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EVALUATION OF LOAD ON STRUCTURES CAUSED BY MINING SEISMICITY FOR MAPS OF CLASH OF OPINIONS - METHODOLOGY

Summary. So-called "maps of clash of opinions" of selected areas enable to determine intensity of seismic loading for given places and/or to detect risk probability for evaluated buildings and structures because of given seismic vibrations. The study and project of methodology for load on structures caused by mining seismicity is presented in this contribution. Karviná region is basic source of experimental data; therefore, empirical coefficients result from character and intensity of mining induced seismicity in this area. Main idea is recalculation of maximum measured values of velocity (according Czech Technical Standard 73 0040) to take into account number of seismic events and number of intensive seismic events especially.

OKREŚLANIE OBCIĄŻEŃ OBIEKTÓW BUDOWLANYCH PODDANYCH WPŁYWOM SEJSMIKI GÓRNICZEJ DLA CELÓW BUDOWY MAP ZAGROŻEŃ – METODOLOGIA

Streszczenie. W ramach artykułu przedstawiono metodologię oceny ryzyka zagrożenia obiektów budowlanych, narażonych na wstrząsy indukowane podziemną eksploatacją górniczą. Do badań wykorzystano wyniki pomiarów z rejonu Karviny (Republika Czeska). Główną ideą prezentowanej metodologii jest odpowiednie przeliczenie maksymalnych pomierzonych prędkości drgań, przy uwzględnieniu takich czynników jak liczba wstrząsów, ze szczególnym uwzględnieniem wstrząsów o dużej energii.

1. Introduction

Seismic assessment and rehabilitation of existing buildings is a very important and current research area. It stands to reason that earthquakes are studied as main source of vibrations (see Booth, 1998, Wasti and Ozcebe, 2003). However, seismic effects/symptoms evoked by mining induced seismicity must be taken into account in areas with intensive underground mining activities (e.g. Kwiatek et al., 1998, Wodyński and Lasocki, 2004).

In the Czech Republic, seismic load on buildings and structures is represented by low natural seismicity and locally also by technical seismicity. The specification of technical seismicity load is its local impact in the area of vibration source and short-term duration (compared to natural seismicity) – days, weeks (working of machines) or years, decades (mine induced seismicity, traffic vibrations, blasting operations). Very specific seismic load is generated by underground mine activity – Karviná region, formerly also Příbram and Kladno regions in Czech Republic, Upper Silesian Basin, Legnica-Głogow Cooper District, Lubin Cooper Basin and others in Poland, and also in others countries.

So-called "maps of clash of opinions" provide basic information about the character of seismic load, its type and intensity in confrontation with types of buildings and objects in selected areas. Cross interference of basic input themes in the maps is used (e.g. GIS technology) to obtain required information. Maps elaboration methodology was published in Lednická et al. (2006) or Lednická and Javůrková (2006). The main principle is confrontation of three basic input themes – area of interest, seismic load and constructional objects and structures. Selected thematic layers with their characteristic parameters will be related to each of these three input themes. Object type in given area (and given time) is confronted with presumed seismic load.

2. Maps of clash of opinions

Selected thematic layers with their characteristic parameters will be related to each of three input themes mentioned above. The thematic layers will be prepared in the form of individual map layers. Subsets, which will be determined by specific behaviours and conditions, will be selected from the basic set of input data because of the cross interference of individual thematic layers.

The following thematic layers were selected on the basis of methodology presented above (Lednická et al., 2006).

Thematic layers of area of interest:

- Geology (depending on selected scale)
- Tectonics

- Depth of groundwater
- Accumulation of water on surface
- Thickness of sedimentary layers
- Deformation of surface due to underground mining
- Undermined regions
- Landslides and other dynamic events
- Behaviour of rock medium (rheology)

Thematic layers of constructional objects and structures:

- Class of resistance
- Economic and social significance
- Age of buildings and structures
- Cultural monuments
- Technology of construction – monolithic structures, framed structure buildings, towers, etc.
- Used materials – masonry, timber, steel, steel-concrete structures, etc.

Thematic layers of seismic load:

- Intensity of natural earthquakes (MSK-64 scale)
- Proposed acceleration of foundations
- Sources of induced seismicity – undermined areas (actual or abandoned mines), reservoirs
- Isolines of maximum velocity on surface (mining induced seismicity)
- Sources of technical seismicity – intensity, range impact

Elaboration of the individual thematic layers will be gradual, depending on the information available, quantity and complexity of data for the various themes and on accuracy during their transformation into the form of map layers. Generally, it is possible to compile maps of clashes of opinions at different scales. Due to complexity of the presented methodology we are only preparing maps with regional scale. Karviná region, densely populated area with very intensive heavy and mining industries, is our experimental area. In this contribution, methodology for evaluation of loads on buildings and structures due to mining induced seismic events is presented. Formerly, the methodology of constructional objects elaboration was presented by Lednická (2006).

3. Input conditions

The Karviná region was selected for presentation of the methodology. This is a region with very intensive seismic activity induced by mining activities (e.g. Kaláb and Knejzlík, 2002, Konečný et al., 2003, Holub, 2000). Annually about 40 thousands seismic events are recorded; from 100 to 500 of seismic events have local magnitude higher than 1. There are also many sources of technical seismicity here, e.g. industrial seismicity or vibrations generated by traffic. On the other hand, many interesting buildings and structures, including historical buildings and cultural monuments, can be found in the region under discussion.

When evaluating the structure response evoked by natural or technical seismicity, we classify the buildings and structures according to their resistivity class and/or their class of socio-economic significance (Czech Technical Standards 73 0031, 73 0036, 73 0040). The classification of objects into classes enables to explore resistivity of these objects according to applied seismic loading.

There are six classes of resistance (signed as A – F) defined. Class A includes unstable buildings, historical buildings, buildings with extensive plastic décor, archaeological structures, and others. Class B is represented by common brick buildings, structures with ground area up to 200 m^2 with maximum of three floors. Class C contains good reinforced structures of panels, large brick buildings, stone bridges etc. Class D includes steel and concrete body structures, wooden and half-timbered houses, monolithic tank towers and others. Class E consists of concrete-steel buildings, steel constructions and steel towers; the most resistant structures, for example hold-outs, are represented by class F.

As follows from classification presented above, the most rigorous postulates are determined for class A (e.g. historical buildings and buildings that do not meet constructive criteria). Building age is one of criterion that will have markedly significant influence on seismic response of structures affected by seismic loading. Changes of behavior (strength properties) of construction materials in time are the main reason. Therefore, structures that appertain to class A will be taken as a base for the methodology presented below.

The Czech Technical Standard 73 0040 evaluates seismic effect of blasts using limit values of maximum velocity in three frequency ranges for given local geological conditions (classes a – c), resistivity of structures (A – F) and degree of damage (0 – 5). Degree 0 represents situation when vibrations do not cause damages but vibrations influence technical conditions of structures. The first indications of damages and occurrence of fissures and cracks up to 1 mm (especially on ceilings) are effects of degree 1. Degree 2 induces light damages, cracks up to 5 mm in plasters, separating walls, chimneys … However, this evaluation of vibrations according the standard does not take the amount of events into account.

4. Methodology for load on structures caused by mining seismicity

As mentioned above, input parameters are derived from local conditions in the Karviná region. The most rigorous criteria are used, i.e. local geological conditions of type **a** and buildings and structures of class **A**. Basic analyzed period **T** is 12 months, i.e. one year. Empirical constants that will be used below are based on these conditions. Maximum values of velocity recorded in buildings represent input data; measurements are performed on referential positions – according to requirements from Standard 73 0040. Component values, $\mathbf{u_i}$, $\mathbf{v_i}$, $\mathbf{w_i}$, or calculated absolute values of space component $\mathbf{x_i}$ are used; the index $\mathbf{i} = 1,2, \ldots,$ N, and **N** is number of measured values in given time period **T**.

The minimum limit value of velocity for evaluation of structure damages is 3 mm/s (Standard 73 0040; a, A, 0). Data set for layer of maps of clash of opinions will be compiled from events, for which one of the component values exceed value of 0.5 mm/s (about 20% of limit value). Next boundary values are derived from limit values for next degree of damage (Tab. 1). Prevailing frequency for mining induced seismic events in the Karviná region is up to 10 Hz (Kaláb and Knejzlík, 2006).

Table 1

Limit values of velocity (Standard 73 0040) depending on degree of damage (local geological conditions of type **a** and buildings and structures of class **A**, frequency range up to 10 Hz)

Degree of damage	Limit values
0	3 – 6 mm/s
1	6 – 10 mm/s
2	10 – 20 mm/s

Limit presumptions are based on long-term monitoring in the Karviná region (e.g. Holub and Rušajová, 2001). To use trigger method (exceeding given value) for long-term recording of events on studied point, the data set is “complete set”. Presented methodology is developed for maximum 500 seismic events per year (minimum is 1 seismic event), data set is presented by maximum value of velocity (from the set of measured data).

Basic steps are as follows (presented on calculated absolute values of space component $\mathbf{x_i}$):

- Long-term monitoring, data set $\{\mathbf{X_i}\}$, $\mathbf{I} = 1,2, \ldots, N$, as **N** is total number of recorded seismic events (with value of one component higher than 0.5 mm/s)
- Determination of maximum component (or absolute value) $\mathbf{x_{max}}$
- Determination of coefficient $\mathbf{C_N}$ that takes into account number of recorded seismic events in time **T** (12 months)
- Determination of coefficient $\mathbf{C_M}$ that takes into account number of recorded intensive seismic events in time **T** (12 months)
- Calculation of so called "total value of velocity" in given point for analyzed period $\mathbf{x_T = x_{max} * C_N * C_M}$

Boundary conditions are derived from knowledge of analyzed region (Karviná), characteristics of seismicity (mining induced seismicity with more intensive events) and limit values of velocity (Standard 73 0040 – changes between limit values for crossing lower and subsequent higher degree of damage). It is comply with following principles:

- Value of $\mathbf{x_{max}}$ would not decrease, i.e. for N = 1 is defined $\mathbf{C_N * C_M} = 1$
- Value of $\mathbf{x_{max}}$ would not increase more than twice, i.e. for N=500 is defined $\mathbf{C_N * C_M} = 2$
- Maximum values of coefficients: $C_N = 1.2$ and $C_M = 1.6$ (for 500 events)

Coefficient $\mathbf{C_N}$, which takes into account the number of recorded seismic events in time **T** (12 months), is calculated using relation

$$C_N = \frac{1}{11} arctg(\frac{N-200}{100}) + 1.1005 .$$

Fig. 1 and Tab. 2 show values of coefficient $\mathbf{C_N}$ depending on number of seismic events **N**.

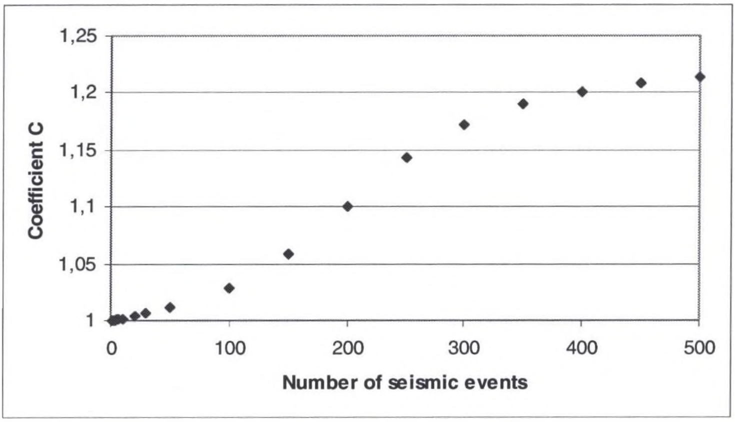

Fig. 1. Relation between number of seismic events and coefficient $\mathbf{C_N}$
Rys. 1. Zależność pomiędzy ilością zarejestrowanych wstrząsów a współczynnikiem $\mathbf{C_N}$

Table 2

Coefficient $\mathbf{C_N}$

N	C_N
1	1
2	1,00022
3	1,0004
4	1,00059
5	1,00078
6	1,00097
10	1,00174
20	1,0038
30	1,00604
50	1,01116
100	1,0291
200	1,1005
300	1,1719
400	1,20115
500	1,21405

Table 3

Coefficients $\mathbf{C_M}$

N	C_{MO}	C_{M1}	C_{M2}
1	1,0126	1,0361	1,071
2	1,02674	1,05371	1,09803
3	1,03501	1,06401	1,11385
4	1,04088	1,07131	1,12507
5	1,04543	1,07698	1,13377
6	1,04915	1,08161	1,14088
10	1,05957	1,09459	1,1608
20	1,07371	1,11219	1,18783
30	1,08198	1,12249	1,20365
50	1,09241	1,13547	1,22357
100	1,10655	1,15307	1,2506
200	1,12069	1,17068	
300	1,12896		
400			
500			

Coefficient $\mathbf{C_M}$, which takes into account number of recorded intensive seismic events in time **T**, is divided into three partial coefficients:

- Seismic events with maximum values in range 3 – 6 mm/s, i.e. degree of damage 0, number of these events is N_0, for $N_0 = 1$ than $C_{M0} = 1.01$, for $N = 300$ than $C_{M0} = 1.13$
- Seismic events with maximum values in range 6 – 10 mm/s, i.e. degree of damage 1, number of these events is N_1, for $N_1 = 1$ than $C_{M1} = 1.03$, for $N = 200$ than $C_{M1} = 1.17$

- Seismic events with maximum values above 10 mm/s, i.e. degree of damage 2 and more, number of these events is N_2, for $N_2 = 1$ than $C_{M1} = 1.05$, for $N = 100$ than $C_{M2} = 1.25$
- $\mathbf{C_{M} = C_{M0} * C_{M1} * C_{M2}}$

Relations for individual partial coefficients $\mathbf{C_M}$ are as follows (see also Tab. 3 and Fig. 2):

$$\mathbf{C_{M0} = 0.0204 * \ln(N_0) + 1.0126}$$

$$\mathbf{C_{M1} = 0.0254 * \ln(N_1) + 1.0361}$$

$$\mathbf{C_{M2} = 0.039 * \ln(N_2) + 1.071}$$

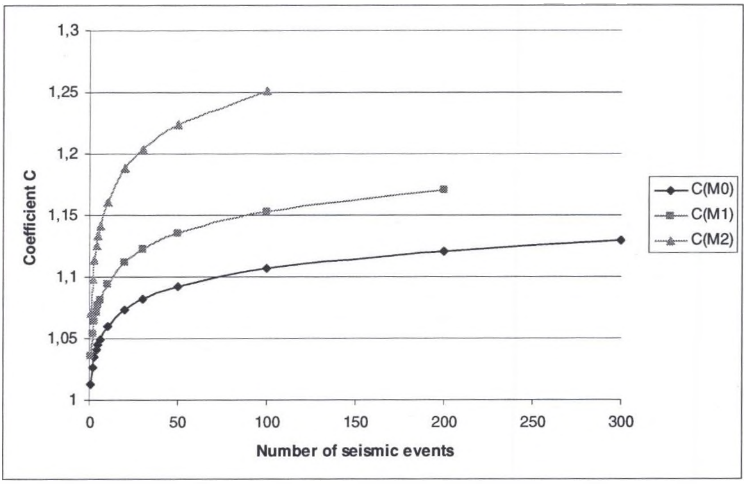

Fig. 2. Relation between number of seismic events and coefficient $\mathbf{C_M}$
Rys. 2. Zależność pomiędzy ilością zarejestrowanych wstrząsów a współczynnikiem $\mathbf{C_N}$

5. Conclusion

Questions of evaluation of seismic load on buildings and structures in the maps of clash of opinions are a very complicated problem. It is necessary to collect and to interpret an amount of seismic data from the particular area, where seismic effects are induced by mining activity and in the given time. On the other hand, seismic loads must be uniquely determined in the discussed maps so that all information from the measurements and interpretations are taken into account. The methodology of determination of seismic load caused by mining induced seismicity, which is presented above, enables to include not only maximum measured value, but also the number of recorded seismic events and the number of recorded intensive seismic events in given time period.

First results from the test of this methodology on data from Karviná region are presented in paper prepared by Lednická (this issue).

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Omówienie

Tak zwane mapy konfliktów opinii, w rozpatrywanych obszarach, pozwalają określić intensywność oddziaływań sejsmicznych dla określonych lokalizacji i/lub ustalić prawdopodobieństwo ryzyka uszkodzeń obiektów, wskutek drgań sejsmicznych. W niniejszym artykule zaprezentowano wyniki badań oraz projekt metodologii określania wpływu sejsiczności górniczej na obiekty. Rejon Karviny był źródłem danych eksperymentalnych, dlatego przedstawione w pracy empiryczne współczynniki wynikają z charakteru i intensywności sejsmiki górniczej tego rejonu. Główną ideą tego projektu jest przeliczenie maksymalnych, pomierzonych prędkości drgań (wg normy czeskiej 730040), z uwzględnieniem liczby wstrząsów, a w szczególności liczby takich zdarzeń, które miały dużą intensywność.