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ASSESSMENT OF MAXIMUM EARTHQUAKE INTENSITIES AND DESIGN RESPONSE SPECTRA FOR LOCALITIES IN CZECH REPUBLIC

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ABSTRACT. Antiseismic design of nuclear power facilities is based on input parameters of safe shut down earthquakes (SSE) such as the macroseismic intensity, design acceleration response spectra and time histories of SSE accelerograms. To assess these quantities with sufficient reliability, monitoring of authentic seismic events in the near zone is necessary. As a supplement to macroseismic monitoring the use of a new seismoscope is proposed.

KEY WORDS: safe shut–down–earthquake, design response spectra, macroseismic field, peak ground acceleration monitoring, seismic switch

1. INTRODUCTION

In the Czech Republic, only a slight seismic activity of the continental intraplate type shows up. According to historical documents, beginning from the 12th century (Kárník 1958), maximum earthquake intensities did not exceed 8° MSK–64. Foci were located in smaller depths, from 5 to 20 km. The recurrence time of stronger earthquakes is comparable with the time of use of instrumental records (60 years), so that instrumental records are unavailable. Prognoses of the seismic hazard to individual localities must therefore rely, above all, on statistic processing of historical data on macroseismically observed earthquake intensities (Zahradník 1985).

For antiseismic design of nuclear power plants, the most probable dynamic characteristics of the SSE earthquake must be imposed. Among these characteristic, the following ones may be quoted:

- peak ground motion acceleration amplitudes (PGA), duration time of strong oscillations τ.
- time history of acceleration and ground motion and response spectra.

An exact prediction of seismic hazard is inexecutable. Relatively most reliable estimations can be made by complex interpretation of various geo-surveys. Syntheses of geological, geodetical, and geophysical surveys are used most frequently. These surveys can be realized on a regional scale (seismic zoning), local scale (detailed zoning) or even on a building-site scale (micro-zoning). However, fundamental importance is attributed to evaluations of historical macroseismic data (Kárník 1987).

The following empirical functions are derived:

- geographical distribution of focal areas and fault zones,
- distribution of earthquakes occurrence within these areas, according to the intensity $N(I_0)$,
- macroseismic fields, maps of isoseists $I = I(I_0, R, \alpha)$,
- relations between the macroseismic intensity and dynamic ground motion characteristics.

However, a sufficiently reliable determination of these relations is not feasible in areas with such a low seismic activity as it show up in the territory of Czech Republic (Buben 1989).

In such a case, analogous relations, derived from foreign data, must be assumed. However, this also is the reason for the low reliability of results, which can involve one order's error. In order to minimize this unreliability, only such empirical relations should be used, which were derived in areas with analogous seismotectonic conditions, but this does not eliminate entirely the mentioned difficulties, because there occur also only a small number of earthquakes in similar seismotectonic conditions.

For this reason, the use of authentic macroseismic information on historical and contemporary earthquakes is still very actual. To this purpose, locally specified relations between macroseismic characteristics and ground motion parameters, obtained from seismograms of actual earthquakes, should be determined.

Local earthquakes with macroseismic manifestations do recur, in Bohemian Massif, after several years. It is therefore very important to determine, already at the time of the first next earthquake, both the macroseismic isoseists and the seismograms on a larger number of sites (teleseismic, regional and local earthquakes). If it would be possible to compare, in this way, macroseismic intensities and ground motion characteristics of some earthquakes on a very large number (hundreds) of sites, this would make up for the missing great number of earthquakes.

In order to make such an experiment possible in a near future, several hundreds of seismic devices should be used. The application of such a large number would require very cheap, reliable, resistant, and simple (for easy attendance) devices to be used. Such requirements are fulfilled by passive indicators, which record e.g. only the exceeding of a peak ground acceleration level PGA. Empirical relations between PGA the earthquake intensity I and earthquake magnitude M are required as a basis for the assessment of the site specified seismic hazard. We shall quote, in the following chapters, such empirical relations assumed from the foreign publications.

2. RELATION MAGNITUDO/INTENSITY

The fundamental dynamic characteristic of a seismic focus is its seismic energy, expressed by magnitude M. However, for historical earthquakes, only data on seismic intensities I are available. The most reliable empirical relations $M(I)$ are based on the value of the mean radius R_i [km] of the i^{th} isoseist I_i. The macroseismic magnitudo M_m thus determined considers the entire macroseismic field, i.e. the largest possible information.

The empirical relation

$$M_m = 0{,}62\, I_i + 0{,}0013\, R_i + 1{,}62 \log R_i - 1{,}1$$

has been derived by Ambraseys (1991) for the area of NE Europe, especially for the boundary of the macroseismic field, i.e. for $i = 3$,

$$M_m = 0{,}1\, I_0 + 1{,}93 \log R_3 - 0{,}14\,.$$

In cases, where such isoseist maps do not exist, simpler relation should be used. For the Bohemian Massif Kárník (1958) derived the relation

$$M_m = 0{,}63\, I_0 + 0{,}5\,.$$

If at least the depth h of the focus [km] is known, he uses the relation

$$M_m = 0{,}55\, I_0 + 0{,}93 \log h + 0{,}14\,.$$

For the determination of the empirical intensity I_0 of the earthquake within Central Europe area from known isoseist surface $S(4)$, $S(5)$ and $S(6)$ of isoseist 4°, 5° and 6°, Procházková (1983) determined the relations:

$$\begin{aligned} I_0 &= 1{,}35 \log S(6) + 3{,}46 \\ I_0 &= 1{,}32 \log S(5) + 2{,}55 \\ I_0 &= 1{,}32 \log S(4) + 1{,}66\,. \end{aligned}$$

For the correction ΔI of the observed intensity, for impedance $(V.\rho)$ of a sediment layer in the subsoil of the observation site, the Medvedev relation is used

$$\Delta I = 1{,}67 \log(V_1 \rho_1 / V \rho)\,,$$

where $V_1.\rho_1$ is the impedance of the standard ground.

For the correction of ΔI for the depth H of the groundwater level below terrain surface, the following relation is used:

$$\Delta I = \exp(-0{,}04.H^2)\,.$$

A more general solution of this problem was treated by Zahradník (1983).

3. RELATIONS MAGNITUDO/PEAK ACCELERATION OF OSCILLATIONS

The peak value of the acceleration of seismic oscillations of ground PGA as well as the strong motion duration time τ [s] are single-numeral parameters, whose relation to the macroseismic intensity I is very complex. Empirical $PGA(I)$ functions involve a considerable dispersion. Empirical dependence of PGA on the magnitude M_m at various distances D [km] of the earthquake focus have also been determined. However, even these relations, assessed by statistical data evaluation, are afflicted by considerable (one order's) dispersion, which limits the reliability of ground motion estimations even with very well known values of M_m.

In order to reduce these uncertainties, only such earthquakes should be evaluated, the focal parameters of which resemble as much as possible those expected in the considered locality. Some of such relations will be discussed as follows:

Phillips (1986) derived, for areas with relatively small attenuation of seismic waves within the far field, the following formula:

$$PGA = 4 \exp M_m / D^{-0{,}7} \qquad [\text{km, cm/s}^2] \, .$$

Petrovski (1986) determined relations for the horizontal acceleration component $PGA\,[\text{cm.s}^{-2}]$, illustrated in Fig. 1.

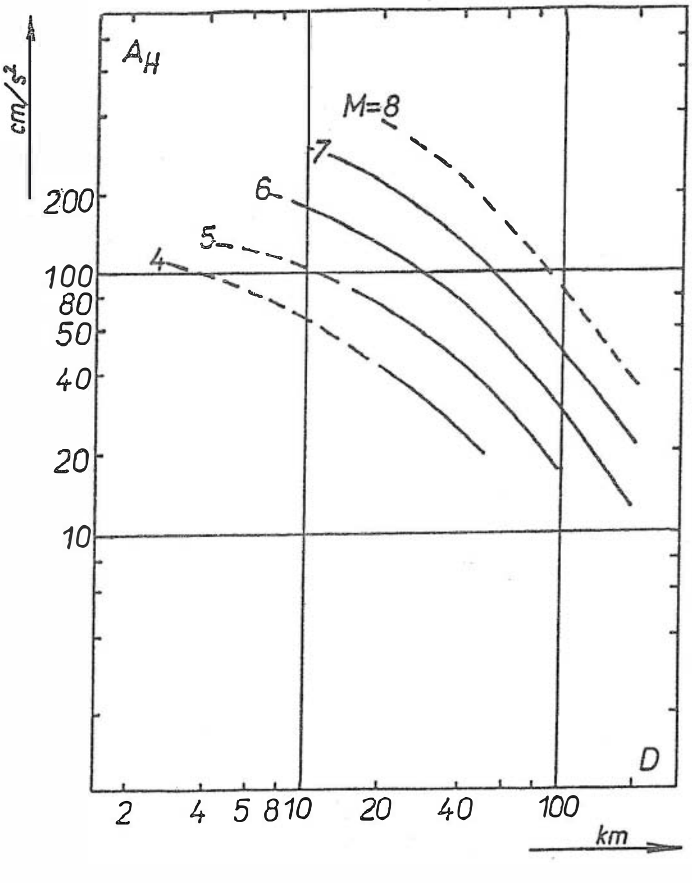

FIG 1. Empirical function $A_H(M, D)$ according to Petrovski (1986)

Kuk (1986) evaluated records from selected earthquakes within the magnitude range of $4 \leq M \leq 7$ with focal distances $2\,\text{km} \leq D \leq 120\,\text{km}$ and with depth of foci h of upto $h = 15\,\text{km}$, recorded on grounds characterized by the mean velocity of shear waves $V_s = 700\,\text{m/s}$. He determined, in this way, an empirical relation, which would seem to be most adequate also for the Bohemian Massif:

$$\log PGA = 0{,}359\,M - 2{,}892\,\log(D + 67{,}45) + 5{,}6\,.$$

The author quotes a considerable dispersion value σ for that relation as $\sigma = 0{,}319$.

Joyner (1981) choose 244 earthquake records from Western and Northern America at conditions $h \leq 20\,\text{km}$, $M \leq 5$. Peak values of the horizontal acceleration PGA were determined from that horizontal component, where they had a higher value. So the following empirical relation has been derived:

$$\log PGA = 0{,}249\,M - \log D - 0{,}00255\,D + 1{,}98 + 0{,}26\,P$$

with the values:

$P = 0$ for the probability $p = 0{,}5$ that the so determined value will not exceed the actual one,

$P = 1$ for the probability $p = 0{,}84$ that the so determined value will not exceed the actual one.

Joyner (1988) published further relations for the peak acceleration $PGA\,[\text{cm/s}^2]$ and also for the peak ground motion velocity $PGV\,[\text{cm/s}]$, which he read on that horizontal component of the record, where they had a higher value:

$$\log PGA = 0{,}49 + 0{,}23.(M - 6) - \log D - 0{,}0027\,D$$

$$\sigma = 0{,}28$$

$$\log PGV = 2{,}17 + 0{,}49.(M - 6) - \log D - 0{,}026\,D$$

$$\sigma = 0{,}33\,.$$

Relations $PGA(M, D)$ for magnitudes $5 \leq M \leq 7{,}7$ are illustrated in Fig. 2. The distance $D\,[\text{km}]$ is about the same as the macroscopic epicentral distance.

Schteinberg (1986) recommends the following empirical relations:

$$\begin{aligned} \log PGA &= 2{,}056 - 0{,}04.D && \text{for} \quad 3{,}5 \leq M \leq 4{,}5 \\ \log PGA &= 2{,}37 - 0{,}02.D && \text{for} \quad 4{,}5 \leq M \leq 5{,}5 \\ \log PGA &= 2{,}65 - 0{,}01.D && \text{for} \quad 5{,}5 \leq M \leq 6{,}5\,. \end{aligned}$$

Crouse (1988) processed earthquakes in South California, recorded on a thick layer (over 60 m) of sediments, with the result:

$$\operatorname{lgn} PGA = 2{,}48 + 0{,}73.M - 0{,}015.M^2 - 0{,}05\operatorname{lgn}(D + 1) - 0{,}0093.D$$

at standard deviation of the value $\operatorname{lgn} PGA\,[\text{cm/s}^2]$ $\sigma_{\text{lgn}} = 0{,}58$.

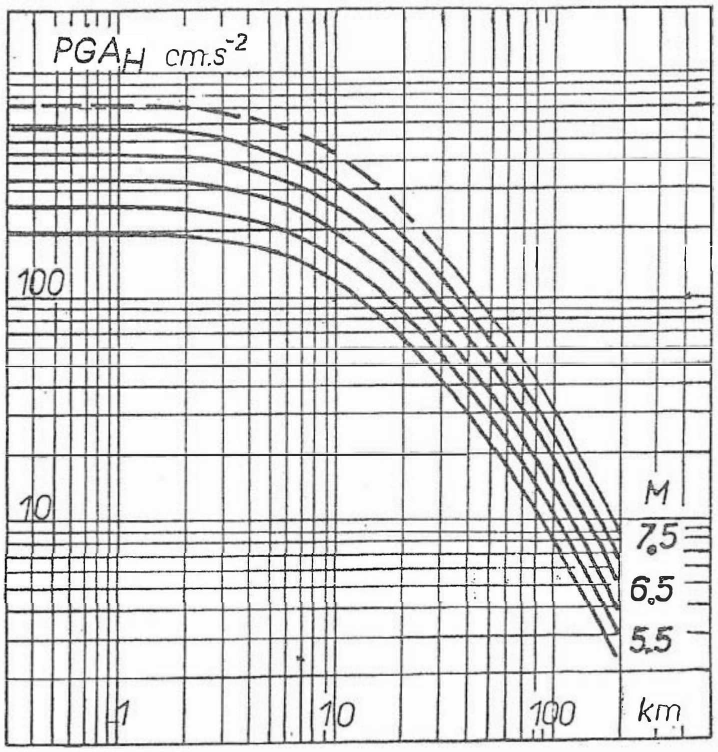

FIG 2. Empirical function $PGA_H(M, D)$ according to Joyner (1988)

TABLE 1.

M	Rocky and solid sediments		Thick sediment layers		σ_{lgn}
	a	d	a	d	
4,5	606	−2,57	189	−2,22	0,70
5,0	617	−2,46	195	−2,13	0,58
5,5	452	−2,28	147	−1,97	0,48
6,0	282	−2,07	98	−1,79	0,42

Idris (1977) derived the formula for acceleration PGA [g] in random oriented horizontal component for magnitudes $M \leq 6$ and for hypocentral distances R [km]:

$$\mathrm{lgn}\, PGA = \mathrm{lgn}\, a + d.\mathrm{lgn}(R + 20)\,.$$

Values of the coefficients a, d and those of standard deviations σ_{lgn} are quoted in the following table, which characterizes the dependence on the magnitude M and on the nature of the subsoil.

If, for example, the intensity $I = 7^{\circ}$ is introduced into the mentioned relations, we will see that the reliability of this method is insufficient. Considering the great dispersion values, we would have to introduce a hight safety factor (median + σ or even median + $2\,\sigma$). However, this would lead to the evidently too high value of seismic hazard, which is unrealistic in conditions of moderate seismic activity. At such a conditions, the only way to increase the reliability of ground motion prediction, we see in the comparison of accelerographs of actual local earthquakes with macroseismically determined intensities. The assessment of local relations between I and PGA only could reduce the dispersion, which is caused by local geological conditions.

The determination of an empirical relation for earthquakes in Austria (Drimmel 1985) was based on a similar idea and it resulted to the relation

$$\log_{10}(PGA) = 0{,}45.I - 1{,}3 \qquad [\mathrm{cm.s}^{-2}]$$

With a low number of weak local earthquakes, say $I = 3$, it is necessary to use a very high number of simple but sensitive devices in order acquire a sufficient data volume in the foreseeable future. An example of the foreign devices is the Medvedev's pendulum seismoscope ($T_0 = 0{,}25\,\mathrm{s}$, $\beta = 0{,}5$). This elementary oscillator records the response y (maximum deviation y from the zero position) to the intensity$I$ of the earthquake, as quoted in the following table (Sandi 1986):

TABLE 2.

I_0 MSK-64	6	7	8	9
y [mm]	1–2	2–4	4–8	8–16

However, the correlation between these values its very low.

We therefore recommend, for the assessment of the locally specified empirical relations between I and PGA, the application of seismic indicators (seismoscopes) of our new construction. Their "vulnerability" by the acceleration should resemble, as well as can be, the vulnerability of building structures.

However, the earthquake effects, characterized by the value of I, do not depend only on the peak acceleration amplitude PGA, but also on the duration time τ of large oscillations and their spectral amplitudes $S(\omega)$. Therefore, it will never be possible to manage with whatever single-numeral characteristic of dynamic effects of seismic oscillations. The entire time history of oscillations will have to be taken in account (accelerograms, velocigrams). However, such records are still not available in the considered localities of the Czech Republic.

4. ANALOGOUS ACCELEROGRAMS

Earthquake accelerograms provide not only data on maximum amplitudes, but also on duration time σ of destructive oscillations and their spectral amplitudes $S(\omega)$. These parameters depend not only on magnitude, but also on focal distance.

At conditions of a moderate intra-plate seismicity, the statistical delimitation of areas of possible earthquake foci is not sufficiently reliable. It should even be admitted, for the internal parts of the Bohemian Massif, that a focus of a possible, if only weak earthquake ($M \leq 5$), can occur at any considered building site.

Phillips (1986) proves that in such a seismotectonic situation, the seismic hazard of an arbitrary site is caused, above all, by foci of weak earthquakes situated at the shortest distances. His evidence is based on the following assumptions:

a) the site is situated within a zone with weak seismic activity, where foci are located relatively uniformly,

b) the frequency distribution of magnitudes satisfies the Gutenberg-Richter relation in the form of

$$N(M) = \text{const.} \exp[3(4 - M)]$$

and the value of M is limited from below by M_1 and from above by M_2,

c) the occurrence of earthquakes is a Poisson's random process.

The seismic hazard to the considered site due to the seismic activity thus defined is expressed as probability P of exceeding the given PGA value within one year.

$$P = 1 - \exp\left[-\frac{\pi}{A}\int_{M_1}^{M_2}\left|\frac{\mathrm{d}N}{\mathrm{d}M}\right| . R^2\, dM\right] ,$$

where R is the distance, $[R] = \text{km}$. Another assumption for this evidence, introduced by Phillips, is the relation

$$PGA = 0{,}4 \,.\, R^{0,7} \,.\, \exp(M) \qquad [\text{km},\%\text{g}] \,.$$

After substitution into the preceding expression, the following relation is obtained:

$$P = 1 - \exp\left[-11 \,.\, A^{-2,9}\left(e^{-0,1.M_1} - e^{-0,1.M_2}\right)\right] .$$

It follows, from the derivation of this expression

$$\frac{\mathrm{d}P}{\mathrm{d}M_2} = 1{,}1\, A^{-2,9} . \exp(-0{,}1.M_2)$$

The probability P increases only very slightly with increasing value of the upper limit M_2. If we introduce, for example, $PGA = 220\,\text{cm/s}^2$, $M_1 = 3$, then, for $M_2 = 5{,}5$, the seismic hazard of $P = 1{,}6.10^{-4}$ is obtained. For a maximum possible magnitudo $M_2 = 7$, this exposure increases only to $P = 2{,}4.10^{-4}$.

It results also, from the quoted relations, that two thirds of the total value of P are a consequence of earthquakes, which occur at the shortest distances of upto $R = 7\,\text{km}$.

However, the course of these weak local earthquakes is different from those of strong, but distant (regional) earthquakes, in spite of equal maximum amplitudes in both cases. Differences are in spectral amplitudes $S(\omega)$ of the time history of oscillations $A(t)$, expressed by Fourier transform $F(A)$. Accelerograms of local weak earthquakes have a relatively lower spectral amplitudes $S(\omega)$ within the low frequency range (below 5 Hz).

Short-distance earthquakes differ from teleseismic ones also by duration time τ of the maximum amplitude phase. For the time τ (during which about 90% of the seismic wave energy runs through the given site), Schteinberg (1986) gives the empirical formula

$$\log\tau = 0{,}207.M + 0{,}264\,\log R - 0{,}65\,,$$

holding true for records of accelerographs situated on a rocky bedrock. For softer subsoils, another formula holds:

$$\log\tau = 0{,}178.M + 0{,}4\,\log R - 0{,}48\,.$$

Drimmel (1985) recommends, for earthquakes within the near field and for solid grounds, the formula

$$\log\tau = 0{,}21.M_s - 0{,}6\,.$$

However, for soft grounds, this time is much longer.

Weak earthquakes within near field ($M = 5$, $R = 15\,\mathrm{km}$) have therefore the duration time of some seconds. These times depend also on the oscillation period T. According to Phillips (1986), $\tau = 4\,\mathrm{s}$ for periods of $T = 0{,}1\,\mathrm{s}$, but for $T = 1\,\mathrm{s}$ the time increases to $\tau = 10\,\mathrm{s}$. We therefore estimate for our OBE level earthquakes that the sites will be subjected to 10 to 40 oscillations.

5. RESPONSE SPECTRA

The frequency distribution of seismic oscillations $A(t)$, given by their Fourier spectrum $F_A(\omega)$, uses to be expressed frequently by means of a function $S_A(\omega)$ called Housner spectrum or the spectral response. This function describes the maximum reaction $S(\beta,\omega)$ of linear harmonic oscillators for the entire course of seismic oscillations. These oscillators have various frequencies ω_0 and various damping β.

Amplitudes of forced oscillation y of these oscillators are described be known equation

$$\ddot{y}(t) + 2\,\beta\,\omega_0\,\dot{y}(t) + \omega_0\,y(t) = -A(t)\,.$$

Let us denote the following values of forced oscillations maximum displacement amplitude

$$|y|_{\max} = S_d(\beta,\omega_0)\,,$$

maximum velocity amplitude

$$\left|\frac{\mathrm{d}y}{\mathrm{d}t}\right|_{\max} = S_v(\beta,\omega_0)\,,$$

maximum amplitude of acceleration

$$\left|\frac{\mathrm{d}^2y}{\mathrm{d}t^2}\right|_{\max} = S_a(\beta,\omega_0)\,.$$

S_d is called response spectrum of relative displacement,
S_v is called response spectrum of relative velocity,

S_a is called response spectrum of relative acceleration,
S_A is called response spectrum of absolute acceleration.

According to Hurting (1984) following relations hold true:

$$S_d = \frac{1}{\omega_0} \left| \int_0^{t_n} A(t) \exp[-\omega_0 \beta(t_n - t)] \, \sin[\omega_0(t_n - t] dt \right|_{\max}$$

$$S_v = - \left| \int_0^{t_n} A(t) \exp[-\omega_0 \beta(t_n - t)] \, \sin[\omega_0(t_n - t] dt \right|_{\max}$$

$$S_a = \omega_0 \left| \int_0^{t_n} A(t) \exp[-\omega_0 \beta(t_n - t)] \, \sin[\omega_0(t_n - t] dt \right|_{\max}$$

It is evident, from the mentioned relations, that it holds

$$S_A = S_a + A \, .$$

If the so-called pseudovelocity response is defined by the relation

$$S_{pv}(\beta, \omega_0) = \left| \int_0^{t_n} A(t) \exp[-\omega_0 . \beta(t_n - t)] \, . \, \sin[\omega_0 . (t_n - t)] \, dt \right|_{\max}$$

then the relation holds true:

$$\omega_0 . S_d = S_{pv} = (1/\omega_0) . S_a \, .$$

It results, from definitions of spectral response that the response spectrum of oscillator velocity at $\beta = 0$ and for $t \gg t_n$ is the same as the Fourier spectrum $F(A)$ of the course of acceleration of exciting oscillations $A(t)$.

Response spectra of oscillators use to have a jagged look. By averaging a larger number of these courses smoothened courses may by obtained, which can then be approximated by several straight-line segments. The courses thus formed, completed by values of the standard deviation values, are called design response spectra.

6. DESIGN RESPONSE SPECTRA

The response spectrum describes the properties of an individual earthquake, while the design spectrum is used as a prescription code for antiseismic design of buildings and structures. Design response spectra are therefore a part of regulatory codes (NRC) for projecting structures with high seismic risk, mainly the nuclear power plants.

Actual regulatory codes US NRC 1.60 holding true in USA are illustrated in Fig. 3. The table beneath the Fig. 3 quotes control values at points designated by letters A, B, C, D. They were derived on the basis of accelerograms recorded mainly in areas with high seismic activity. They respect therefore the effects of strong to medium-distant earthquakes. They are plotted in trilogarithmic coordinates, which helps the values of both the acceleration response and the pseudo-displacement or pseudo-velocity response to be read easily.

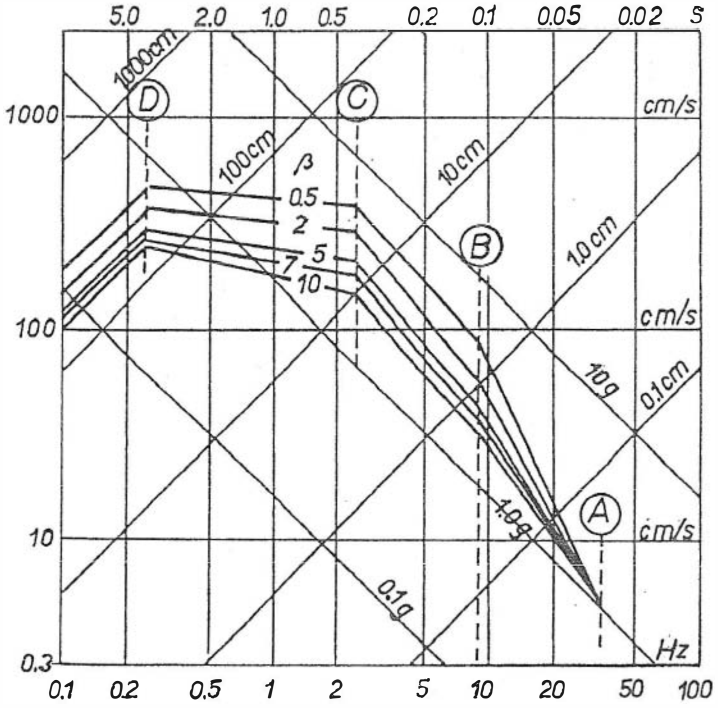

FIG 3. US NRC 1.60 horizontal design response code

As parameters, values of attenuation $\beta = 0{,}005$, $0{,}02$, $0{,}05$ and $0{,}1$ are quoted. The attenuation β should agree with the attenuation of the own oscillations of projected structures. For example, the new Japanese seismic code (Kato 1978) prescribes for pipe ducts, $0{,}005 \leq \beta \leq 0{,}025$, for cable bridges $\beta = 0{,}05$.

The application of these standards to our areas with low seismic activity results, however, in unrealistically high requirements on the antiseismic design of nuclear power plants. The reason is that the weak near earthquakes involve for frequencies $f < 3\,\mathrm{Hz}$ significantly lower values of response spectra than those prescribed by US NRC 1.60.

The dependence of the response spectra on the focal distance is suggested in Fig. 4 (Phillips 1986). This concerns the result of processing the earthquakes in Japan, recorded on rocky bedrock and at focal distances of $R = 5\,\mathrm{km}$, $15\,\mathrm{km}$ and $60\,\mathrm{km}$.

The standard US NRC 1.60 is so far assumed also in other countries with moderate seismicity. Its modification is actual, for example in France and U.K. The proposed design response spectra are quoted in Fig. 5 (horizontal component $\beta = 0{,}05$). These are normalized to the value of 0,25 g for frequencies of 30 Hz.

The narrowest maximum has the spectrum denoted by the letter C for an earthquake in France ($M \leq 5$, $R \leq 10$). The course B concerns an earthquake on the UK territory, recorded on rocky grounds. The course denoted by A, suggested for Canadian territory, has a relatively largest width of the maximum response segment (between point 3 and 4).

The influence of ground properties in low to moderate activity zones has been investigated by Woo (1986). The choice of 145 accelerograms was made according

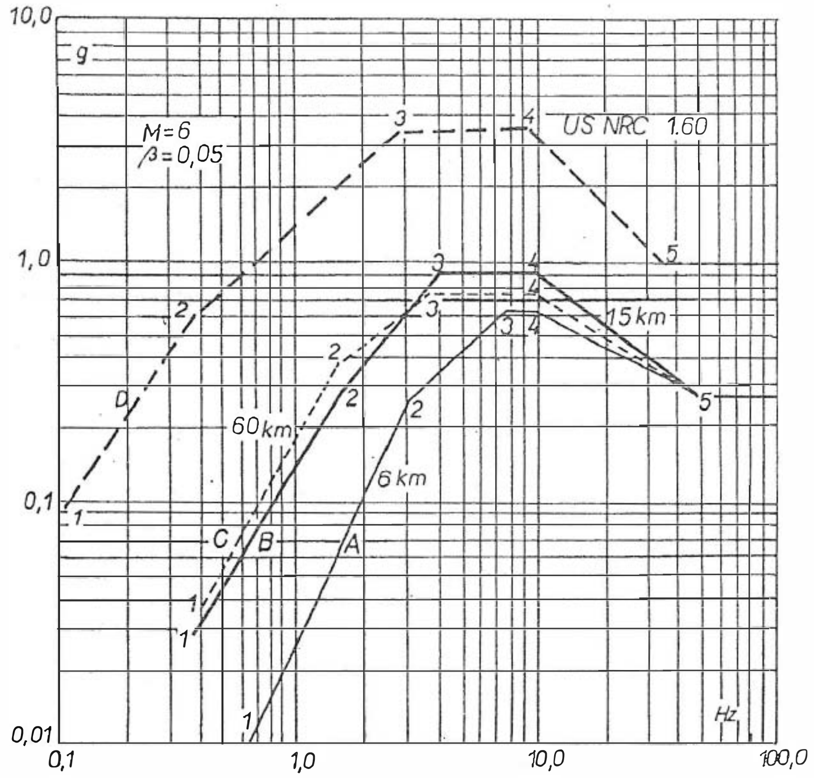

FIG 4. Design response ($M = 6$, $\beta = 0{,}05$) for rock sites, $D = 6$ km, 15 km, 60 km, scaled to 0,25 g at 50 Hz according to Phillips (1986)

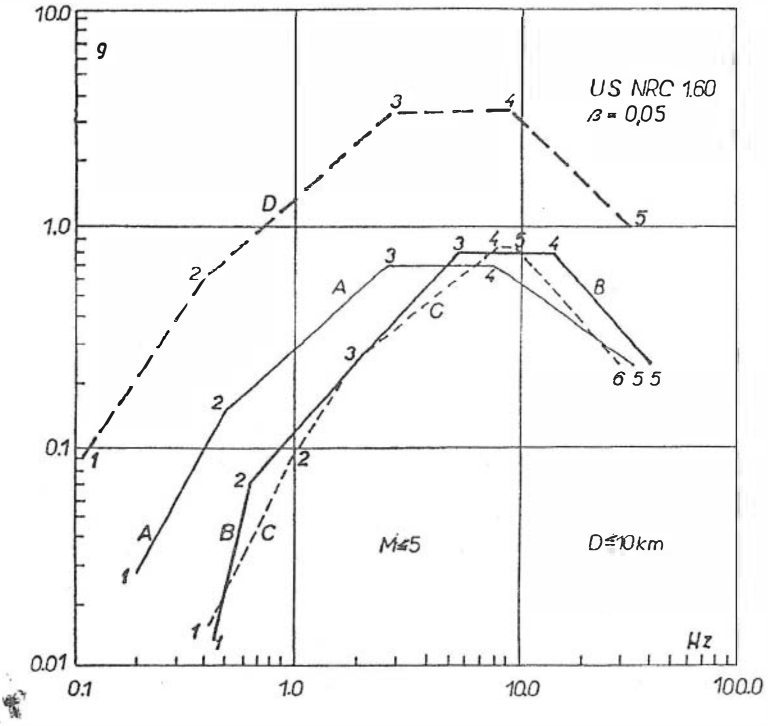

FIG 5. Horizontal design response spectra for rock sites A: Canadian, B: UK, C: France, compared with D: US NSR 1.60, for $M \leq 5$, $D \leq 10$ km, $\beta = 0{,}05$, scaled to 0,25 g at 50 Hz, according to Phillips (1986)

to the following rules:

a) $4 \leq M_L \leq 6{,}2$,
b) focus depth up to $H = 30\,\mathrm{km}$,
c) epicentral distance $R \doteq 50\,\mathrm{km}$.

These accelerograms were divided into three groups according to the subsoil characteristics:

1) hard rock,
2) consolidated sediments,
3) soft sediments.

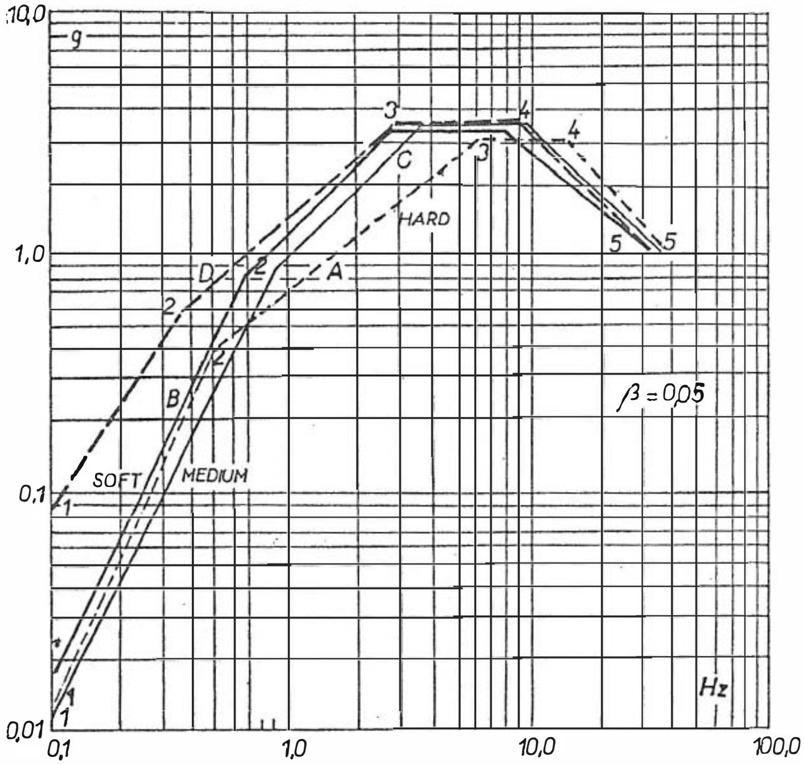

FIG 6. Horizontal design response spectra scaled to 1 g at 33 Hz for various recording-station ground conditions A: hard rock, B: soft, C: medium in comparison with D: US NRC 1.60 according to Woo (1986)

The response spectra ($\beta = 0{,}05$) thus determined are illustrated in Fig. 6. For comparison, there are drawn also design spectra NRC 1.60. For soft sediments, the response course approaches US NRC for frequencies within the range of $3 \leq f \leq 8\,\mathrm{Hz}$. But in all other cases, the US NRC requires higher values.

In the Germany, the standard KTA 2202.2 from 1975 has still been used. It is, in principle, identical with American NRC. The moderate activity of Germany is characterized by maximum earthquake intensity of $I_0 = 8°$ MSK-64. The modification proposal of the German design response spectrum (Wittman 1966) is based on the evaluation of accelerograms with focal distances of upto 20 km.Fig. 7 illustrates the suggested design response spectrum for $\beta = 0{,}05$ and for $7 \leq I \leq 8$. The curve C holds for first category of grounds, the curve B is for the second and curve C for the

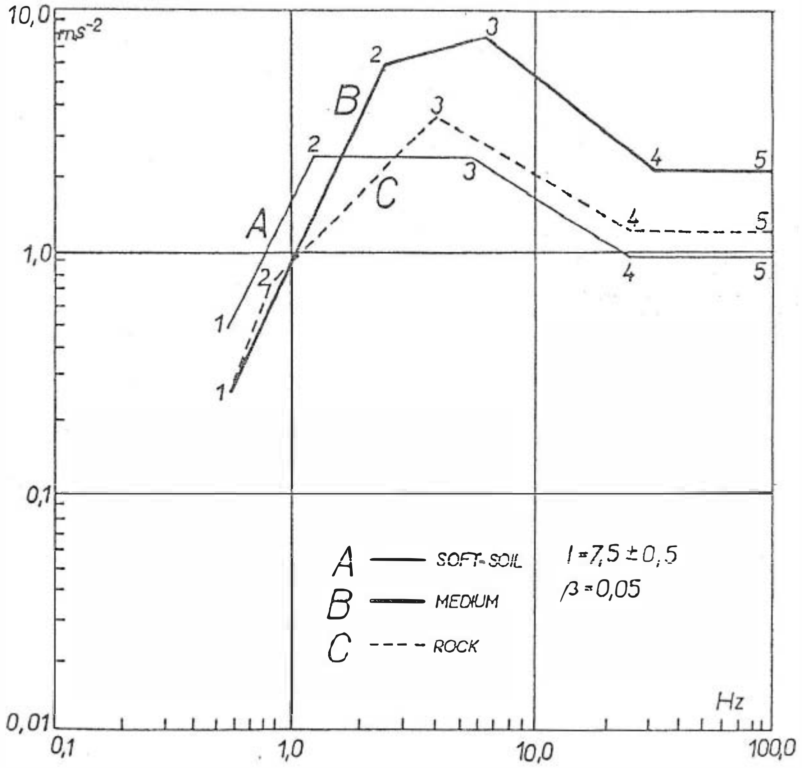

FIG 7. Horizontal design response spectra at $\beta = 0{,}05$ for local earthquakes with epicentral intensity $I_0 = 7{,}5$ for A: soft soil, B: medium sediments, C: rock ground, according to Wittman (1986)

third category of grounds. The applicability of these codes also for the Bohemian Massif area is facilitated by the fact that these respo [illegible]

A similar proposal of a non-normalized design response spectrum has been published by Schteinberg (1986), See Fig. 8. Spectra are specified for magnitudes ($4 \leq M \leq 8$) and for distances $R < 20\,\mathrm{km}$ and for $20 \leq R \leq 40\,\mathrm{km}$. Sections of constant maximum response are widened with increasing magnitudes towards the low frequencies. The relation between the lower limit of these sections f_d and magnitudes M is

$$\log f_d = 1{,}04 - 0{,}135.M\ .$$

The application of the non-normalized spectra of Wittman or of Schteinberg is of great advantage. The scale factors need not be assessed which is a very problematic matter.

Weak local earthquakes have a very short phase of strong oscillations, which can even have the form of a single-peak amplitude. Such amplitudes do not produce such large destructions as the same amplitudes lasting during a longer duration time. An irreplaceable significance must therefore be attributed to the accumulation of new accelerograms and macroseismic data and assessment of locally specified empirical relations between macroseismic intensities and the ground motion characteristic. We are therefore proposing new seismic acceleration indicators, whose response would consider also the duration time of oscillations.

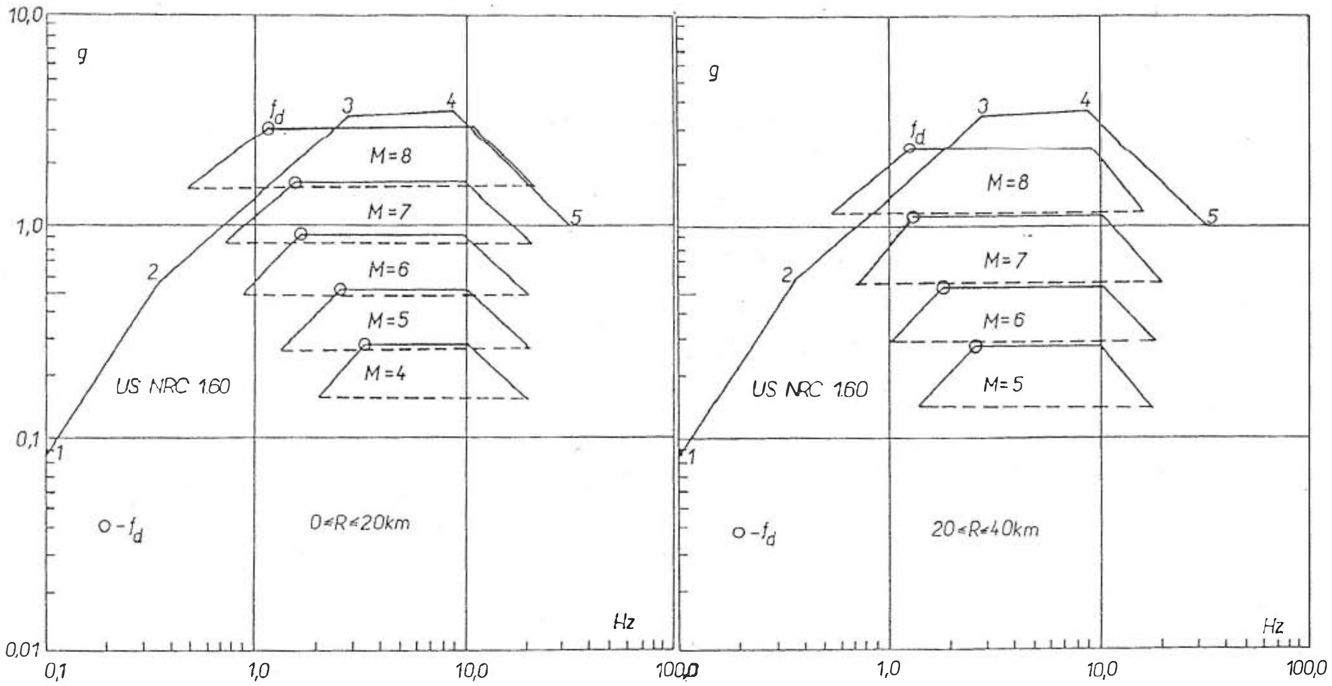

FIG 8. Horizontal design response spectra, $\beta = 0{,}05$ for earthquakes with $M = 4, 5, 6, 7, 8$, at distances 0–20 km – A and 20–40 km – B, not normalized, in comparison with US NRC 1.60, according to Schteinberg (1986)

7. INDICATOR OF GROUND MOTION ACCELERATION

The principle issues from the classic Newmark's model of sloppy terrains: a rigid plate (block of the mass m) with a smooth and planar bottom face is laid on an inclined support plate of similar properties. By gravity, the upper plate may slip on the bottom plate (Newmark 1965).

In the construction of this device, the support face may be represented by the inside of a glass tube (length 200 mm, diameter 20 mm), Fig. 9a. A cylinder (diameter 10 mm, length 80 mm) made e.g. of well polished chrome-plated steel is freely inserted into this tube. The longitudinal tube axis forms a small angle γ with horizontal plane. Let the sliding cylinder be shifted, in the initial position, towards the higher end of the tube. Let the centre of gravity of the sliding cylinder have, in this position, the coordinates $x = 0$ on the X axis,which is firmly connected with the tube. At the angle $\gamma = 0$ of the cylinder is at rest, $\mathrm{d}x/\mathrm{d}t = 0$.

If we increase slowly (quasi-statically) the angle γ to a critical value of γ_{cr}, the cylinder starts to advance along the inclined tube surface. The critical angle γ_{cr} is defined by the condition that the gravity component equals the reversely acting force of Coulomb friction, which depends on the value of the coefficient of static dry friction μ, thus

$$m.g.\sin\gamma_{\mathrm{cr}} = \mu.m.g.\cos\gamma_{\mathrm{cr}}\,,$$

$$\mu = \mathrm{tg}\,\gamma_{\mathrm{cr}}\,.$$

The value of the friction coefficient μ depends on materials of both the tube and

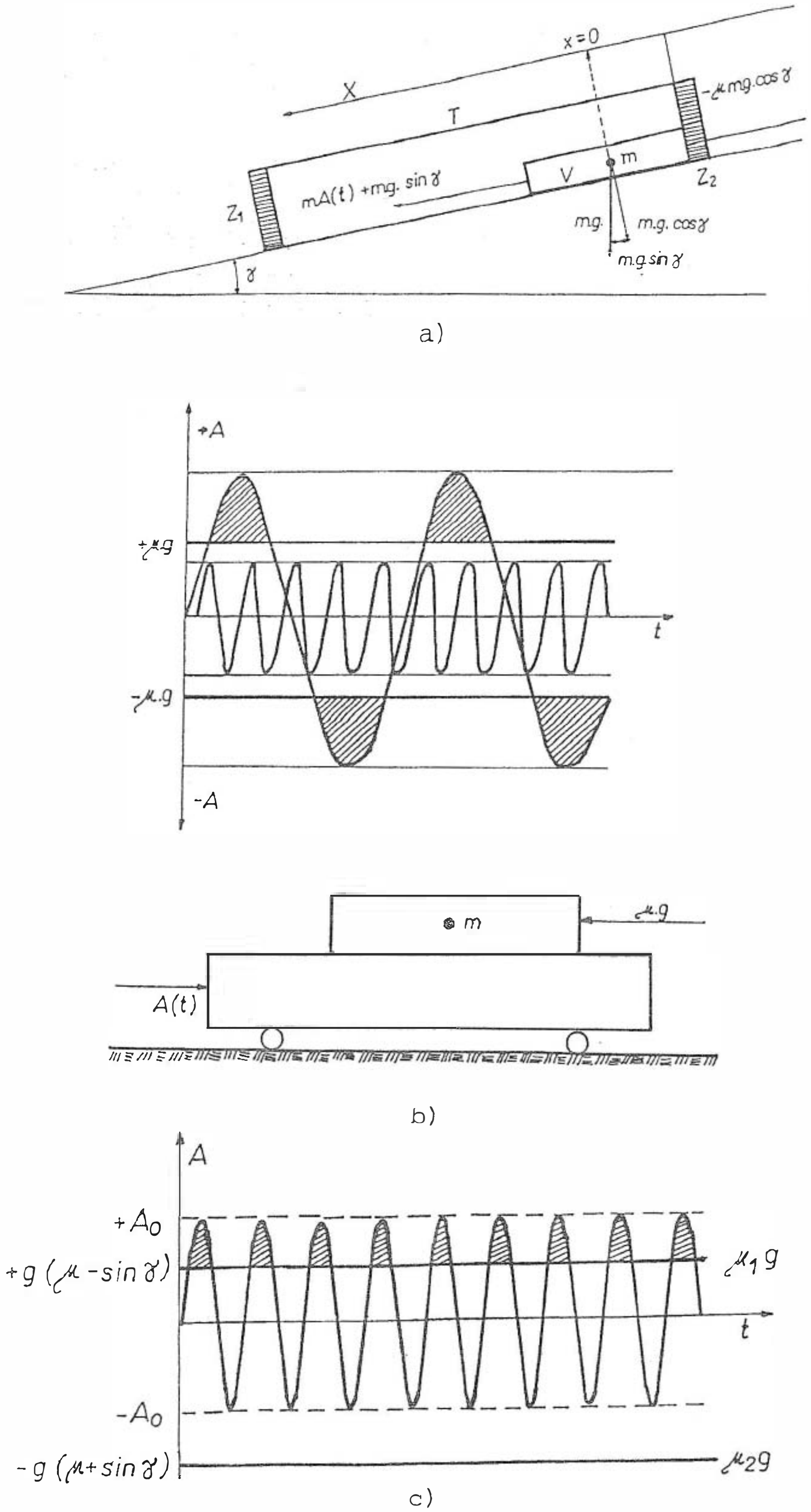

FIG 9. Sliding block model as seismic acceleration indicator.

a. principle of instrument

b. conditions of motion for $\gamma = 0$

c. conditions of motion for $\gamma \neq 0$

cylinder and on the smoothness of their surfaces. With various materials, we obtained the value

$$\sin\gamma_{\mathrm{cr}} = 0{,}125\,.$$

When using this arrangement as seismic indicator, the angle γ is set up to a subcritical value, say $\sin\gamma_s = 0{,}1$, at which the cylinder does not move. It starts shifting if the tube would be subjected to certain acceleration $A(t)$ acting in the direction of X axis.

However, for harmonic motion

$$A = A_0 \sin\Omega t\,,$$

the cylinder will be shifted only in those time intervals, during which the condition

$$A \geq \sin\gamma_{\mathrm{cr}} - \sin\gamma_s$$

is fulfilled, thus in the described experiment if

$$A \geq 981.(0{,}125 - 0{,}1) = 25 \qquad [\mathrm{cm/s}^2]\,.$$

The Newmark's static safety coefficient of stability F_s (Pelli 1992) is defined by relation

$$F_s = \sin\gamma_k / \sin\gamma_s\,.$$

In our case, $F_s = 0{,}125/0{,}1 = 1{,}25$. According to Newmark's definition, a sliding model is in the state close to static stability, if it holds true $1{,}2 \leq F_s \leq 1{,}5$. The described device satisfies this condition, so it can be used as an indicator of ground motion acceleration.

The reaction of this indicator to the earthquake intensity I can be preliminarily estimated by the use of relations $PGA(I)$, quoted in chapter 2 and 3. According to them, this indicator should reliable react to earthquakes with intensities $I \geq 4^\circ$. It has a higher sensitivity than the Medvedev seismoscope and can thus be used for monitoring weak earthquakes within the Bohemian Massif.

The relative motions of the cylinder within the tube are described by solution of the equilibrium equation

$$m.a = m.A(t) + m.g/sin\gamma + \mu.m.g.\cos\gamma\,, \qquad (1)$$

where $a = dv/dt = d^2x/dt^2$ is relative acceleration of the cylinder, $F_A = m.A$ is the force produced by ground acceleration, $F_\gamma = m.g.\sin\gamma$ is the gravity component, and $F_f = m.\mu.g$ is the friction force.

Let us first consider the case, when the tube is in horizontal position: $\sin\gamma = 0$, $f_\gamma = 0$, Fig. 9b. As far the seismic acceleration is small i.e. $|A| = \mu.g$, the cylinder remains at the rest, $dx/dt = v = 0$. However, if at certain time intervals the acceleration $A(t)$ acquire the value

$$|A| > \mu.g$$

then, within these time intervals, the relative acceleration $a(t)$ of the cylinder within the tube satisfies the relation

$$a(t) + \mu.g.\mathrm{sign}(v) = -A(t)\,. \tag{2}$$

Due to the change of sign of the friction force in dependence of the sign of motion velocity [sign(v)], the response of such a system is linear only by parts. It holds evidently that the displacement amplitude x decreases with increasing friction coefficient μ.

The equation (2) can be solved by the method of simulation of $A(t)$ by the following stationary processes:

a) white noise (Gaussian process),
b) white noise with filtration (Kanai and Tajimi process).

The Gaussian process $S(\Omega)$ is defined by the unilateral output spectral density G_0

$$S(\Omega) = G_0$$

for $0 \leq \Omega \leq \infty$. At Gaussian input motion, the solution can be found by the use of an equivalent linear viscous system with the equivalent attenuation coefficient β,

$$\beta = \mu^2.g^2/(\pi.G_0)\,.$$

The accuracy of this approximation increases with increasing value of β (Betbeder 1992).

Constantinou (1984) proposed the solution of (2) for the input process of the Kanai type, also with the use of equivalent viscous attenuation.

Now, we will be concerned the case illustrated in Fig. 9a, when $F_\gamma \neq 0$ and the motion is described by equation

$$a(t) + g[\sin\gamma + \mu \sin(v)] = -A(t)\,.$$

In this case, the system behaves so as if the friction coefficient would be asymmetrical. Depending on the sign of the motion velocity sign(v) there occur two effective friction coefficients, $\mu_2 > \mu_1$.

This problem has been solved (Constantinou 1984) by the use of an equivalent coefficient of viscous attenuation β_{as} for input stationary Gaussian noise. It holds

$$\beta_{as} = \frac{2\,g^2\mu_1^2\mu_2^2}{\pi\,G_0(\mu_1^2 + \mu_2^2)}\,.$$

The following relation holds true for the velocity of motion of the cylinder within the tube:

$$v = \frac{\pi}{2\,g}.G_0.\frac{\mu_2 - \mu_1}{\mu_1\mu_2}\,.$$

Its accuracy increases with increasing asymmetry, i.e. the value $(\mu_2 - \mu_1)$.

It has been confirmed, by our repeated experiments on a vibration table (harmonic stationary oscillations 1 to 3 Hz, displacement amplitudes $d_0 = 3\,\mathrm{mm}$), that the average velocity v is constant, but the dispersion of individual values is considerable high (tens of %).

The average total displacement length Δx of cylinder within the tube is thus directly proportional to the duration time τ of input oscillations. With a general course of the input acceleration $A(t)$, it is possible to determine the displacement Δx as double integral of those sections of the $A(t)$ course, which exceed the friction zone, as it is illustrated in Figs. 9c and 10.

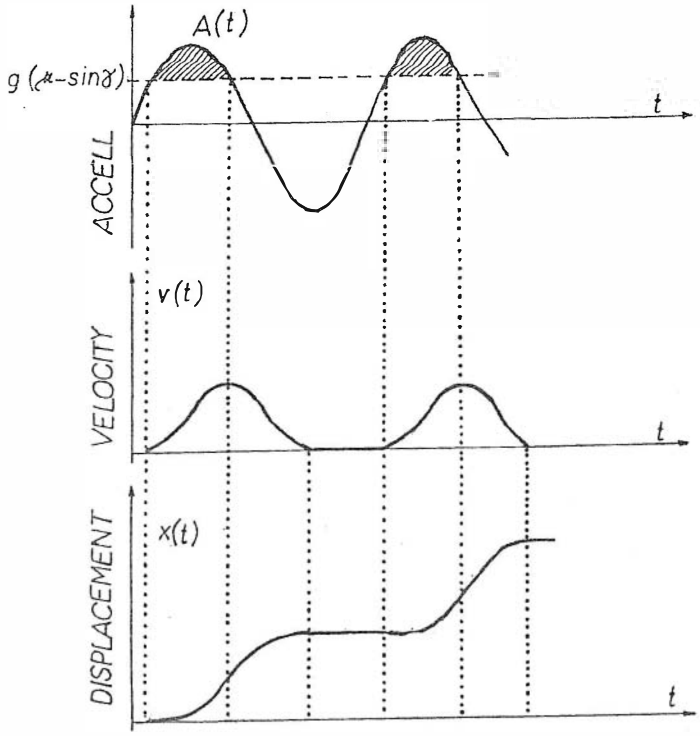

FIG 10. Displacement computation by twice integrating the segments of the acceleration time history $A(t)$ which exceed the critical acceleration value A_{cr}

However, when obtaining large number of values Δx on the vibration table, a considerable dispersion was found. That is the reason, why quantitative conclusions about $A(t)$ from the value of Δx would not be reliable.

As it results from preceding chapters, the expected weak and near-focus earthquakes will be characterized by duration τ of the order of seconds and by frequencies about of 5 Hz. Using this indicator only it can be determined:

a) whether there occurred an earthquake with $A > A_{\mathrm{cr}}$ manifesting itself by the displacement Δx,

b) whether the number of oscillations $N = f.\tau$ was sufficient for Δx reaching a certain critical value x_{cr}.

A seismic indicator constructed on principle described should therefore be composed of several tubes with various inclination angles γ, corresponding to some preset values of A_{cr}.

For signalling the state $x \geq x_{\mathrm{cr}}$, the tubes could be bended to an arch so that γ would increase with increasing x (upto the value say 60°) starting with the point $x = x_{\mathrm{cr}}$, as suggested in Fig. 11.

Than the position of the moving cylinder would be irreversible and end at the bottom plug, where it lies down with most of its weight. This can be simply used to reliably switch (on — off) the electrical contact in the microswitch, which is built in the bottom plug of the tube. The time of occurrence of a seismic phenomenon can be intercepted by interrupting the feeding of a standard electric clock, equipped also with a calendar.

Such an earthquake indicator can be proposed also as a seismic switch, which is a mandatory component of nuclear power plants.

According to the U.S. national standard (ANS.2.2/Ni8.5-1974), there should be used, in addition to other seismic devices, also the so-called independent seismic switches. Their function consists in transmitting a signal for the immediate remote indication of exceeding a preset acceleration value (e.g. 0,1 g to 0,2 g).

Such a remote indication should be effectuated by a signal fed preferentially to the power plant's control room. This signal should form a base for immediate administrative measures or for after earthquake decisions.

The seismic switch must function without power feeding, it should be stable in time, with maximum reliability. Its function should not be disturbed by the surrounding physical environment. The suggested indicators would fulfill all these requirements.

Measurements of the stationary vibrations, occurring during the normal operation of the nuclear power plant of the type VVER 440 MW, were made on several sites of the reactor's foundation plate. It has been found that vibrations have, within the spectra range of 60 to 300 Hz, several narrow local maxima. Spectral acceleration amplitudes attain here values of upto the first m/s, which is comparable with the prescribed acceleration values even the SSE. It is, however, known that the vulnerability of structures is much lower, at such high frequencies, than within the "seismic-engineering zone" of upto 35 Hz. Neither the seismic indicator should react to such high frequencies.

This can be achieved by the following construction modification: The tube is connected by means of springs. An oscillating system is thus formed with one degree of freedom within the tube's axis. Its own frequency can be set (by the elasticity of springs and mass of the switch) to the value $f_0 \doteq 5\,\mathrm{Hz}$. This frequency is considered, because the design response spectra will attain its maximum values on it. This results from empirical data, quoted in preceding chapters and illustrated in Figs. 3. to 8. The attenuation of this oscillating system approaches the necessary value of $\beta = 0{,}02$ so that the application of additional damping device is no more necessary.

The seismic switch of this type thus indicates the exceeding of the critical value of acceleration response of an elementary oscillator ($f = 5\,\mathrm{Hz}, \beta = 0{,}02$). Obviously, it would be quite easy to use an even large number of these switches, also for other frequencies. No serious technical and economical problem should therefore prevent their application (Buben 1990).

Before installation of indicators, their calibration should be made with the use of a vibrating table. It should be determined, for each indicator:

a) the dependence of the critical value of horizontal acceleration A_{cr} as a function of γ,

b) the dispersion of this values, which is not negligible. Great dispersion is the consequence of dry friction forces used for measuring purposes. In order to reduce this values, it is necessary to use most perfectly polished, clean and dry friction faces in hermetically closed tubes;

c) setting the optimum position of the point x_{cr}, see Fig. 11.

An isolated peak value of the acceleration should not actuate the switch, but the number of periods of the SSE must be sufficient to shift the cylinder at least into its critical position x_{cr}.

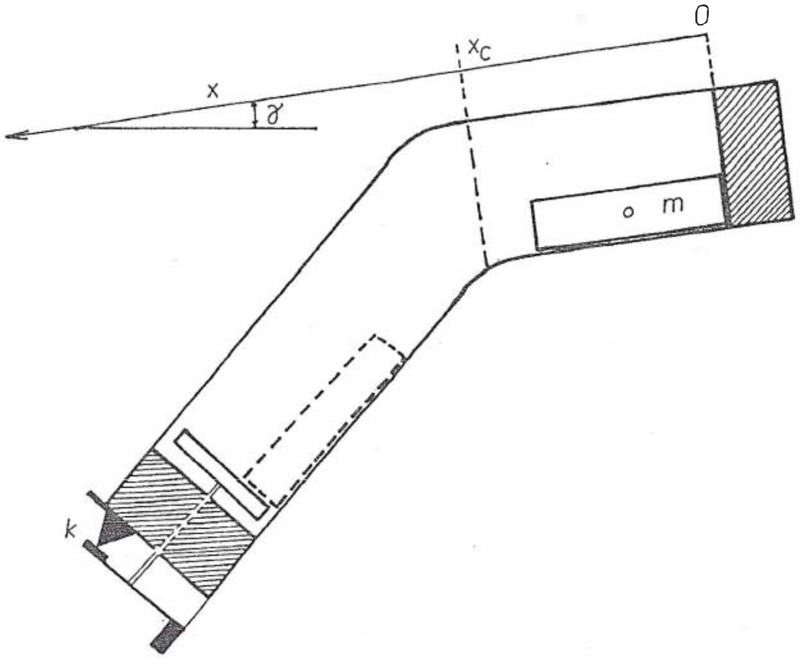

FIG 11. Seismic switch

9. APPLICATION AREA

a) The relation between anomalies of isoseists and tectonic faults has been revealed by Zátopek (1956) in his pioneer works dealing with the propagation of East Alpine earthquakes through Bohemian Massif. He called these lineaments "mobile zones". From this point of view, a new interpretation of all existing isoseist maps has been made by Šimůnek (1991). The faults show up to be conducting channels for foci in certain area, while for foci in other areas they cause anomalous attenuation of intensity.

Tectonic faults of deep foundation, which were reactivated in the Neotectonic era, should be considered as possible sites of earthquake foci in the future. More accurate data on geometry and structural heterogeneity of faults are very important for the prognosis of their seismic potential. The theoretical and practical significance of these prognoses is obvious and their solution belongs to priorities of engineering seismology.

During the seventieths and eightieths, an interpretation of the deep faults has been made on the basis of deep seismic sounding on several profiles throughout the Bohemian Massif (Blížkovský 1986). It is our actual target to complete the fundamental picture thus obtained. To this purpose, both the methods of "shallow refraction" and the macroseismic methods can be used which could be completed and refined by means of seismic indicators applied in a large number together with the network of local seismographs, built up to now in six localities of Bohemia (Buben 1992).

The ellipticity of isoseists in the epicentral zones is related to both the seismic moment tensor and to the structure of the source zone. For this reason, the observation point should be condensed to the zones of most probable occurrence of earthquakes.

b) The matter of monitoring technical seismicity is to evaluate its effects on surrounding structures. The damage of structures is initiated at ground motion velocities with amplitudes of first cm/s. The prevailing frequency of these oscillations are around $f = 10\,\mathrm{Hz}$, so the ground motion acceleration amplitudes exceed $60\,\mathrm{cm/s^2}$. The occurrence of such motions can be easy monitored by proposed indicators. Their application in the neighbourhood of technical and mining blasts (quarries, open-pit mines) would therefore seem adequate.

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INTENSITA A PROJEKTOVÁ SPEKTRA ODEZVY MAXIMÁLNÍCH VÝPOČTOVÝCH ZEMĚTŘESENÍ PRO LOKALITY NA ÚZEMÍ ČR

Robert Brož and *Jiří Buben*

Protiseismické zabezpečování staveb, jejichž seismické riziko je velmi vysoké, se neřídí běžnou stavební normou. Na příklad pro projektování jaderných zdrojů a úložišť radioaktivního opadu jsou nezbytná mnohem obsáhlejší vstupní data, která charakterizují vlastnosti maximálního výpočtového zemětřesení MVZ, předepsaného pro danou lokalitu. Velikost tohoto zemětřesení se stanovuje na základě pravděpodobnosti P jeho ročního výskytu $P10^{-4}$. Tato velikost zemětřesení je charakterizována jeho intenzitou I, dobou trvání prudkých kmitů τ, dále místně specifikovaným spektrem odezvy a konečně též souborem místně specifikovaných akcelerogramů.

Uvedené charakteristiky MVZ v oblastech se slabou až mírnou seismickou aktivitou se však stanovují velmi obtížně, protože je k dispozici pouze velmi malý počet pozorovaných jevů.

Přebírání analogických charakteristik, které byly stanoveny v zahraničních oblastech s vysokou seismickou aktivitou, má za důsledek nerealistické nadhodnocování seismického ohrožení. Je proto nezbytné jak vytěžit maximální informaci z historických makroseismických dat tak i získávat přístrojové záznamy současných mikrozemětřesení a technických zdrojů. V současné době na území ČR již registruje šest lokálních seismických sítí vybavených krátkoperiodickými velocigrafy v lokalitách Kladno, Ostrava, Střední Čechy, Jižní Čechy, Západočeské lázně, Severozápadní Čechy. Současná makroseismická pozorování je třeba doplnit a objektivizovat s použitím seismoskopů.

V tomto sdělení je podán návrh konstrukce a využití seismoskopu nové konstrukce, založené na principu klouzavého pohybu tělesa na šikmé ploše, vyvolaného seismickými kmity. Tyto seismoskopy doplněné elektrickým kontaktem mohou být použity též jako seismické spínače, t.j. indikátory překročení jisté hladiny zrychlení pohybů půdy s jistou frekvencí a se zachycením časového údaje tohoto překročení.