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INVESTIGATION OF INDUCED SEISMIC PHENOMENA IN THE BITUMINOUS–COAL KLADNO DISTRICT

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The bituminous–coal mines of Kladno coal region belongs among the oldest rockburst–prone mines in the Czech countries. First rockbursts were reported already in the eightieth of the 19^{th} century, when the coal mining was initiated (the first mines were opened around 1870). Since the very beginning, the territorial distribution of the rockburst occurrence has been highly uneven. Likewise the relation between the frequency resp. energy of rockbursts and the volume of mining works has not been sufficiently evidenced (the cases are known, when the rockbursts were encountered during the development shaft sink in the depth 300 – 350 m under surface). It follows, from the macroseismic effects recorded in the so–called "detonation books", that the first rockbursts resulted in footwall creeping.

It results, from the macroseismic data:

- rockbursts occur unevenly (as concerns their location), namely the mines in the vicinity of a Tertiary volcanic effusions of the Vinařická hora (Vinařice Mt.) are exposed; this concerns, for example, the mines Ronov, Mayrau and (partially) the Max mine.
  A border of the rockburst occurrence on the western side is formed by an important tectonic fault;
- first rockbursts occurred in a practically intact rock medium (during a shaft sinking) and in small depths (some 300 m). The main Kladno seam – only extracted one – has an average thickness of 6 m and lies in the depth of 450–600 m under surface.
- the most frequent destructive rockbursts consisted in footwall creeping or wall clenching,
- the rockbursts were found to be induced mainly by entries driving. The above macroscopic data confirm high primary stress state of the rock massif; they are in agreement with the conception of increased values of horizontal stress components.

Research on rockbursts in the Kladno coal mine region started in the end of fifties; it was conditioned by establishment of the first seismic station "Kryt" in the mine (of that time) Gottwald II (now Kladno II Mayrau). At that time, the first recordings of acoustic pulses were performed in this mine's seam together with the measurements of seismic noise covering wider area, aimed to the selection of further seismic stations' suitable sites [Buben 1962; Holub, Tobiáš 1963]. The seismic station MNV–Vinařice was found in 1961 [Rudajev, Buben 1964]; it has been working since 1962 up to the present days as a three–component station (seismographs VEIGIK, $T_0 = 1{,}5\,\mathrm{s}$, galvanometers GB–III, $f = 15\,\mathrm{Hz}$, $V \sim 1800$) with galvanometric recording. Further enlargement of seismic stations number enforced elaboration the advanced methods of processing and interpretation of local seismic records [Buben, Rudajev 1965]. These methods established a basis for processing of data from further local stations networks in rockburst–prone regions of the Czech republic [Rudajev 1966; Rudajev, Buben, Hrdlička 1965; Buben, Rudajev, Fučík 1981].

The first seismic results enabled formulation the following conclusions:

- the rockbursts are clustered in smaller areas related to mine openings, however, their origin and the release energy are not in a simple way related to the progress of the mine operations,
- the rockburst–prone regions can be mutually distinguished on the basis of type analysis. This approach has been deployed for the first time in the Czech Republic specially for the rockbursts in Kladno mine district [Buben 1964];
- strong rockbursts originate preferably overlying sandstone strata [Přibyl, Rudajev 1969],
- based on elaborated determination method of local rockburst energy, their energy range has been assessed within 10^2–$10^{6,5}$ Joule,
- prevailing frequency of rockbursts in the focal distance 800–1500 m lies within 1–10 Hz. No clear relation of frequency on the quantity of the released energy was by proved [Buben 1964];
- the energy–frequency distribution of rockbursts was confirmed; at the same time, for selected time intervals, some deviations from the negative–exponential distribution were observed. Variation of γ parameter of this distribution ($\log N = A - \gamma \log E$) in time and site were established. Small values of γ ($\gamma < 0{,}4$) indicated an increased risk of rockburst occurrence [Rudajev 1966; 1967; 1971];
- unevenness of the rockburst occurrence in time has been established. The Benioff dependence of the cumulative energy on time has been applied. Based on the energy flow analysis for time interval and for individual areas, the prediction relations have been established [Rizničenko et al. 1967; Rudajev 1966].

During the seventieth, the rockburst research was aimed to the study of mechanism of rockburst foci and development of the statistical prediction methods. It has been found that the models of shear foci do not characterize fully and sufficiently the properties of mining–induced seismic phenomena. Dimensions of these foci, determined from local network records, are unrealistically large and the distribution of the first onset signs do not agree with the emission characteristics of shear source. Therefore, the conception of a volume–bound source, corresponding to the observed sign distribution (dilatation) of P–waves, has been developed and derived relations for geometrical focus dimensions resulted in more realistic values. Results of these analyses are summarized in the report cycle "Physics of rockburst foci I–IV" [Buben, Rudajev 1968; Fučík, Rudajev 1976; 1978; 1980] and in other publications [Fučík 1980].

Statistical prediction methods were developed based on the extrapolation of random time series. The derived methods as well as their applications to the Kladno region rockbursts are quoted in the report cycle "Statistical prediction methods of mine bumps I–IV" [Rudajev, Buben 1973; Rudajev, Buben, Pěč 1975; Rudajev, Fučík 1977; 1979].

These results were presented on international conferences (Czech–Polish seminars) [Fučík, Rudajev 1979 a,b; Rudajev, Fučík 1976; 1982; Rudajev et al. 1985].

During the eightieth, the mechanism of the rockburst foci was subjected to further analysis. It was stated that the probable focus model includes two displacement components – a shear one and an implosive one. This combined model was based on the theoretical calculations of stress distribution in a medium weakened by mine openings, and confirmed by tests on physical models with a fissure in a weakened medium by means of perspex models. Finally, it has been applied for measurements for the Kladno rockburst area [Rudajev, Šílený 1985; Rudajev et al. 1986].

The long–term seismic research of rockbursts pointed out the necessity of multidisciplinary research utilizing further geophysical and geomechanical methods. In several cases the complex approach yielded also practical results useful for the prediction the occurrence of rockbursts and enabled efficient prevention measures [Rudajev et al. 1973; 1978].

However, in spite the successful solution of several partial problems, general solution of deformation processes of the rock massif resulting from mining activities and from geometry of mine openings is still to be searched for. Investigation of induced deformation processes within a heterogeneous, anisotropic and tectonically faulted medium requires a complex approach, which would enable the stress and strain variations of rock massif to be followed from the very beginning of the affection by impacts of anthropogenic activities till the final phase of limit levels of deformation and occurrence of rockbursts.

The multidisciplinary rockburst research consists not only in the common local and simultaneous application of different methods, but also in common synthetic processing of results. New digital, computational systems enable more advanced statistical methods to be used, which respect non–stationarity of the evaluated time series. Such an interpretation of results requires permanent correlation of measured data with mining operations.

The present situation on the Kladno mine Mayrau gives an excellent occasion, when the excavation is concentrated in a single area (the disturbing effect of surrounding stopes being excluded). Also the hanging wall is formed by compact sandstone and sedimentary benches.

The measurement of induced deformation processes and induced seismic activities is based on the application of geodetical, seismical, seismoacoustical, ultrasonic and deformation (convergence) methods. Model experiments and calculations of ground displacements of undermined Earth surface during the simulation of mining activities have been carried out as well. This research began in 1993 and its main object is the obtaining the new information about induced deformations taking place in a medium affected by mining activities, about the physics of foci of induced seismic phenomena, mutual relation of data from various methods, and about possibilities to predict strong seismic events.

Present issue of Acta Montana is devoted to topical results of the above mentioned rockburst research.

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