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CRITICAL POINTS OF SEISMIC HAZARD ASSESSMENT FOR SELECTED LOCALITY FOR TECHNOLOGICAL FACILITIES

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Seismic hazard value of a real locality is influenced by both, the earthquake sizes the impacts of which in a given site may be expected, and the properties of geological structure through which seismic waves spread from earthquake foci to a given site. The paper describes usually used procedures of hazard assessment of important sites. The attention is especially paid to the basic steps as the data collection (homogeneity level), the focal region boundaries and the maximum expected earthquake size in each focal region that must be taken into account, because they substantially influence the hazard value. Discussion is concentrated to the attenuation factor that in Central Europe substantially depends on the azimuth between earthquake focus and the given site.

Keywords: Seismic hazard assessment, Return period, Annual Exceedance Probability, Attenuation parameter, Focal region

Introduction

The seismic hazard value is a fundamental quantity for the seismic risk assessment and for the determination of terms of references of seismic design of important facilities as dams, chemical plants, nuclear power plants etc. In real sites the seismic hazard value is influenced by both, the earthquake sizes the impacts of which in a given site may be expected, and the properties of geological structure through which seismic waves spread from earthquake foci to a given site. The seismic risk is predetermined by hazard value, distribution of assets in the given site and by asset numbers and vulnerabilities.

Selection of a site suitable for an important facility is one of the basic steps of provision of its safety. There are many locality characteristics that might be taken into account, mainly the bedrock stability and structure, locality setting with regard to other facilities, population density, environment, meteorological and hydrological conditions, groundwater, seismic conditions etc.

Though the Czech Republic region is considered as low seismic active, the civil and technological facilities have to respect the protective measures with regard to earthquakes and similar events. The first step of the design process of civil and technological facilities is the seismic hazard assessment.

2. Seismic Hazard

The strong earthquake occurrence is sporadic and irregular. Each seismogenic structure has from physical reasons only a certain strain capacity predetermined by its size and location in the planetary tectonophysical fields [8]. According to the definition in [2, 3] the seismic hazard can be expressed by the earthquake size (measured by the earthquake intensity or PGA) that can be expected in the given locality during the specified time interval with a certain probability, usually 0.95. The seismic hazard is a function related to the variables of place and time [5], i.e.

seismic hazard depends on the locality position to focal regions, the earthquakes of which can affect this locality. Important factors are the earthquake source – site distance and the attenuation between source and site. It depends on the considered time interval – the longer one is, the stronger quake is expected. It should be understood as the earthquake potential to cause damages, losses and harms on assets which are essential for human life.

The Czech Republic region is usually regarded as low seismic active, but even though by standards both the civil and the technological facilities have to respect the protective measures with regard to earthquakes and other similar natural and severe events. Therefore, the design process of civil and technological facilities begins with the seismic hazard assessment.

3. Input Data

Input data must create a representative data set from methodical reason. Therefore, the verified catalogue of earthquakes [4] was used; data organization is shown in Tab. 1. Items indicated for each earthquake are origin time (GMT), geographical coordinates, focal depth, earthquake size in epicentral intensity, maximum observed intensity, magnitude etc. [4]. The focal regions determined for Central Europe are in Fig. 1 [4]. According to the methodology of seismic hazard assessment described in [3, 4] respecting the IAEA requirements the focal regions belonging to an area with radius of 200 - 400 km around the locality has to be involved in the assessment process. For the city Plzen (Pilsen, Czech Republic) the selected area is shown in Fig. 1 with the borders of Czech Republic.

DATE	TIME [GMT]	GEOGRAPHICAL COORDINATES		FOCAL DEPTH	EPICENTRAL INTENSITY	MAGNITUDE	NOTE
		°N	°E	[km]	I_o ° [MSK-64]	M	Focal Region
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Tab. 1: Example of data organization in the earthquake catalogue

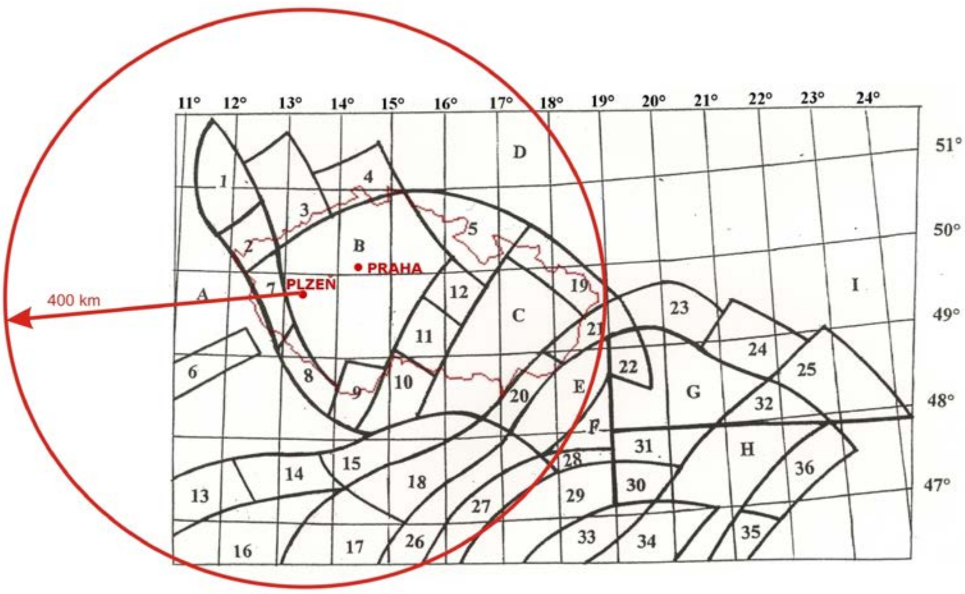

Fig. 1: Map of focal regions in Central Europe, area with radius of 400 km for the Plzen city seismic hazard assessment

For this Plzen city region the frequency graph was created, Fig. 2. It describes distribution of earthquake cumulative frequency N_c (I_o) vs. earthquake epicentral intensity I_o [°MSK-64]. The cumulative frequency describes the number of earthquakes with intensity equal or more than the value I_{oi}. It begins with the highest intensity values and so differs from the classical statistical cumulative frequency. The dependence is substituted by the

$$\log N_c = a - bI_o.$$

Parameters *a, b* are determined with the least square method, Monte Carlo Method or other simulation methods. Parameter *b* expresses the slope and it is the basic parameter that describes the physical process for each focal region [1].

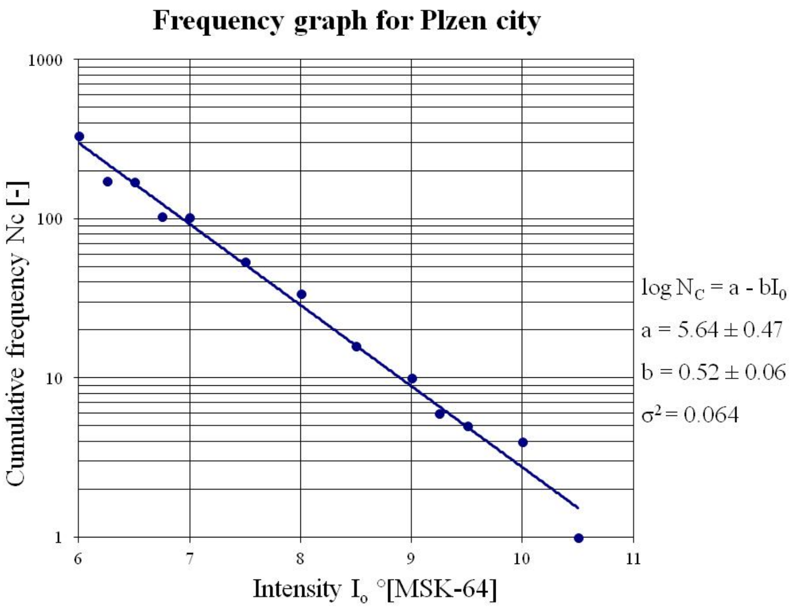

Fig. 2: Frequency graph for Plzen city

We can show two deterministic methods applied to the example of Plzen city.

4. Map of maximum observed intensities

The simplest deterministic seismic hazard assessment method goes out from the maximum observed intensity map, Fig. 3. This map respects all earthquake impacts on the Czech Republic territory; insufficient input data were substituted by realistic simulations [7]. According to this map the Plzen city seismic hazard is evaluated by intensity 5° MSK-64. This method is used for civil objects and for technical facilities that don’t need to satisfy special safety requirements - the national standards (CSN). For facilities with demanding safety requirements, e.g. nuclear power plants, the situation is different.

The hazard calculation based on the extreme value method, described in [3], goes out from

$$R_t(I_0 \geq I_{0i}) = 1 - \left\{ \frac{T}{T + t.P(I_0 \geq I_{0i})} \right\}^{n+1},$$

where T is the earthquake observation time interval, n is the observed earthquake number and function P is defined by the equation

$$P(I_0 \geq I_{0i}) = \frac{e^{-\beta I_{0i}} - e^{-\beta I_{0max}}}{e^{-\beta I_{0min}} - e^{-\beta I_{0max}}} .$$

In both equations the I_{omin} is the minimum intensity value (from it the catalogue is complete, it represents the data set homogeneity limit); the intensity I_{omax} is the maximum intensity value in the given region. For the intensities the relation can be written

$$I_{0\,min} \leq I_0 \leq I_{0\,max} .$$

Parameter $\beta = b \ ln \ 10$ is determined using the parameter b from the frequency equation $log \ N_c = a - b \ I_{oi}$, where N_c is the cumulative frequency. Function $R_t(I_0 \geq I_{0i})$ is the probability that the intensity of earthquake I_o won‘t pass the intensity I_{oi} during the time interval t and $P_t(I_0 \geq I_{0i})$ is the probability that the intensity of earthquake I_o will pass the value I_{oi}.

The Plzen city seismic hazard assessment using the extreme value method is shown in Fig. 4. The curves describe the probability of occurrence of an earthquake of the size 1 - 11 (according to MSK-64 scale). Time periods were chosen 50, 100, 200, 500, 1000 and 10 000 years. We can see that for 50 years the line of 5% probability cross the probability curve of non-exceedance of the intensity in the value of 10.95. Considering the intensity attenuation curve [5] and the distance of 300 km, the intensity decrease is 5.5 °MSK-64; i.e. the Plzen city seismic hazard for time interval of 50 years is 5.5° MSK-64. The longer time interval is, the higher value is, i.e. for the time interval of 10 000 we get the value of 6.1 °MSK-64.

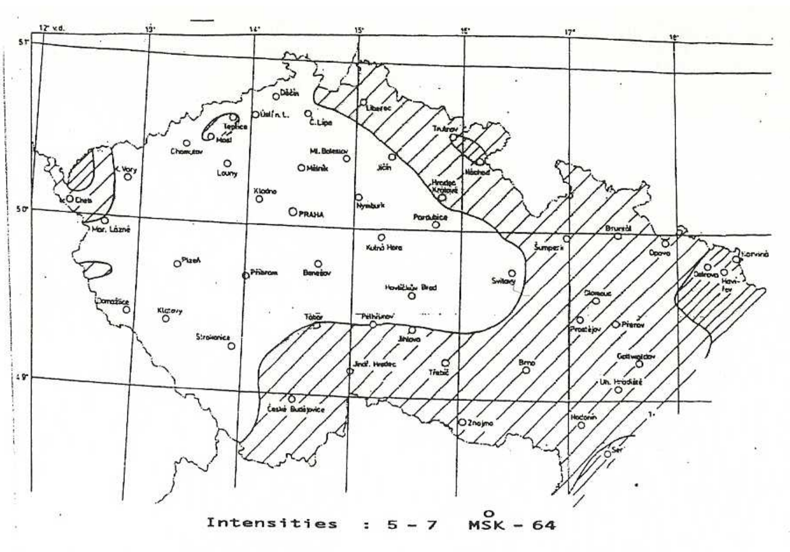

Fig. 3: Map of maximum observed intensities for the territory of the Czech Republic (intensity of 7° MSK-64 - densely hatched, intensity 6° MSK-64 - sparsely hatched, intensity of 5° MSK-64 - not hatched)

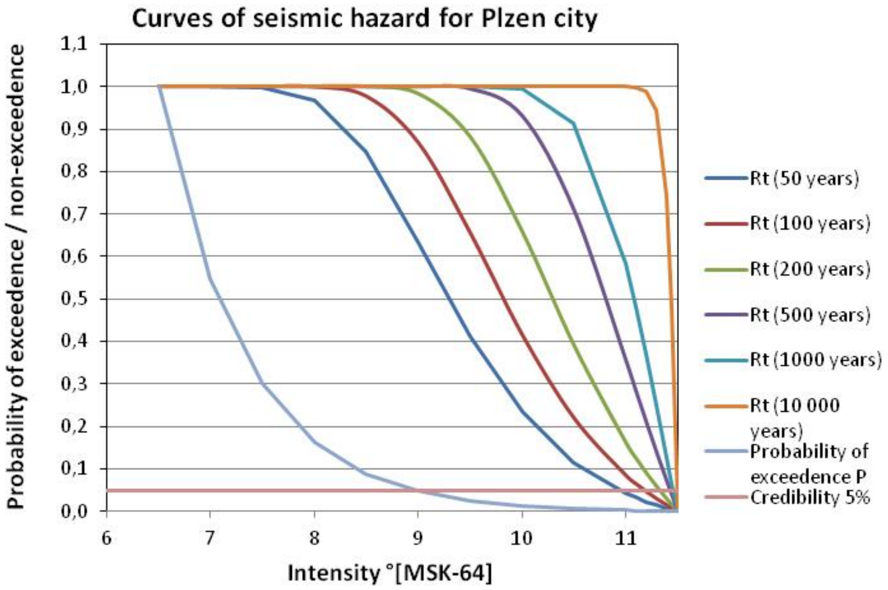

Fig 4: Probability curves of earthquake occurrence according to the MSK-64 scale

5. Return Period and Annual Exceedance Probability

In practice there are two approaches for the description of the frequency of occurrence of recurrent events. The first one is the return period and the second one is the annual exceedance probability.

The value of the return period τ for the intensity of I_0 = *time t* is given by relation for probable mean value, i.e.

$$R_\tau = 0.633.$$

For the calculations of risk we need to know hazard that can be caused by extreme events. Both, the hazard and the return period use to their assessment in practice:

- algorithms of extreme value method,
- experimental observations and mathematical modeling,
- expert´s approaches based on judgment, analogies and experience.

We start the calculation with the equation for the probability $R_t(I_0 \geq I_{0i})$. It means that each τ_i is calculated according to the equation

$$1-\left\{\frac{T}{T+\tau_i \cdot P(I_0 \geq I_{0i})}\right\}^{n+1} = 0.633.$$

By this way we can determine the return period τ_i for the intensity of disaster I_{0i}

$$\tau_i = \frac{1}{P(I_0 \geq I_{0i})} \cdot \left[\frac{T}{\sqrt[n+1]{0.377}} - T \right].$$

Let's consider the central value of return period τ_i for the intensity of earthquake I_{0i} and then we can express the calculated mean cumulative frequency $\overline{N}_{ci}$

$$\overline{N}_{ci} = \frac{T}{\tau_i}.$$

Calculated values of return periods τ_i and calculated mean cumulative frequencies $\overline{N}_{ci}$ are shown in Tab. 2.

I_{0i} [°MSK-64]	***τ_i [years]***	$\overline{N}_{ci}$ (calculated)
6	2.31	347.0107
6.5	4.20	190.3030
7	7.68	104.1856
7.5	14.07	56.8606
8	25.93	30.8536
8.5	48.30	16.5617
9	91.87	8.7077
9.5	182.17	4.3916
10	396.09	2.0197
10.5	1116.86	0.7163

Tab. 2: Calculated values of return periods τi and values of calculated mean cumulative frequencies $\overline{N}_{ci}$ of earthquake in the region with diameter of 400 km for the selected locality - Plzen city

In case of a homogeneous input set of data, we can compare the calculated values of mean cumulative frequency with the observed cumulative frequency determined in section 3. Compliance between the two cumulative frequencies verifies the representative set of data and confirms good physical assumptions of the earthquake phenomenon. The comparison of cumulative frequencies is shown in Tab. 3.

In terms of comparison of the values of observed cumulative frequency and calculated values of mean cumulative frequency we can conclude that the values of both frequencies are comparables for the corresponding values of earthquake intensity. It means that the collected and selected set of input data for seismic hazard assessment and return period determination was representative. I.e. the input set of data represents time interval long enough and is homogeneous for a satisfactory width of interval.

6. Attenuation Factor

Each of the focal regions included in the circle with the diameter of 400 km (see Fig. 1) has its own characteristics. The attenuation factor describes the propagation of seismic waves from the focal region to its vicinity and the attenuation of seismic waves with growing distance.

Great influence on hazard value is caused by great differences in azimuth attenuation curves. Bohemian Massif is characterized with very low seismic attenuation in comparison with its vicinity [2]. In Fig. 5 an example of differences in the propagation of macroseismic effects of earthquakes in cardinal points is shown. Basically, the parameters of attenuation differ not only with distance but also with the principal points of compass.

I_{0i} [°MSK-64]	N_{ci} (observed)	$\overline{N}_{ci}$ (calculated)
6	332	347.0107
6.5	171	190.3030
7	102	104.1856
7.5	54	56.8606
8	34	30.8536
8.5	16	16.5617
9	10	8.7077
9.5	5	4.3916
10	4	2.0197
10.5	1	0.7163

Tab. 3: Comparison of observed cumulative frequency Nci determined in section 2 and calculated mean cumulative frequency $\overline{N}_{ci}$

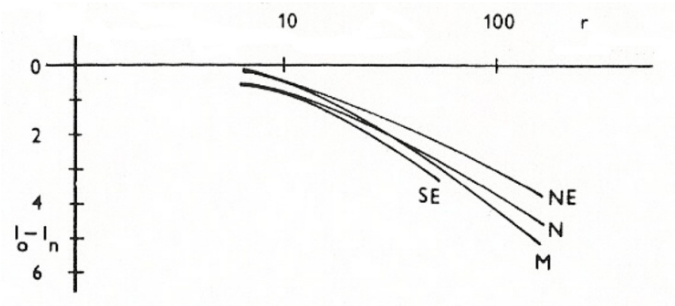

Fig 5: Example of attenuation curves for the Kraslice region [5]

The attenuation factor was determined in [5] for each of the focal regions shown in Fig. 1. In case of knowledge of the value of maximum possible intensity of earthquake in each of the focal regions and of the attenuation parameter for the direction focal region - Plzen city, we obtain results in Tab. 4:

- name of the focal region,
- maximum possible intensity of earthquake in the focal region,
- least favourable distance focal region - Plzen city,
- attenuation parameter with distance for the focal region,
- estimated earthquake intensity from the focal region in Plzen city.

Tab. 3 shows the considered data. All the data labeled with * are out of reality because the attenuation parameters presented in [5] corresponds to minor distances than the real least favourable distances focal region - Plzen city are. Therefore, estimated intensities in Plzen city are under the level of human registration.

It is shown that the focal regions, which significantly contribute to the seismic hazard of Plzen city, are 6 – Regensburg – Augsburg, 7 – Domažlice – Tachov, 13 – Innsbruck and vicinity, 14 – Salzach – St. Martin, 15 – Linz – Pregarten – Molln – Neulengbach and 17 – Friuli.

Focal regions with diffuse seismicity (in Fig. 1 marked with letters A-J) are not included in the table because low number of data did not allow determining the clear characteristics of seismic activity. The activity of these regions is represented only by isolated local seismic events.

Focal region	Maximum intensity [°MSK-64]	Least favourable distance [km]	Intensity attenuation factor in direction for Plzen city	Estimated intensity of earthquake in Plzen city
1 –Thüringer – Wald Gera	8	135	6*	*
2 – Kraslice – Aš – Plauen	7.5	70	6*	*
3 – Komořany – Leipzig	8	70	3*	*
4 – Zittau – Bautzen (Upper Lausicz)	4.5	120	3*	*
5 – Trutnov – Klodsko – Strzelin-Šumperk	7.5	200	5*	*
6 – Regensburg – Augsburg	8	85	3*	5
7 – Domažlice – Tachov	7	20	2.5*	4.5
8 – Šumava – Grafenau – Thalberg	6	45	3*	3
9 – Kaplice – Freistadt	5.5	100	3*	*
10 – Waidhofen – Jindřichův Hradec	5	140	-*	*
11 – Jihlava and vicinity	5	140	-*	*
12 – Vysoké Mýto – Litomyšl – Svitavy	5.5	160	-*	*
13 – Innsbruck and vicinity	9	240	3.5	5.5
14 – Salzach – St. Martin	7.5	215	3	4.5
15 – Linz – Pregarten – Molln – Neulengbach	9	205	3	6
16 – Bolzano – Lienz	7	260	5.5	1.5
17 – Friuli	11	260	5.5	5.5
18 – Eastern Alps	9.5	260	7*	*
19 – Český Těšín – Opava	7.5	280	5*	*
20 – Malé and Biele Karpaty Mts.	8.5	290	7*	*
21 – Trenčín – Žilina	7.5	320	5*	*
26 – Graz – Maribor – Oberschützen – Sopron – Kapuvár	5.5	310	7*	*
27 – Körmand – Györ	8.5	340	4*	*
28 – vicinity of Komárno	9	330	4*	*

Tab. 4: Values of seismic hazard for the Plzen city caused by individual focal regions

Conclusion

The Bohemian Massif is considered as low seismic active but even though by standards, both the civil and the technological facilities have to respect the protective measures with regard to earthquakes and other similar natural and severe events. According to the IAEA standards for the Bohemian Massif, the area of 400 km around the selected locality has to be involved in the seismic hazard assessment process.

The Plzen city seismic hazard assessment is 5 ° MSK-64 by maximum observed intensity map, by the method of extreme values is 5.5 maximum observed intensities for 50 years time interval up to 6.1 for 10 000 years time interval. The deterministic approach using the extreme value method than ensure higher level of safety.

Each of the focal regions belonging to the circle of 400 km has its own characteristic attenuation. Intensities of 6 °MSK-64 in Plzen city can be originated by extreme earthquakes in focal regions: Innsbruck and vicinity, Linz – Pregarten – Molln – Neulengbach and Friuli.

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