Acta Geodyn. Geomater.Vol.1, No.1(133), 35-39, 2004

IMPACT OF SEISMICITY ON SURFACE IN MINING AFFECTED AREAS: GENERAL DESCRIPTION

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(*Received* October 2003*, accepted* January 2004)

ABSTRACT
General description of expected types of seismicity in mining affected areas is given in this paper (mining induced seismicity, natural earthquakes, technical seismicity and industrial vibrations). Their basic characteristics are specified. The main parameters influencing the intensity of seismic effect on the surface will be pointed out and the specifications of seismic loading in mining affected area will be briefly discussed. Except direct influence of seismicity on building objects it is also necessary to consider indirect influences, e.g. changes of slope stability.
Mining tremors represent some of the most important causes of damages and acceleration of technical wear of buildings in mining area. The evaluation of influence of seismicity on buildings in the Czech Republic is solved by the technical standards (ČSN 73 0036, 73 0040), eventually by prepared Eurocodes. The intensity of seismic effect is providing by mathematical or physical simulation, generally supplemented by experimental measurement in investigated areas or in areas with similar conditions.

KEYWORDS: seismicity, mining affected areas

INTRODUCTION

Mining of mineral raw materials is always accompanied by negative environmental impact. The corresponding attention is paid to this problem in dependence on their relevance and, last but not least, also their popularity. In this paper the main attention will be fixated on influence of mining induced seismicity on surface in area affected by mining activity. It is necessary to take into account that mining activity evokes the number of negative manifestations, which may be interacting each other. Therefore, it is impossible to study individual negative effects separately without paying attention to the others at the same time.

Possible demonstrations of underground exploitation, which have direct affect on surface and structures on the surface, can be divided into three basic groups (according to Kwiatek, 1999):

- Change of groundwater conditions - irrigation, drainage
- Movement of solid rock mass elements - continuous deformations (reclines, falls, flexures) and non-continuous ones (fissures, cracks, faults, void spaces)
- Vibrations of rock massif - vibration of bedrock

The hydro-geological changes, deformations of terrain, transfer and vibration of rock mass are the final effects, which can lead to observable changes on surface and structure damages.

For instance, more than centennial black coal production in Ostrava-Karvina district on the Northern Moravia (Czech Republic) results in very complicated combination of all observed demonstrations. There are also frequent occurrences of mining induced seismic events here because part of production followed from seams with high seismic risk. Very intensive seismic events are documented in area under discussion (e.g. Rudajev, 1993) - the most intensive events originated in April 1983; having the radiated seismic energy about 10^{10} J. Today, seismic networks in this area record till 30 thousand seismic events per year and quantity from 100 till 500 of them with seismic energy greater than 10^4 J (local magnitude about 1).

Two standards for evaluation of seismic loading on structures exist in the Czech Republic: ČSN 73 0036 (or ČSN P ENV 1988-1-1) for natural seismicity and ČSN 73 0040 for technical seismicity. Mining induced seismicity belongs to both types of seismicity due its specific basic characteristics; therefore, both these standards could be used for evaluation. It is also necessary to take into account that building objects have various sensitivities on vibrations and, therefore, their responses are also very different.

TYPES OF EXPECTED SEISMICITY

One can find three main types of seismicity in mining affected areas. The first type is mining induced seismicity, which is very closely connected in space and time with mining activities. The origin of seismic events that are induced by previous mining activity, however, may be seen also after longer time period when the works were closed, because the stress-strain condition in rock massif must reach stable stage. Response of the rock massif on mining activities is very different according to particular locality in dependencies on petrological, physical and technological parameters. Therefore, there is no possibility to create simple diagram for evaluation of development of mining induced seismicity.

Mining induced seismic events have several specific characteristics, which are necessary to be kept in mind at evaluation of seismic loading on buildings in mining affected areas:

- "Quickly" migrated focal areas depending in time and space with underground mining activities
- Seismic event foci in small depth (in comparison with natural earthquakes) with significant percent occurrence
- Broad amplitude range (till tens of $mm.s^{-1}$ in epicenter areas) and broad frequency range (0.1 till 30 Hz at surface)
- Complicated mechanisms of focus origins (explosive, implosive, combined also)

Long-term monitoring in the Ostrava-Karvina region documented complicated pattern of time-space changes of seismic regime (e.g. Holub and Rušajová, 2001). Experimental measurement of seismic effects of mining induced seismic events on surface objects in Karvina region in years 1999-2003 shows that ground velocity of the most intensive tremors exceeds value of 10 $mm.s^{-1}$ (value of acceleration reaches 500 $mm.s^{-2}$). These values are in such a degree of intensity that there exist real possibilities of damaging of buildings and vibrations will evoke unpleasant feeling around inhabitants (Kaláb and Knejzlík, 2002, Kaláb et al., 2002). Fig. *1* demonstrates results of measurement in very affected area (stations in villages of Doubrava and Orlová) during the time period of first half of the year 2000.

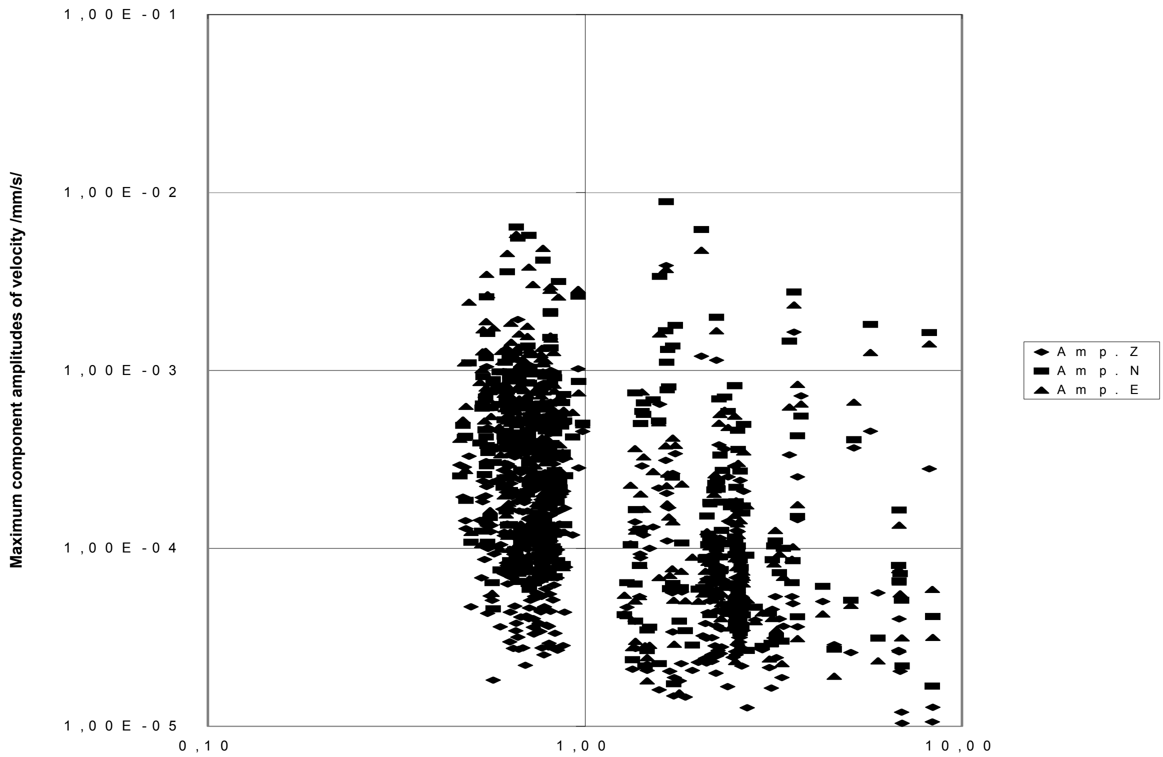

Fig. 1 Diagram of maximum component values of velocity versus epicentral distances from Doubrava and Orlová villages in 1-6/2000

Natural seismicity (natural earthquakes) is another type of seismicity, which will appear in mining affected areas. The number of these events and their intensities depend on epicentral distance. There are documented also mining localities, which are the source areas of natural earthquakes at the same time. In this case, it is inevitable to make separation between natural seismicity and mining induced seismicity to have possibility to make effective prevention of seismic event origins induced by mining activity. Earthquakes with near foci display like mining induced events, generally, their foci are situated deeply. Spectra of these records are also “narrower” because of higher frequency waves propagating through the rock massif.

Technical seismicity and industrial vibrations represents last type of seismicity. We understand under this term the seismic effects of car and rail traffic, blasting (both opencast and underground mines), hammering, pressing, revolving and vibrator machines and the rest of human activity. The seismic effects of these sources could be more significant in dependencies on particular geological conditions and also source locations.

Evaluation of seismic impact on buildings is executed according to the Czech technical standards ČSN 73 0036 and ČSN 73 0040, where is written: "Demonstration of mining induced seismicity is classified like effects of natural earthquakes. Because the seismic waves of the mining tremors have much higher frequency than natural earthquake, it is necessary to judge the seismicity in focal areas according to measured value of vibration." The measurement is taken on so called reference point of object, which is generally a base of building fast connected with underlying rock, and the values of ground velocity is recorded (the values of acceleration or the values of displacement can be obtain by mathematical recalculation). The values of maximum ground velocity amplitude on individual components (generally two geographically oriented horizontal axes and a vertical axis) and prevailing frequencies on event records are the main parameters for evaluation of vibration response of the object (that means transmission function characterized behavior of the object at seismic loading in dependencies on prevailing vibration frequencies). The first nominative parameter is determined from wave pattern of vibration; the second parameter is determined after Fourier transformation or harmonious analyze of the measured signal.

It is necessary to take into account that evaluation of seismic loading on structures using standards represents generalized rules, which do not reflect specifications of individual areas, recurrences of extraordinary events etc. Therefore, it is necessary to verify obtained results, which represent mathematical simulation, physical simulation, and/or comparison of results of studying locality with results from similar conditions. The basic verification is performance of experimental measurement, naturally. The mathematical simulation represents frequently used method for verification. Evaluation of seismic loading on the buildings according to the Eurocode 1988-1-1 is based on proposal spectra of linear calculation. Physical simulation arises from measuring of vibrations on models placed on a shaking table. The biggest one in Europe is in the ISMES´s test-room in Italy. Accuracy and usability of obtained results are influences of the knowledge of input parameters or their realization at physical simulation (e.g. Janotka et al., 1997, Janotka and Viskup, 1998, 2002, Gallipoli et al., 2002).

THE MAIN PARAMETERS AFFECTED THE INTENSITY OF SEISMIC EFFECTS ON THE SURFACE

This chapter does not propose exact and complete delimitation of all parameters affected the intensity of seismic effects on the surface but resumes the main parameters. From the special point of view we can divide these parameters into three groups:

- *Seismological parameters* – the intensity of seismic events, prevailing frequency of oscillating and duration of maximum phase, dimension and depth of the foci, epicentral distance
- *Geological parameters* - local geological pattern (response of surface and sub-surface levels), position of faults, characteristics of rock massif, in which seismic waves are propagated
- *Constructional parameters* - type of base soil, "contact" of basement with bedrock, proportions and type (design) of objects, lay of mass in object, resonance characteristics of object.

As already has been mentioned, it is always complicated interaction of different parameters, which influence the intensity of seismic loading, respectively seismic response of studying building. Generally, it is impossible to find the simple interaction of the chosen parameter on the intensity of seismic loading on object.

If we review problems arisen in consequence of deep mining (first of all there are surface deformations and mining seismicity), then it is necessary to take into account both economic and also social viewpoints (e.g., Kolibová and Mikulík, 2003, Mikulík et al., 2001). From economic view expenses on solving problem can be imposed on to two groups, namely financial expenses needed to eliminate possible damages and expenses needed to decrease en-dargement due to mining activities. It is evident, that it is necessary to find optimum value of input expenses to reach the lowest level of both sorts of expenses. Expenses on decreasing of seismic consequences include expenses on organization-legal activities, changes of the project, changes of the mining technology, changes for technical equipment of mining work and additional expenses on active hazard prevention (according to Stec, 1999).

The response of the object is motion, transfor-…mation or state of stress, which is induced by the loading. Quoted standards generally advice to measure the ground velocity for evaluation of the loading of the structures by seismicity. Measured sensors have to be set on masonry of the lowest floor or on the base of the object that means on the reference point. In other places, where the failure of buildings can happened, recorded velocity might be greater than value measured on reference point (e.g. influence of the response of the object on seismic vibration). In case, that outside effect (natural or induced vibration) is frequently matched with eigen-frequency of the object, then the biggest damage can happen.

Each technical project (that means buildings, technologies…), which is implemented practically, reflects the level of recognition from time of its development and realization, and corresponds to technological scope and the volume of financial expenses. In consequence of ageing process, the implement project, knowledge and technological options are corresponding to time of the projection and its realization and, therefore, the object vulnerability accumulates. Removal of this problem is in search of new technological and financial possibilities and good knowledge of current possibilities first of all. In general, we can see the current aim in projections of seismic resistance constructions, which are resistance to vibration until certain intensity, and in determination for suitable progress for reconstruction. Otherwise said, seismicity supply to total loading of structures has to be inconsiderable.

INDIRECT EFFECTS OF THE SEISMIC EVENT ON BUILDINGS

It is necessary to take into consideration also indirect influences of seismic events on buildings on the surface except direct influence. Changes of bedrock quality in consequence of induced vibrations are possible to insert to this group of influences first of all. Because of influence of mechanical vibrations, the physical - mechanical parameters of bedrock are changed (e.g. liquefaction). Detailed evaluation techniques of physical, technological and mechanical quality of the rock can be finding in literature (e.g. Hatala and Trančík, 1983, Beavis, 1985). Changes of pressure conditions in the bedrock soil, stability of slopes and level depth of groundwater belong to the most frequent consequences.

CONCLUSION

Mining tremors are one of the most important causes of damages and acceleration of technical wear of buildings on mining area. It is evident, that significant seismic effect from the most intensive mining induced seismic events can be observed on the surface, especially from events with shallow foci. These effects are often theme of discussions and contentions, especially if people or housings are in surroundings of underground exploitation. Vibrations are often regarded as the reason of damages on the buildings. In fact, there are very often other consequences of underground mining activity, (e.g. deformation of terrain or changes of level depth of groundwater) or there are consequences unrelated with mining activity (e.g. wrong-based object, unloading or overloading of objects after their reconstruction).

Analyses of long-term series of mining induced seismic events make possibility to review their percent occurrence in individual categories of their intensity, which contribute to determination of necessary, but also inevitable demands on projects of structures. The review of influences of seismic events on structures covers next points:

- Specification of acceptable seismic loading
- Prognosis of seismic loading
- Determination of seismic risk
- Supplementary photo-documentation of all damages on buildings, especially for monuments and strong damaged objects
- Seismic measurement of induced vibrations
- Evaluation of safety at existing seismic loading (corrections of current state)
- Monitoring of state of current damages.

ACKNOWLEDGEMENT

This research was partially funded by the Grant Agency of the Czech Republic (No. 105/03/0078) and by the Program of Research Development of Key Scientific Areas of Academy of Sciences of the Czech Republic.

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