensity, return periods and the level of occurrences of individual events (Fig. 4). The input data based on estimates of physically independent earthquakes seem to be the only realistic data.

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