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SEISMIC RISK BY OPEN–PIT MINING NEAR SLOPES OF KRUŠNÉ HORY MTS

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ABSTRACT. In addition to the natural gravitational slope movements, the occurrence of seismo–gravitational movements at Krušné hory Mts cannot be neglected in the region where earthquakes with maximum intensity of 7° are expected. Both phenomena raise potential danger to open–pit mines situated nearby foots of some risk slopes. Three factors for determination of seismic risk are necessary to know: (i) *Price of machinery* as well as the *secondary losses* caused by sliding masses should be completely estimated by the mine holder. (ii) Ground particle acceleration 0.1 – 0.2 g and moving masses up to a million cubic metres should be taken into account according to the published values for the joint estimation of *vulnerability*. (iii) *Seismic hazard* based on the local macroseismic observations and calculated for a 100 years interval amount to 0.6 – 0.8 at the seismic intensity 6° and 0.2 – 0.4 at the intensity level 7°.

KEYWORDS: seismic risk, open–pit mining, Northwest Bohemia

1. INTRODUCTION

Potential jeopardy of open–pit mines in basin under slopes of Krušné hory Mts due to the gravitational rock slides or rock falls concerns in the present coal mine ČSA; its pit is situated close–by foot of slope of Jezerka and mining continues to the next risk slope of Jezeří. Unexpected slope seismo–gravitational movements may be triggered by the dynamic loading of slopes during earthquakes. In this case, the constant vertical action of earth acceleration is supplemented by the acceleration variable in time and direction. Occurrence of sufficiently strong local earthquake can be considered on the one hand as an exotic matter which it is not necessary to study in region with weak seismicity in the past. On the other hand, occurrence of local earthquake with sufficient intensity cannot be fully excluded as well as excitation of seismo–gravitational rock movement at natural slopes which long–term stability might be impaired by mining operations. Neither time of occurrence nor earthquake intensity at given place can be predicted at present, nor the origin of event can be forestalled. Nevertheless, some safety measures to reduce damages to property and inhabitants can be prepared in advance.

Seismic risk R_s, i.e. value of expected losses due to slope slides excited by earthquake, may be expressed by generalized relation [Fournier 1978]

$$R_s = \sum(C_i \cdot V_i) \cdot H\,. \tag{1}$$

Here C_i denote prices of particular mining machinery and relevant losses of men exposed to danger directly due seismic event. Among other factors, C_i secondary consequences of slope slide, e.g. money compensation for labour disability, values of lost production, inaccessible coal reserves and devastated natural slopes, should be taken into account. Factor V_i means the vulnerability, i.e. a part of the full value C_i which is expected to be totally destroyed or only partly damaged: $0 \leq V_i \leq 1$. H is seismic hazard, i.e. the probability of seismic event occurrence with intensity I which is able to cause expected losses at the given place and during the given time interval: $0 \leq H \leq 1$.

We consider seismic events to be all natural tectonic earthquakes including also artificial "man-made" earthquakes induced by surface mining [Tobyáš 1996]. Unfavourable influence of strong seismic waves of big blasts carried out often in mine pits are omitted. They act on small area of adjacent slopes, their origin times are known in advance and application of suitable controlled blasting operations enable to reach negligibly small seismic hazard. That is why seismic risk of quarry blasts will not be further discussed.

For determination of seismic risk R_s according to (1) three independent factors should be given: values of C_i are completely in hands of mine holder, V_i should be commonly estimated on basis of engineering seismology and geology about slope movements during earthquakes. For determination of the last factor H, knowledge of seismicity of the given region is applied. In this paper, published data on amounts of slope movement are collected and estimations of seismic hazard based on the extended previous calculations for local macroseismic observations are given [Tobyáš 1995].

2. DATA FOR ESTIMATION OF VULNERABILITY

The strongest earthquake in the region was observed near Duchcov in 1784. Its intensity was evaluated in the range from 6.5° to 8° ± 0.5° [Nikonov 1996]*. Maximum expected intensity of seismic event is limited to 7.5° – 8.5°. Intensity in the area Jezerka – Jezeří is at most about 1° smaller than the epicentral intensity of earthquake located anywhere in the region. It covers the sector between Teplice and Kadaň, i.e. in epicentral distances up to 20 km. Depths of local earthquakes derived from macroseismic observations are about 6 – 9 km. The estimated maximum acceleration of ground motion at the horizontal component amounts to 200 – 150 $\mathrm{cm/s^2}$ and about one half in the vertical component. In this case, the additional dynamic force which acts on nature and structures on surface reaches about 1/5 of their weight in the horizontal direction and 1/10 in the vertical direction [Tobyáš 1995].

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* *Comments of the Editorial Board:* The paper [Nikonov 1996] has not been accepted for publication in Acta Montana, Series A because of its unrealistic reinterpretation of parameters of the Duchcov earthquake of 20 March 1874. From the same reason the paper by A.A.Nikonov "A Multidisciplinary Approach to the Estimation of Parameters for Historical Earthquakes: The Krushny Hory Event of March 20, 1784", Seismology in Europe, Island, 1966, pp.617–622 was criticized by German seismologists during the XXV General Assembly of the European Seismological Commission, Reykjavik, 9–14 September 1996 (see Abstracts, G.Grünthal, p.139)

Classification of the earthquake scale [Medvedev et al. 1964] gives description of some characteristic effects for the given intensities as follows: fright till panic among people, slight damage till destruction of buildings and possible permanent deformations in terrain: cracks up to width of 1 cm in wet soils, occasional landslides in mountains, land–slips on steep slopes of roadways, cracks in stone walls, breaks of pipelines, slip of sandy or gravelly banks, changes in yields of springs and levels of ground–water tables. These data are insufficient for our purpose and must be supplemented by results of special research.

Some generalized data about ranges of deformations expected at several intensities are given in Table 1 according to [Shebalin 1975].

TABLE 1. Permanent deformations caused by earthquakes

Intensity MSK–64	5°	6°	7°	8°
Deformation [cm]	0.001 – 0.1	0.05 – 0.1	1 – 8	5 – 55

The following Table 2 represents first information on geological conditions for cracks origin and rough estimation of slope movements [Medvedev et al. 1975].

TABLE 2. Cracks and slope movements

Intensity	6°	7°	8°
Cracks in soils in flat terrain	several mm	about cm	several cm
Cracks in soils on hill slopes	about 1 cm	several cm	about 10 cm length 10 m
Slides and falls of slopes	exceptionally	in separate cases	data are missing

For description of earthquake effects on slope and classification of seismo–gravitational movement the classification proposed by [Nemčok et al. 1974] for gravitational slope movements was accepted. Four basic groups of movement are as follows: creep, sliding, flow and fall:

(i) *Creep* is a geologically long–term non–accelerated movement of rock masses. It constitutes a preparatory phase for the next three group of movement.

(ii) *Sliding* is a relatively fast, short–term movement of rock masses along one or more parallel slip surfaces. Resulting form of the movement is slide.

(iii) *Flow* is a rapid, short–term movement of masses resembling in character the movement of liquids. Flow is the resulting form of movement.

(iv) *Fall* is a sudden, short–term movement of rock masses on steeply inclined slopes. Masses become loosened and their movement is that of a free fall. During the slope movement, in addition to free fall, the other groups of movement are applied at the same time. At the stage when the strength on the contact of surface layer and the underlying bedding is decreased, the probability of seismic effect is the biggest. Then all basic types of slope movements can be triggered: small friable fragments of soft bedrock to soils are replaced by rolling and leaping downslope, hard rock fragments are suddenly replaced by free fall, then by rolling or moving downslope, rock walls are suddenly replaced by free fall, sudden replacing of rocks by combining a sliding movement along predisposed surface with free fall.

A questions arises to what extent the previous earthquakes could create the recent slope inclination. We use the relation from [Safonov, Kuznecov 1967] for determination of stable inclination angle α. The condition $\alpha \leq \alpha'$ must be satisfied, where

$$\alpha' = \arctan\left[\frac{1 - a_m/g}{1 + a_m/g}\right] . \qquad (2)$$

Parameter a_m denotes maximum ground acceleration during earthquake, g gravity acceleration in the place of observation. Real angle of the seismic stable slope is smaller than the angle calculated according to relation (2). Correction factor for $100 \leq a_m\,[\mathrm{cm/s^2}] \leq 350$ amounts to 0.75 – 0.85.

For the steepest slope 35° of the hill Jezerka, we get the mean maximum acceleration $a_m \approx 100\,\mathrm{cm/s^2}$. Such ground acceleration occurs according to different macroseismic scales at earthquakes starting with intensity 5° and more. Comparing frequencies of maximum acceleration measured during earthquakes [Pavlov 1988], we obtain for intensity 7° this acceleration with approximative probability 0.5 (in 130 records greater maximum acceleration occurred in 60 % cases). From this comparison we obtain the maximum acceleration $100\,\mathrm{cm/s^2}$ as a representative for the intensity 7°. Local earthquake with such intensity could create the recent slope inclination in Pleistocene epoch when the landslide by Šibeniční hůrka occurred [Marek 1979; Špůrek 1974; Váně 1960]. Probably here is the greatest rockfall on the territory of the former Czechoslovakia which amounts to 20 million cubic metres.

Only one information about landslide during earthquake in this region is at disposal but without any details. It happened near Chomutov on March 31, 1785.

Naturally, the stage of slope stability during earthquake depends on the slope inclination. Several data on seismo–gravitational movements with slope inclination and the presence of ground–water (+) are given in Table 3 according to [Dedova 1965]. The steepest slopes under top of the hill Jezerka are in orthogneisses and granitegneisses [Rybář 1987]. With the over–top height of 400 m the slope inclination reaches 35° which is treated as long–term stable [Rybář 1986].

For further estimation of expected danger we have at disposal ranges of amounts of rockfalls and rockslides based on observations of recent earthquakes abroad [Popova 1984]. Data for intensities of 7° and 8° are collected in Table 4. The first value denotes mean volume and the second under slash the maximum volume of given rocks in thousand of cubic metres.

Mean volumes are in part of cases negligible. Of course, we have to suggest the unfavourable factor with seismo-gravitational movements, i.e. the moment of surprise. Analogical estimates of landslides volume may be evidently applied for

Table 3. Conditions for seismo–gravitational movements

Group of movement	Slope	Bedding	Water	I
Creep	40° high	rock with clayey interlayers	+	7°
	15° – 20° middle	clayey with weathered surface, sandy–clayey, stratified	+	6°
Sliding				
a) Hard rock	35° – 40°	sound rock	0	7°
b) soft rock	25° – 30°	with weathered surface sandy	0	6°
Flow	15° – 20°	clays, silts	+	6°
Fall	40° to vertical with overhangs	sound rocks with cracks	0	7°

Table 4. Volumes of rock movement

Type of rocks	Rockfalls		Rockslides	
	7°	8°	7°	8°
Weathered rocks	0.03/300	2/500		
Sandy–clayey soils			0.2/1000	10/15000
Dtto water saturated			2.5/15	100/500
Sandy–clayey soils with gravel	0.3/500	40/1000	0.1/50	3.5/5000
Dtto water saturated	3/300	400/500	1/5	12/1000

slopes of internal and external heaps.

Negative effects of seismic waves with smaller intensities cannot be excluded on slopes with the recent movements. Due to unloading of slopes foots by surface mining, deformations of slope foots are caused [Rybář 1983]. Deformations are presented in the first stage by long–term negligibly small movement – creep. In the second stage, creep is characterized by increased constant velocity. If the movement does not spontaneously stop during this stage and the new stable slope is created, the movement goes to the third stage. At the same time, velocity of movement is increasing till the final stage of sudden destruction of slope.

Strong earthquake can accelerate slope movement at all stages. By temporary passing of seismic waves the shear stress in rocks is increased and in water–saturated soils shear strength is decreased. Thus the transition from the second stage to the third one may be reached even when under undisturbed conditions it should not happen. During the third stage of movement sudden destruction of slope can be initiated by seismic ground particle acceleration.

For the reliable determination of real resistance of slopes to earthquakes of given intensity we have at disposal neither the time course of seismic ground motion at given place nor the mechanical parameters of rock and the stress distribution acting in different phases of the natural slope deformations. Effects of local earthquakes can be tested only to some extent by the dynamic loading of slope by seismic waves excited with large quarry blasts which are often applied when mining hard coal overburden.

3. DATA FOR ESTIMATION OF SEISMIC HAZARD

Earthquake is a natural phenomenon with many unknown parameters for determination of its reliable magnitude and time of occurrence. We substitute seismic hazard H in relation (1) by probability P_t of earthquake occurrence with given magnitude during given time interval t. Calculations are based on some presumptions about statistical distribution of earthquakes in time and local macroseismic observations between 1784–1910. Probabilities in Table 5 are for the magnitude classes from 2.4 ± 0.3 to 4.8 ± 0.3. The lower limit corresponds approximately to earthquake epicentral intensity 3°, i.e. to weak tremor which is observed only by very sensitive people. The upper limit corresponds to the intensity 7° which corresponds the maximum expected epicentral intensity of earthquake in the region. For every time interval two values of P_t are given for the same magnitude class centre: the first one is valid for the lower estimate of maximum expected intensity 6.5° and in the following line indicated by asterisk the P_t is calculated for upper estimate of maximum expected intensity of 8° [Nikonov 1996]. The first case differs slightly from former data published in [Tobyáš 1995] due to the double–precision calculations applied. Probability P_t increases with increasing time interval t and constant magnitude M_i to the upper limit equal to 1. The second alternative reaches greater values of the earthquake probability.

A hundred years elapsed since the last local earthquake swarm in 1896. Probabilities of earthquake occurrence in the time interval of 100 years are $0.6-0.8$ for the epicentral intensity of 6° and greater and $0.2-0.4$ for intensity 7° and greater. Probability of strong earthquake occurrence is increasing with prolonged calm period.

Earthquakes with intensity 4° at least, if occurred in the present time, could not be ignored by inhabitants and should be recorded by standard seismic stations located near the region. Weaker earthquake with intensity of 3° does not attract attention of inhabitants because no damage to buildings or permanent deformations in terrain are created. Seismic event is like vibration due to passing of a light truck and only some sensitive people can notice it. In the contemporary stage of industrial activity and mining operations in the region, no attention is paid to these phenomena. Such tremor should be reliably detected and recorded only by the local seismic station. Since the end of 1982, when the local station at Vysoká Pec was put in operation, but weaker local earthquakes (microearthquakes) were recorded. Their magnitude were below 2.4 under the level with macroseismic effects. Their energy is so small that about one million of such microevents release in total the energy of one earthquake with the intensity 7°.

TABLE 5. Probability P_t of earthquake occurrence with $M \geq M_i$ in the time interval t

t (years)	M_i				
	2.4 (3°)	3.0 (4°)	3.6 (5°)	4.2 (6°)	4.8 (7°)
0.5	0.10	0.04	0.01	0.00	0.00
*	0.11	0.05	0.02	0.01	0.00
1	0.19	0.08	0.03	0.01	0.00
*	0.21	0.10	0.04	0.02	0.00
2	0.35	0.15	0.06	0.02	0.00
*	0.37	0.18	0.08	0.03	0.01
5	0.66	0.34	0.14	0.05	0.01
*	0.68	0.39	0.19	0.08	0.02
10	0.88	0.56	0.27	0.10	0.02
*	0.89	0.63	0.35	0.15	0.05
20	0.98	0.81	0.46	0.18	0.04
*	0.99	0.86	0.57	0.28	0.10
50	1.00	0.98	0.78	0.40	0.09
*	1.00	0.99	0.87	0.56	0.22
100		1.00	0.95	0.64	0.18
*		1.00	0.98	0.80	0.40
200			1.00	0.86	0.33
*			1.00	0.96	0.64
500				0.99	0.63
*				1.00	0.92
1000				1.00	0.86
*				1.00	0.99

TABLE 6. Mean periods τ and frequencies n_i of microearthquakes for 6 1/4 years

M_i	τ (years)	n_i	
		calculated	observed
0.0	0.111	56.3	6
*	0.169	37.0	
0.6	0.285	22.2	29
*	0.380	16.5	
1.2	0.715	8.7	10
*	0.855	7.3	
1.8	1.82	3.4	0
*	1.93	3.2	

Recurrence interval of earthquake with the expected maximum intensity of 7° can be also estimated with the aid of Benioff graph [Tobyáš 1995]. According to energy release in time, occurrence of strong earthquake with intensity about 7° cannot be excluded at the end of this century. Two assumptions must be satisfied in this case: accumulation of tectonic stress will continue as in time interval with the observed macroseismic events, and seismic energy will not be released stage by stage by weak macroseismic events.

Relation between above mentioned data and the microearthquakes recorded in the recent time can be compared by extrapolation of magnitude–frequency relation for macroseismic observations to smaller magnitude classes with $M_i \leq 1.8$. Then the mean recurrence period τ (i.e. t for $P_t = 0.633$) were calculated for both variants of maximum expected intensities as in Table 5. Single frequencies in individual magnitude classes n_i calculated for the interval of 6 1/4 years were compared with the results of observations for this time interval. Frequencies given in Table 6 prove surprising agreement of observations with calculations at two middle magnitude classes. At the minimum magnitude class $M_i = 0$ smaller number of recorded events is probably due to the limited detection ability of the nearest seismic stations Vysoká Pec and Berggiesshübel used in this test. Zero frequencies of observed events at the magnitude classes 1.8 and greater are real because the detection ability of seismic stations is sufficient in this range.

4. CONCLUSIONS

An attempt of seismic risk determination introduced complete data about seismic hazard in the present paper. Probabilities of earthquake occurrence in the time interval of 100 years reach 0.8 – 0.2 for maximum expected epicentral intensities 6° – 7°. Collected data on seismo–gravitational movements are at disposal for the further experts decisions on the vulnerability of open–pits situated close to or at the risk slopes foots. Dynamic forces corresponding to maximum ground acceleration of $0.1\,g$ in the vertical component and $0.2\,g$ in the horizontal component should be taken into account on the territory of the whole district.

To mitigate seismic risk, script of safety regulations should be prepared in advance also in relation to classification of macroseismic effects. It refers, for instance, to potential interruptions of different pipelines (for water, gas, oil and hot–water supply). The result of contemporary action of more negative factors may be disastrous.

Staff of mines should be acquainted with the fact that occurrence of middle intensive earthquake in the coal district cannot be neglected and that it can cause from frightening up to panic. Release of seismic energy passes usually in series of weaker foreshocks before the main one or by main shock followed by series of aftershocks. The last earthquake swarm of 31 tremors observed in 1896 continued for six days. Their epicentres were situated between Hora Sv. Kateřiny and Most also on territory of recent open–pit mines and the intensity of the main shock reached 5.5°.

Seismo–gravitational movements of some slopes in Krušné hory Mts cannot be considered to be unforeseeable phenomena. For further improvement of the seismic risk assessment it will be necessary to continue observations of seismicity of the whole coal district and adjacent Krušné hory Mts. In addition to monitoring of the slopes stability with standard geotechnical methods, it is recommended to record continuously ultramicrotremors originated by crystalline rock failures on risk slopes and to define independent "seismic" warning states.

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