ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2006
Seria: GÓRNICTWO z. 271 Nr kol. 1715

Zdeněk KALÁB
Institute of Geonics, Academy of Sciences of the Czech Republic
Ostrava, Czech Republic

MEASUREMENTS OF SEISMIC VIBRATIONS INDUCED BY QUARRY BLASTS AT THE MOSTECKÁ BASIN

Summary. This contribution deals with presentation of measurements of quarry blasts seismic effect that were made in the Mostecká Basin. Obtained values of this seismological measurements were used not only for evaluation of seismic loading of buildings and structures in surroundings according the Czech Technical Standard 73 0040 but also as input data for mathematical modeling. Example of wave pattern is presented because unusual shape of wave patterns was recorded. To explain the origin of the group of surface waves, several working hypotheses were tested.

POMIARY DRGAŃ SEJSMICZNYCH WYWOŁANYCH ROBOTAMI STRZAŁOWYMI W KAMIENIOŁOMACH NIECKI MOSTECKIEJ

Streszczenie. W artykule przedstawiono pomiary zjawisk sejsmicznych towarzyszących urabianiu skał za pomocą materiału wybuchowego. Uzyskane, na podstawie pomiarów sejsmiczności, wyniki użyte zostały nie tylko do określenia sejsmicznego obciążenia budynków i konstrukcji w rejonie wstrząsów według Czeskich Standardów Technicznych nr 73 0040, ale także jako dane do modelowania matematycznego. W artykule przedstawiono przebiegi zarejestrowanych drgań i przeprowadzono próbę wyjaśnienia wpływu źródła wstrząsu na przebieg fal powierzchniowych.

1. Introduction

The main objective of the work was to record and interpret the seismic effect of quarry blasts. Usually, the experimental measurements of the detonation of explosives produce typical records of seismic effects, i.e. short wave impulses with rapid attenuation. The measured duration of the whole event lasts no more than 5 seconds. However, vibrations at the Mostecká Basin that are also induced by blasts made as a part of the extractive process in an opencast mine near Tušimice (DNT Mines) have unusual shape. The duration of the recorded wave patterns was up to 35 s. Records of seismic events made at a distance of 2 to 5 km from the blast show body waves in groups, the duration of which is from 3 to 7 s. The record reveals an intensive group of surface waves following this with a pattern of harmonic vibration lasting for 15 - 30 s. The prevailing frequency in this part of wave pattern is about 2 Hz, and the maximum recorded value of vibration velocity also occurs in the majority of these records. The wave field that is generated after blasting operations is very complicated. Seismic records obtained from sites with different geological settings show that the structures in the basin have a marked effect on the shape of the wave patterns (e.g. Kaláb and Knejzlík, 1999, Kaláb et al, 1997, Kaláb, 2003).

From the other hand, many seismological and local geological and hydrogeological conditions must be taken into account to evaluate variability of surface wave field. This so called site effect is often discussed and modeled (e.g. Bullen and Bolt, 1993, Viskup and Janotka, 1995, Ansal, 2004, Janotka et al., 2006).

2. Geological and seismological situation

The Mostecká (formerly North Bohemian Brown Coal) Basin is a relict of a Tertiary sedimentary basin, filled with sedimentary material mostly during the Miocene era. Geological section is presented in Fig. 1. At that period 22 to 17 million years ago, more than 500 meters of clays, sands and organic material was gathered in the basin. A brown coal seam developed in most parts of the basin, formed from layers of peat deposited in a Tertiary swamp. Near river mouths feeding the swamp with water, the peat sedimentation was suppressed by depositing sands and clays. At these locations the seam is either completely replaced by alluvial or delta sediments, or split into several bands. According to the manifestation of these impacts on the seam cross-section, the Mostecká Basin can be divided into several parts. Most affected by sand and clay deposits was the Žatec delta area. In the remaining part, a more or less integral, 25 to 45 meters thick brown coal seam developed. The outcrop of the coal seam or its equivalent represents the present basin border. Today's remnants of the Mostecká Basin spread over an area of about 870 km^2. The deepest part of the basin is the so called Central Region between the towns of Litvínov, Osek and Duchcov and villages Lom and Mariánské Radčice. At present, the coal seam is mined by five open cast mines. Two of these - Bílina and Libouš, are run by Severočeské doly, a.s. Chomutov (according www.sdas.cz).

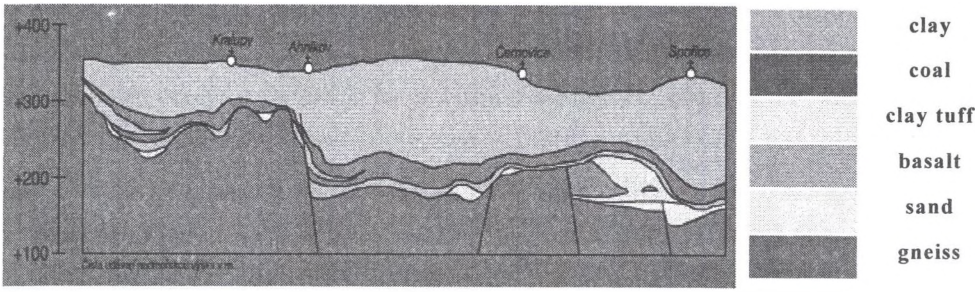

Fig. 1. Geological section in the Mostecká Basin (assumed from www.sdas.cz)
Rys. 1. Przekrój geologiczny Niecki Mosteckiej (na podstawie www.sdas.cz)

The locality under discussion, in which the experimental measurements in question were taken, represents, from the seismological point of view, an environment which is characterized by very low natural seismic activity and seismic effects resulting from anthropogenic activity. In the course of measuring, seismic manifestations corresponding to the blasting operations in the near DNT mines and seismic manifestations produced by "common activity", such as traffic, excavations, train passages, etc., were monitored. It can be briefly stated that the taken experimental measurements made it possible to judge the rate of seismic load on measured sites for the given intensity of anthropogenic activity.

3. Main characteristics of seismic manifestations

When registering seismic manifestations due to the blasting operations, in small distances wave patterns are usually recorded that correspond with the record of the group of volume waves - P longitudinal and S transversal ones and their mutual interference (see Bullen and Bolt, 1993). The record is characterized by a steep increase in the amplitude of a signal and its quick damping (see example in Fig. 1). The typical duration of the record is usually several seconds that is typical parameter of the record. This type of signals forms a basis for the construction of a lot of commercial monitoring apparatus designed mostly as three-component digital recorders of a seismic signal supplemented, if need be, by a channel for the recording of a pressure wave. Their time of recording is often limited owing to the capacity of storage to about 10 s; in this interval the maximum recorded amplitude of a signal is also mostly read automatically.

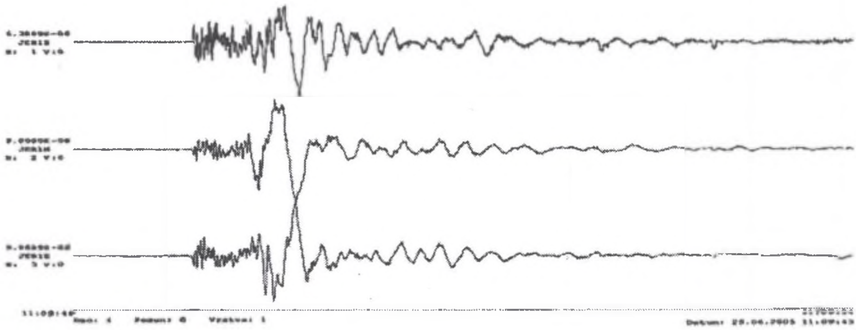

Fig. 2. Typical wave pattern of blasting operation (Krásno quarry, epicenter distance about 5 km)
Rys. 2. Typowy przebieg fali sejsmicznej wywołanej robotami strzałowymi. (Kamieniołom Krasno, epicentrum w odległości około 5 km)

Already during the first experimental measurements in the surroundings of the DNT Mines we found that wave patterns had a quite different character with the time of duration of up to 35 s - see the typical example in Fig. 2. In this figure, records of the vertical, north-south and east-west components are again illustrated from top to bottom. Scales of amplitudes in particular vertical axes have the norm prescribed for the maximum recorded value (the value on the left of the record), and therefore they are various. In the horizontal axis the time is given (1s/unit distance, approximately half shortening of 1 s between fig. 1 and 2).

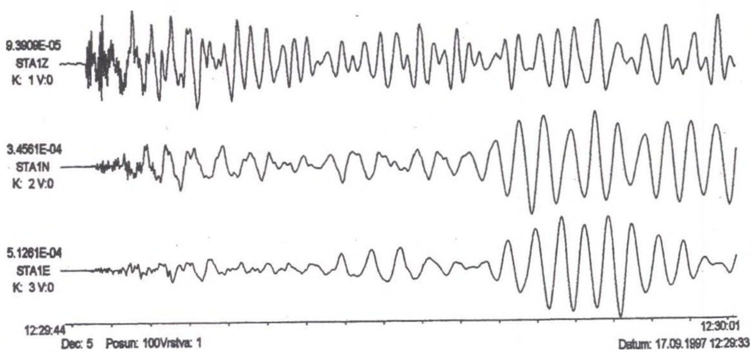

Fig. 3. Typical wave pattern of blasting operation; record continues but to have more detailed information about first wave groups it is cut off (DNT Mines quarry, epicenter distance about 3.5 km)
Rys. 3. Typowy przebieg fali sejsmicznej wywołanej robotami strzałowymi, zapis ciągły z wycięciem, celem uzyskanie większej dokładności (Kopalnia odkrywkowa DNT, odległość epicentrum około 3,5 km).

4. Experimental measurements on slopes

To obtain needed information for evaluation of impact of quarry blasts on slopes, seismic station was located here. First position was placed near inspection tunnel (distance to blasts was about 1 km), second one was placed on concrete bridge on hill (distance about 200 m from slope, about 1.5 km from blasts, see Fig. 4. Maximum measured velocity amplitudes were almost (component value) 5 $mm.s^{-1}$ with prevailing frequency 2.3 Hz. Both positions were on slopes that are used for mathematical modeling.

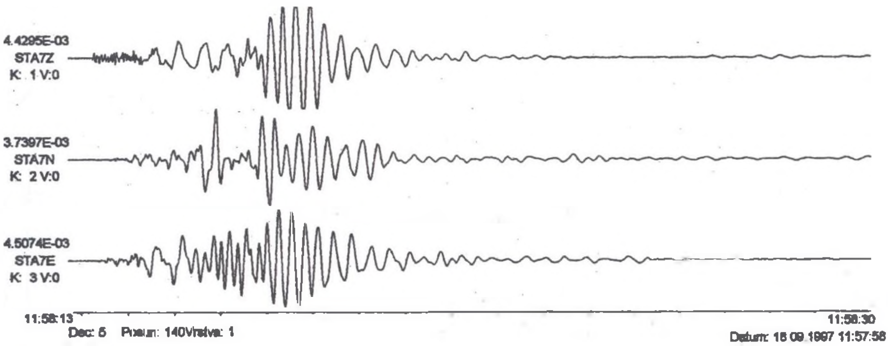

Fig. 4. Wave pattern of blasting operation recorded on concrete bridge near hill of slope (DNT Mines quarry, epicenter distance about 1.5 km)

Rys. 4. Przebieg fali sejsmicznej wywołanej robotami strzałowymi zarejestrowany na betonowym moście w pobliżu zbocza (Kopalnia odkrywkowa DNT, odległość epicentrum około 1,5 km)

The first part of the record on position under discussion (duration of about 2 seconds, 5-20 Hz frequency range of signal, prevailing frequencies in higher values) seems to correspond to volumetric seismic waves that are generated by the blasting of explosives and propagate through a rock. In the wave patterns, the onset of the P-wave, and subsequently also the onset of the S-wave, can be unambiguously identified. These waves spread through the basement of claystones and of coal layers, the velocity of the P-wave can be determined at about 4.5 $km.s^{-1}$.

The second part of the record (duration of about 5 - 10 seconds in our positions, however in detail is possible to determine this surface waves up to 20 s, 2 - 4 Hz frequency range is the most significant) corresponds to surface waves. The generation of this wave group is not reliable explain. At this locality, there is no need to fear of the effect of tectonic release of seismic energy that comes from the intensive blasting of explosives in the geologically complicated and tectonically considerably damaged conditions.

5. Discussion about surface wave origin

In the duration of measurement, the level of the seismic noise reached even the value of $6x10^{-6}$ $m.s^{-1}$. The increasing of the seismic loading, as mentioned above, occurred especially in connection with excavation operations. It was a case of seismicity closely related in time with the proper works when the amplitude of vibration velocity grew in peaks even to the values of $2x10^{-4}$ $m.s^{-1}$ (in surroundings of exploited area). Next important source of seismic events is traffic. The maximum value of vibration velocity of these seismic events often exceeds the 10^{-4} $m.s^{-1}$ limit. The duration of this vibration is various; more intensive effects reach even 15 seconds.

To explain the origin of the group of surface waves, several working hypotheses were tested. By a process of elimination, an effort was made to verify or to disprove them experimentally by using a single three-component station moved progressively throughout the surroundings of the mine. The following possible explanations for the origin of surface waves were considered:

- a wave induced by the pressure wave spreading through the atmosphere,
- a wave induced by the vibration of some secondary surface source, e.g. a large mechanical structure with a high quality factor (e.g. the boom of a large machine, high chimney, etc.),
- a wave induced by the channel wave propagating through a coal seam or other marked stratum in the geological sequence,
- some large subsurface structure, e.g. flooded spaces of a nearby underground mine, which played a significant part in the origin of the surface wave,
- a wave induced by a complex mechanism at the source of vibration, i.e. the pattern of firing the explosive charges,
- a classic example of the generation and propagation of a surface seismic wave.

It became obvious from experimental measurements carried out at various positions in the surroundings of mines that the intensive group of surface waves develops as a result of the technique used in blasting operations (especially as the result of the detonation of explosives in shallow boreholes). The intensification of the surface wave takes place in the subsurface layers of rocks with high wave impedance. In this case, it is probably the bedding structure of the basin, i.e. the coal seam and the strata which overlie it, usually clays (and/or shale), and vast heaps of overburden material. Records from almost all of the measured sites confirm this finding. The measurements made outside the basin are an exception to this general finding; in these cases only a group of body waves was recorded (e.g. point in Hasištejn castle).

6. Mathematical modeling

Mathematical model of influence of quarry blasts on slope stability was created using programming system Plaxis (Finite Element Method). Single –point bounded source was modeled to study influence of blasts on slope stability. It was made by means of stress-deformation state of reverse slope in different sections of slope. Evaluation of vibrations on railway tracks was the main task. Seven types of mediums were defined in axially symmetric model.

Parametrical analysis enables to evaluate the development of stability and stress – strain conditions of simulated slope. Reverse slopes are stable according to the model using dynamic load (coefficient of stability F=1.4). Distance between source of vibrations and base of slope was variable parameter. Its start values was 480 m than this distance was shortening (step was 50 m). Course of potential slip planes, horizontal movements, vertical movements and changes of pore pressure were calculated. This analysis was performed both with and without material absorption. Differences between finite values of horizontal displacements in these two models were minimal. In this case, we documented that discussed distances do not have principal influence on the degree of slope stability but takes more significant effect on deformation situation in the slope. Detailed results were published in Hrubešová and Luňáčková (2006).

7. Conclusion

The records of seismic events in the surroundings of the DNT Mines made in the distances in range 2 - 5 km are marked with the 3 - 7 s duration of the group of volume waves. After that, the record of the group of surface waves manifesting themselves in a vibration of the harmonic type for 15 - 35 s follows in the wave pattern records. In this second group of waves with the prevailing frequency of about 2 Hz, the maximum recorded value of vibration velocity occurs in the majority of records too. The obtained type of record in the area before the DNT mines is very similar to some records of near shallow earthquakes. These records are also characterized by intensive surface waves whose amplitudes can exceed the amplitudes of volume waves as well.

On the whole, in terms of judging the seismic load on buildings in surroundings of DNT Mines according to the standard for seismic loading (ČSN 73 0040) it can be stated that the value of 3 mm.s^{-1}, which is a minimum limit value at the „0“ degree of damage (i.e. without any damage) was never reached during any blasting of explosives in the DNT Mines. If we admit the „1“ degree of damage (i.e. the first damages – small failures), we can present that the minimum limit value of 8 mm.s^{-1} is three times higher. Common used relations between distance (actual or reduced), weight of explosives (total or charge fired in one time stage) and maximum velocity amplitudes do not exist. Maximum recorded value of velocity amplitude in buildings was 2.8 mm s^{-1}.

Investigations of the seismic loading of buildings and structures have a direct bearing on the implementation of new European standards for the design and protection of civil engineering structures (EUROCODES). Seismic measurements will play an important part in evaluating the seismic loading of structures at specific sites and in gathering data to enable mathematical modeling of their structural responses.

Acknowledgement

This research is partly sponsored by Research Programme of Academy of Sciences of the Czech Republic, No. OZ30860518

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Recenzent: Dr hab. inż. Piotr Strzałkowski, prof. nzw. w Politechnice Śląskiej

Streszczenie

W ramach artykułu przedstawiono pomiary drgań sejsmicznych wywoływanych urabianiem materiału skalnego w kopalniach odkrywkowych Niecki Mosteckiej. Pomiary wykonywano w rejonie oddalonym od źródła drgań o 2 do 50 km. Grupę drgań objętościowych rejestrowano w czasie około 3 – 7 sekund, a następnie rejestrowana była grupa drgań powierzchniowych przejawiająca się jako drgania typu harmonicznego. W tej drugiej grupie przeważały drgania o częstotliwości 2 Hz.

Zarejestrowane przebiegi drgań w rejonie kopalń DNT wykazują znaczne podobieństwo do drgań wywołanych płytkimi trzęsieniami ziemi. Drgania te charakteryzują się dużą intensywnością, a ich amplitudy przewyższają amplitudy drgań objętościowych.

Oceniając wpływ prowadzonych strzelań i następnie generowanych nimi drgań górotworu, na podstawie norm dotyczących oddziaływań sejsmicznych (ČSN 73 0040) można stwierdzić, że urabianie za pomocą materiałów wybuchowych nie stanowi zagrożenia dla budynków i konstrukcji zlokalizowanych w rejonie Niecki Mosteckiej.

W artykule przedstawiono także próbę numerycznego modelowania wpływu na stateczność zbocza wstrząsów wywoływanych urabianiem skał za pomocą materiałów wybuchowych. Do modelowania numerycznego również zastosowane zostały wyniki prowadzonych pomiarów.

Badania w zakresie obciążenia budynków i konstrukcji oddziaływaniem sejsmicznym posiadają bezpośrednie odniesienie do nowych europejskich standardów dotyczących projektowania i ochrony obiektów inżynieryjnych.