SEISMIC PROCESSES IN MINING REGIONS EXEMPLED BY THE POTASSIUM SALT DEPOSITS IN BULGARIA AND BELARUS

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General Information

In many regions the large urbanized areas are overlapped with the regions of manifestations of different natural disasters. This is one of the reasons that has provoked bilateral international project exploring the problems of the natural and technogenic hazards and their possible mitigation (Paskaleva et al., 1992; Aronov et al., 2005). Next items described technologically provoked problems in the salt mines Mirovo (near Provadia, $\varphi=43.06^0$N, $\lambda=27.45^0$E), Bulgaria and Starobin $\varphi=52.84^0$N, $\lambda=27.47^0$E, Belarus.

Like in the case of the Provadia mining region, negative ecological consequences are considerable deformations of the ground over worked out underground mines, vast areas occupied by wastes of potassium production, as well as phenomena of induced seismicity. An intensity of individual shocks is as high as 4-5 on the MSK-64 scale. The impact of deposit mining work is responsible for troughs resulted from pushing together movements and for deformations of buildings and constructions on the earth's surface.

The regional seismic situation and monitoring

The **Provadia** region is considered to belong to a zone with moderate seismicity between 1900 and 1970 (Rangelov et al., 1994). The seismicity of this region is determined mainly by the Devnya fault in the north of Provadia. The region is characterized by compression stresses in NE-SW direction which is in agreement with the general situation in northern Bulgaria (Knoll et al., 1995). According to the potential seismic source map the maximum expected magnitude at this site is M=5.6-6.0 and depth 5-10km. Within the time, since 1900 there were only few events felt near the Mirovo salt deposit (in 1901, with M=3.8 and epicentral intensity I_0=V MSK-64; 1901, M=3.6, I_0=V; 1902, M=3.6, I_0=V; 1903, M=2.6, I_0=III). Up to 1964 there are not other data concerning the seismicity of the Mirovo district.

The nearest seismological station, PRV (Provadia), was established somewhere in 1980. In 1981 a strong ground motion network with five instruments SMA-1 was built. The digital Reftek station was installed and calibrated by the GTU Ingenieur Buro Knoll specialists (Paskaleva et al., 1994).

More than 200 strong ground motion components registered by the SMA-1 instruments were processed. All the records are "saturated" with high frequency vibrations. According to the response spectra for the accelerations and 5 % damping the maximum periods are in the range 0.085-0.2 sec for the vertical and 0.1-0.57 sec for the horizontal components (HOR). Another feature of these events is their short duration (0.12-2.97 sec), most of these earthquakes act as impact excitations. The peak ground accelerations (PGA) are quite high; in some records they overcome 0.5g. The dynamic effect of single events obtained from the response spectra with 5% from 1.2 to 6.0 for the HOR and reaches up to 7.0 for the vertical components (VER). The ratio between the PGA, VER and HOR, is 0.17-2.26, which shows the predominant influence of the VER component and confirms the local origin of the earthquakes. The duration of the intense part of the accelerograms is about 3 sec. Such short duration means that these events act as single short-time impulse load on the chamber-pillar system. The fact that the vertical PGA are often higher than the horizontal (50 % of the registrations), has to be considered when perform a dynamic analysis of the stress-strain state of the system too, since there is a possibility for pillar failure due to vertical cracks occurrence. The available records can be efficiently used for the vulnerability analysis of the structures in the region of Provadia, for pillar capacity reestimations.

Starobin. According to a division of the east European platform west into seismotectonic regions, the territory of the Starobin deposit of potassium salts is related to the Pripyat potentially seismic superzone with a magnitude M=4.0 and a focus depth H=5 km (Garetsky et al., 1997).

As to induced earthquakes, the first of them was recorded in 1978 (K=9, I_0=V) by the seismic station "Minsk" located at a distance of 170 km from it. Continuous instrumental seismic observations in the deposit region were carried out in 1983 by equipment with short period seismographs. Operating frequency bands were 1-10 Hz with analog recording. Besides within 1983-2000 observations were carried out by self-contained seismic instruments with operating frequency bands of 0.5-60 Hz and duration of independent work of 20 hours, and the information was recorded on magnetic tape. About 1000 seismic events were recorded in the region within this period (Aronov et al., 20035).

A seismologic telemetric complex was installed in 2004, and the information was transmitted into the computer. At the first stage the complex was composed of four observation stations. A total of 6 observation stations were envisaged. Each station was instrumented with three-component short-period seismic detectors with capacitance-type transducer and magnetic-electrical feedback. The operating frequency band was 1-70 Hz. The information was continuously transmitted to a computer in the real time network and then to a computer when it was accumulated, processed and stored. Observation stations were located both in mines, and on the ground surface. A dynamic range was at least 120 dB. A reception range was at least 30 km.

A three-level database was the result of long-term seismic monitoring based on an automated telemetric complex contains: level 1- general geological and geophysical information on the territory under monitoring, specific data on the seismograph network, tectonic blocks, velocity models, seismic wave travel time curves, etc; level 2 -digital seismograms of recorded seismic events, digital event seismograms, arrival times and amplitudes of seismic phases, major wave groups with maximum amplitudes, etc; level 3 - the main results of interpretation, i.e. space and time, energy parameters of foci of seismic events as well as some other parameters. The data are considered to be most important for studying geodynamics of the Soligorsk industrial region.

Results

Over the period 1983 till 2004 more than 1000 seismic events have been registered in the area monitored, 4 of which produced a tangible effect: 10 May 1978; 2 December 1983; 17 October 1985; 15 March 1998. The energetic class which is connected to the magnitude correlating K=1,8M+4 for those events is located within the diapason of 8,0- 9,5. The intensity of soil shaking rose up to 4-5 scores. All the earthquakes were accompanied by macro-feelings: rumble, window glass rattling, swaying of hanging objects, furniture and floor creaking on the ground floors of wooden constructions. The scattered plaster cracks were observed. During the earthquakes 1978 and 1998 roof collapse took place. This map also shows rupture dislocations active at the present-day stage. The strongest seismic events recorded recently in the Soligorsk region are confined to zones of tectonic disturbances active at the latest stage. These are a set of the North-Pripyat superregional faults, the Chervonaya Sloboda and Stokhodsk-Mogilev fault systems. This is also evidenced by the prevailing fracturing orientation measured immediately in mines and by the regional stress system of the East European Platform west. At present continuous seismic observations at the Soligirsk geodynamic testing ground are carried out with an automated telemetric seismic complex intended for prompt monitoring of space and time distribution of seismicity and assessment of the geodynamic environment by outlining seismically active areas (tectonic blocks).

The Provadia deposit area is situated in the eastern part of Bulgaria. Seismic observations have been carried out there since 1994 by a local network of five stations. Most of epicenters are confined to a zone measuring 20 km across and situated between the settlements of Markovo, Dulgopol and Momino. The strongest earthquake of this region with a magnitude of 4.4 also took place there in December 18, 2003. The other smaller zone where epicenters are abundant is situated 30 km southwestward. The area of epicenters extends to approximately 70 km sublatitudinally and 65 km submeridionally. In the first epicentral zone events with a magnitude of 1.5÷2.4 are slightly prevalent, and in the second zone events with a magnitude of 2.5÷3.4 are dominant. In both deposits epicentral areas of seismic events overstep the limits of mine workings. This is typical of induced seismicity zones.

The seismic energy of the Soligorsk events was calculated from wave patterns. The energy in

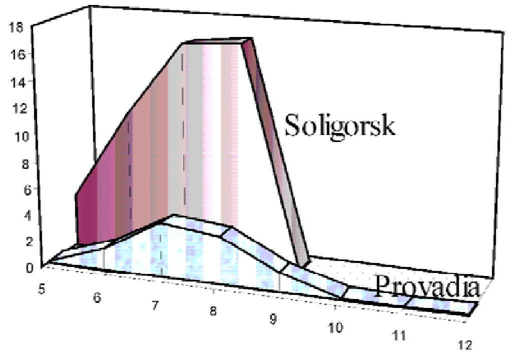

Fig.1. The curve of recurrence for the Soligorsk and Provadia regions.

Provadja was calculated from the local magnitude using lg$E(J) = 1.8M + 4$. The Fig.3 presents a curve of recurrence calculated by the method of intervals for both regions. The average annual value of a number of seismic events is plotted as ordinates. This curve shows that in the region of Soligorsk the seismic activity is higher for a range of energy classes 4÷9. The curve shape in this range is almost uniform. It should be noted that this range of energies correspond to rock-tectonic shocks according to Malovichko classification (Malovichko et al. 2000). A quasi-similarity of curves suggests the similar origin of seismic events.

However, in the Provadia region seismic events with energy class of 9 and higher, i.e. in the energy range related to technogenic earthquakes class 4 are more abundant. One earthquake which took place between the settlements of Markovo and Momino in December 18, 2003 had a magnitude of 4.4 (K≈12). The time distribution of the seismicity in Provadia and Soligorsk is shown in Fig.3. Annual values of seismic energy (E) for the Provadia and Soligorsk regions are given in Fig.3. This Figures 2 and 3 represent the total annual number of seismic event and the summary value of released seismic energy. A quasi-periodic character of a number of seismic events with the general tendency to increase is characteristic of the Provadia and Soligorsk regions. The summary annual energy value agrees in general with a number of events. This regularity has been slightly disturbed since 1996 in the Soligorsk region. When a number of events increase there the summary annual energy is tending to decrease. For the curves drawn from the Provadia data two extreme points are not quite informative as during 1994 and 2004 the observations were not carried out regularly there. In the Soligorsk region events of the less energy class are dominant suggesting a technoge-nic effect. Besides, there are suppositions that the seismicity in the Soligorsk is

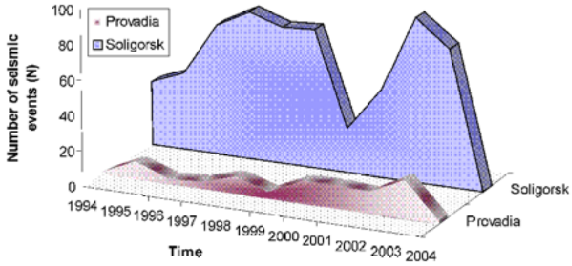

Fig. 2. Annual number of seismic events (N) for the Provadia and Soligorsk.

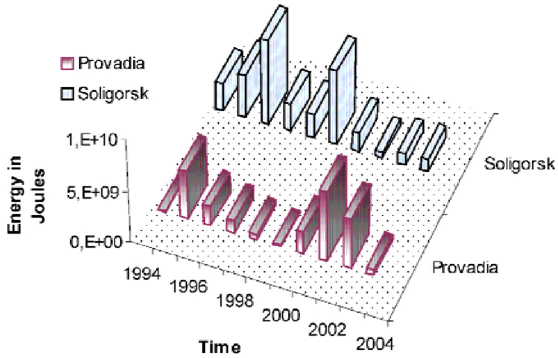

Fig.3. Annual values of seismic energy for the Provadia and Soligorsk regions.

influenced (though to a lesser extent) by the other factors, e.g. lunar-solar tides (Seroglazov, 2003). In the Provadia region tectonic processes seem to play the more important part, which is confirmed by the stronger seismic events that occur there. This is due to the fact that the Provadia region is situated in the seismically active zone.

Seismic processes in the regions of potassium salt deposits of Provadia and Soligorsk show the following characteristic features: a) the identity of the curves of recurrence of seismic events of the energy range of 4-8; b) a quasi-periodic character of the seismicity activation in time against the general trend of seismicity activation increasing; c) zones of epicenters of seismic events are larger that mining areas.

There are some differences in the pattern of seismic processes, such as: a) seismic activity in the range of small energies (K=4÷8) is higher in the Soligorsk region; b) events of the higher energy class K>9 are characteristic of the Provadia region.

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СЕИЗМИЧНИ ПРОЦЕСИ В РАЙОНИ НА МИННИ ИЗРАБОТКИ НА ПРИМЕРА НА СОЛНИ НАХОДИЩА В БЪЛГАРИЯ И БЕЛАРУС

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Фокусът на тази работа е върху оценката на сеизмичния риск, свързан със солните находища в Провадия и Солигорск (Беларус). За целта е извършен мониторинг от белоруски и български специалисти в рамките на двустранният проект.

Представени са дългосрочни проучвания от 1983-2005 г. на единственото експлоатирано българско солно находище (Провадия, φ=43,060 N, λ=27,450 E) и белоруското (Старобин φ=52,840 N, и λ=27,470 E) във връзка с наблюдаваната повишена сеизмична активност и възможните проявления на техногенната сеизмичност във споменатите райони.

Установени са характеристиките на сеизмичните процеси като на графика на повторение на сеизмичните събития със стойности на енергията. Установен е квази-периодичния характер на сеизмичността във времето на фона на общата тенденция на увеличаване на сеизмичността. Изследването показва, че епицентралните зони са по-големи от областите на минни работи.

Показани са някои различия в закономерността на земетръсните процеси - сеизмичната активност с малки стойности на енергията (К=4-8) е по-висока в района на Солигорск. Наблюдавани събития от по-висок енергиен клас К>9 са типични за района на Провадия.