Induced seismic events in the Staříč and Paskov mine fields, Czech Republic

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Indukované seismické jevy v důlních polích dolů Staříč a Paskov, Česká republika

Jednou z oblastí, kde byl prokázán výskyt indukovaných seismických jevů v průběhu posledního desetiletí, je jihozápadní část ostravsko-karvinského revíru, kde se nalézají doly Staříč a Paskov. Od r. 1990 byly některé indukované seismické jevy detekovány 10-ti staničním regionálním seismologickým polygonem (SP DPB) a od r. 1992 také 5-ti staničním polygonem na Frenštátsku (SPF). Několik ze serie indukovaných jevů bylo také zaznamenáno seismologickými stanicemi české národní sítě (CNSN), a to stanicemi: Ostrava-Krásné Pole (OKC), Vranov u Brna (VRAC), Moravský Beroun (MORC), Dobruška (DPC) a jeden jev byl detekován i stanicemi Průhonice (PRU) a Kašperské Hory (KHC).

Od února 1990 do června 2002 bylo monitorovacími sítěmi SP DPB a SPF detekováno a lokalizováno celkem 49 indukovaných seismických jevů, jejichž energie se pohybovaly v řádu 10^3 J. Z celkového počtu jevů bylo 11 jevů současně zaznamenáno oběma sítěmi. Žádný z uvedených seismických jevů neměl charakter důlního otřesu s následnými devastacemi důlního díla. V zásadě se jednalo o projevy zavalování vyrubaných prostor nebo rozrušování zbytkových podlimitních pilířků při postupu porubu podél stařin. Na základě lokalizace ohnisek pak bylo možno posoudit vzájemnou polohu ohniska vypočtenou na základě dat jedné, či druhé sítě. Excentrická poloha obou sítí vůči ohniskovým oblastem, jejich seismogeologické podmínky a použité rychlostní modely se projevily na výsledcích lokalizace. Rozdíly ve vzdálenostech vypočtených ohnisek 11 společných jevů se pohybovaly v rozmezí r ≈ 0,5 – 2,8 km.

***Key words**: Ostrava-Karviná Coal Basin, induced seismicity, seismological monitoring*

Introduction

Since the 70´s the eastern part of the Ostrava-Karviná Coal Basin (hereafter OKR) where mines Dukla, Lazy, Doubrava, ČSA, Darkov, 9.květen and ČSM are situated, has been considered as the area with a rising level of induced seismic activity due to the increasing of coal winning. In order to monitor this activity, two monitoring systems were gradually put into operation during the time period 1977-1988. It is a local seismographic network consisting of 7 microarrays currently operating at individual mines and a regional seismic network consisting of 2 parts, i.e. seismic polygon SP DPB and a monitoring system erected in the region of Frenštát p. Radhoštěm (SPF). Besides the mines mentioned above where a frequent occurrence of induced seismic events has been observed for years, according to theseismological monitoring a new focal region appeared in the area of mines Paskov and Staříč which are situated southwest of the central part of the coal basin. Detection of seismic events that originated within the last decade in these mines was possible due to the proximity of seismic stations of the SPF system and the suitable position of the station Brušperk, which recorded several seismic events during the initial stage of the operation of the SP DPB system.

The present paper deals with a brief analysis of time series, location plots and wave pattern interpretation of 49 induced seismic events which occurred in the mines Paskov and Staříč within the period from February 1990 to June 2002.

The layout of seismological stations

The construction of a network of seismological stations for monitoring the seismic activity induced by coal mining in the central part of OKR was motivated by a frequent occurrence of intense seismic events which often possessed the nature of rockburst manifested by mine working deformations. The first seismological station in the Karviná partial coal basin was built up on the surface of Darkov colliery (previously 1. máj). The first results of the operation of this station confirmed assumptions of a suitable application of the seismic monitoring method as well as a justification for further gradual expanding of the seismological network aimed at the objective assessment of particular mining induced events (Trávníček and Holečko, 1980).A further progress in the construction of a local monitoring network led to the application of the digital instrumentation and its data transmission and central data processing at the ČSA colliery as well (Holub et al., 1995; Kalenda and Holub, 2000).

As mentioned above, besides the local seismographic network, a construction of a regional seismological network has been in effect since 1987. For this reason, a conceptual proposal of a regional network named Regional Diagnostic Polygon (RDP) was elaborated, which should link up local and national seismological networks. The issue of the instrumentation of the regional network by means of a high quality digital equipment remained to be a principal problem. The originally proposed regional system consisting of 18 stations was later

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modified and structured into two parts. The first part surrounding the eastern area of the Ostrava-Karviná coalfield (10 stations), forming the present seismological polygon (SP DPB), is operated by the DPB Paskov now (Trávníček et al., 1992). The other, located in a broader area of newly-built-up Frenštát mine (5 stations) is operated by the Institute of Geonics AS CR in Ostrava (Kaláb, 1992). While the distribution of the Frenštát seismological network of stations (SPF) has not been changed since the start of its operation in 1992, partial modifications of station positions of the eastern OKR part were made. The essential change in the regional network configuration was related first of all to the site Brušperk. This station, operating within the period 1989 - 3/1995 in the neighbourhood of Paskov and Stařič coal fields, was afterwards moved to the ČSM colliery where it was in operation from 3/1995 until 3/2001. Returning this station to the original Brušperk site in March 2001 and the change of triggering conditions of the monitoring network SP DPB was justified primarily by the necessity of a more reliable detection and monitoring of seismic events occurring in the area of Paskov and Stařič collieries.

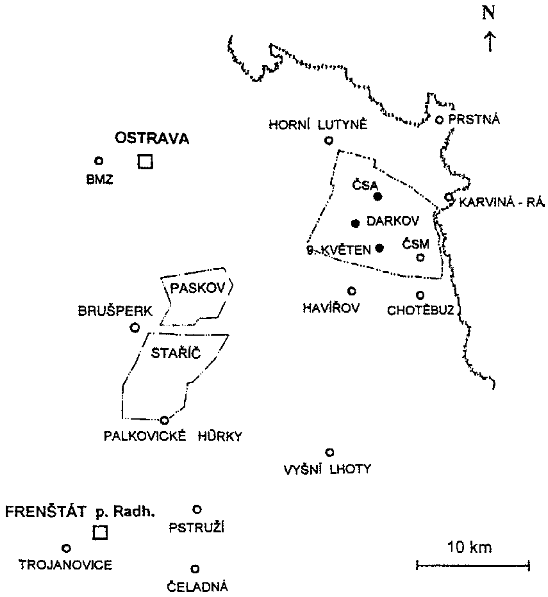

Fig. 1. Distribution of seismological stations within broader area of the Ostrava-Karviná coalfield (SP DPB) and in Frenštát area (SPF)., • - underground site, o – surface site.

In addition to the above-mentioned regional seismic monitoring systems, several seismic events originating in the area of Paskov and Stařič collieries were recorded simultaneously by broad-band seismographs at stations of the Czech national seismological network (CNSN), i.e. on the one hand, by the stations of Vranov near Brno (VRAC) and Moravský Beroun (MORC), operated by the Institute of Physics of the Earth of the Masaryk University in Brno (Skácelová, 1996), and on the other hand, by the Ostrava-Krásné Pole (OKC) station, whose operation has been supervised since 1994 by VŠB-Technical University of Ostrava, being methodologically managed by the Institute of Geonics AS CR in Ostrava since 1998 (Holub et al., 2000). Moreover, three seismic events (Nos 42, 43 and 44) were detected also by the seismological station Dobruška (DPC), and one (No 44) was recorded even by seismological stations Průhonice (PRU) and Kašperské Hory (KHC) (see Table 1). These seismological stations are operated by the Geophysical Institute AS CR in Prague.

The current distribution of stations of both parts of the regional seismological network is given in Fig. 1 together with the mine fields of Paskov and Stařič collieries. The OKC station is situated in an experimental gallery and its position is identical with any of the SP DPB stations, the designation of which is BMZ. The closest two stations of the CNSN, i.e. OKC and MORC, are located within an approximate distance range of about r ≈ 18 and 51 km, respectively.

Time series of seismic events

The first seismic event in the area under investigation was recorded at the SP DPB stations situated in the eastern part of OKR in February 1990. Since 1992, when the monitoring system in the broader area of Frenštát was put into operation, some seismic events have been recorded at these stations as well. Since March 1994 and June 1998, some of these mining-induced events (which originated within the region of interest) were also recorded by the seismological stations VRAC and MORC, respectively. Since early 2001 special attention was paid especially to mining induced seismic events from Paskov and Stařič mine fields in the interpreation of digital data of broad-band seismographs at the OKC station (Ostrava-Krásné Pole).

An overview of events recorded at seismological stations of both regional monitoring networks since February 1990 until June 2002 is represented by Table 1. The repeated increased number of seismic events localized by SP DPB since March 2001 (which is obvious in this table), was connected with the reopening of a seismological station at the Brušperk site. The data are characterized as follows: the origin time of event T_0 (UTC) and focus coordinates x, y in the rectangular system calculated during the location procedure; additionally also the seismic energy of a given event E (J) calculated on the basis of SP DPB data, is mentioned. In column remarks, other seismological observations at various CNSN stations, which have recorded the respective events, are also quoted.

As shown in Table 1 a total of 39 and 21 seismic events were recorded by SPF and SP DPB stations, respectively, 11 of which are considered to be common ones. The seismic events could be mostly evaluated as low energy ones (within the range of OKR energy scale mostly of 10^3 J order), none of which had the character of a rockburst accompanied by any destruction of workings.

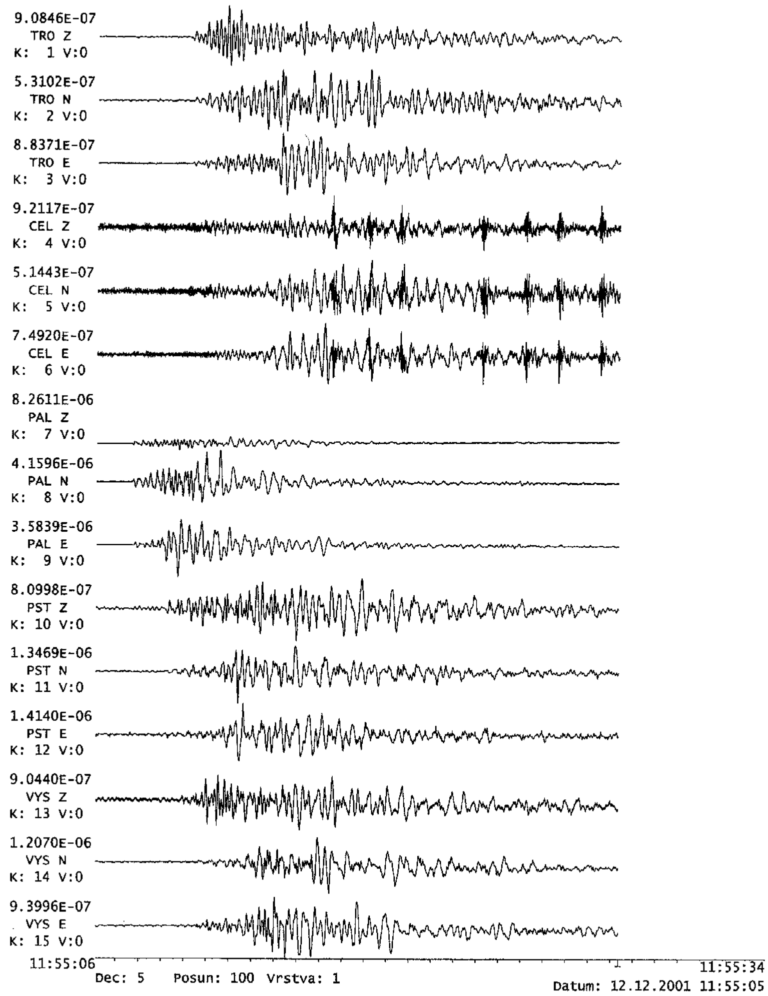

Fig. 2. Seismic event on December 12, 2002 recorded at stations of the network SPF,date 12.12.2001 on time 11:55:06.

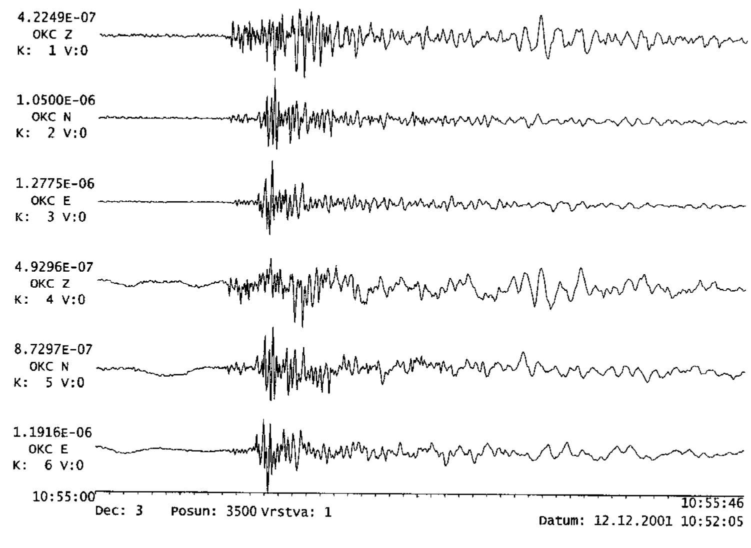

Fig. 3. Seismic event on December 12, 2002 recorded at station OKC. 1-3 short-period seismographs, 4-6 medium-period seismographs.

In Fig. 2 an example of seismograms of an induced seismic event, which was recorded on December 12, 2001 at SPF seismological stations, is represented. In Fig. 3 is the same seismic event recorded at the seismological station Ostrava-Krásné Pole (OKC).

Since January 2001, 11 events have been recorded at the OKC station where in all eleven cases both Pg and Sg waves have been interpreted, their time difference Δt being 2.1 – 3.4 s. In one case a very weak event was recorded which followed the event on January 5, 2001 within a pause of about 6s and which (except of the OKC station) was not detected by any other station and therefore it is not mentioned in Table 1.

According to bulletins of seismological stations VRAC and MORC prepared by the Institute of Physics of the Earth at the Masaryk University in Brno, the following facts were confirmed. During the period between February, 1991 and June, 2002, totaly 12 events were detected by the seismological station VRAC. In the first arrivals, mostly Pg waves were interpreted, while weak events displayed only the Sg wave group. In six cases, both Pg and Sg waves were interpreted and their time difference oscillated within the range of Δt = 14.3 – 16.5 s. On the contrary, the MORC station which has operated since October 1994 recorded in total 15 events. For 14 events the time difference Δt = 5.7 – 7.0 s was defined, and in the case of the event No.33, which was relatively weak, only Pg wave in the first onsets was interpreted.

Tab.1. Overview of events recorded by seismological stations of regional monitoring systems SPF and SP DPB as well as by stations of the Czech national seismological network.

No	Date	SPF			SP DPB				Remarks
		time (UTC)	x	Y	time (UTC)	x	y	energy (J)	
1	24.2.1990				02:18:40.270	1120.96	475.02	3.10e+03	
2	18.5.1992				00:16:29.950	1112.13	471.48	1.30e+03	
3	25.5.1992				00:52:16.910	1111.94	471.46	1.90e+03	
4	2.6.1992	08:55:17.260	1114.143	470.159	08:55:17.168	1114.62	470.21	1.60e+03	
5	3.6.1992	17:09:39.890	1114.713	470.218					
6	23.9.1992				04:15:55.260	1118.68	471.85	2.10e+02	
7	22.10.1992	18:02:19.540	1116.618	475.763	18:02:18.630	1118.76	473.93	1.20e+04	
8	13.1.1993	14:03:52.590	1116.790	473.289	14:03:52.210	1117.23	474.39	1.70e+03	
9	14.1.1993	18:41:44.760	1116.964	472.852	18:41:44.010	1117.78	473.72	6.40e+02	
10	26.9.1993				21:18:13.960	1112.79	470.16	2.60e+02	
11	22.3.1994	04:13:41.770	1117.786	473.676					VRAC
12	15.12.1994	19:42:28.600	1116.481	475.431	19:42:27.880	1117.51	475.96	5.15e+03	
13	16.12.1994	13:30:14.930	1115.114	474.900					
14	17.12.1994	04:49:44.650	1116.266	475.810					VRAC
15	19.12.1994	02:48:14.560	1116.061	475.381					VRAC
16	19.12.1994	14:02:36.190	1116.352	475.259					
17	20.12.1994	23:41:28.460	1114.598	471.268					
18	27.10.1995	14:41:03.790	1114.065	472.408					
19	23.8.1996	15:36:23.930	1116.667	475.928					
20	4.3.1997				02:53:10.040	1111.04	470.14	1.30e+03	
21	6.4.1998	14:49:21.370	1116.610	474.579					
22	26.6.1998	07:18:26.400	1117.733	473.933	07:18:25.300	1118.02	474.58	1.10e+04	MORC,VRAC
23	4.7.1999	13:11:10.890	1116.757	473.995					MORC
24	17.11.1999	22:13:21.630	1116.293	466.805	22:13:20.610	1111.26	468.00	2.55e+03	MORC,VRAC
25	9.3.2000	07:45:32.360	1116.085	470.758					
26	9.3.2000	12:33:00.970	1114.797	471.776					
27	10.3.2000	04:49:49.510	1114.183	469.805					
28	14.3.2000	03:40:52.830	1114.621	471.367					
29	29.8.2000	20:31:33.120	1116.453	474.812					MORC
30	15.9.2000				05:22:30.717	1118.56	471.71	9.94e+02	
31	9.10.2000	22:01:30.390	1118.154	475.729					
32	17.11.2000	16:01:43.330	1116.470	475.114					MORC,VRAC
33	22.11.2000	14:20:31.400	1116.754	475.728					MORC,VRAC
34	23.11.2000	14:10:00.800	1116.545	475.341					
35	5.1.2001	11:23:08.290	1116.036	475.675					MORC,OKC
36	23.1.2001	14:34:03.940	1116.535	475.146					MORC,OKC
37	7.2.2001	16:07:50.520	1117.549	473.646					MORC,OKC
38	9.3.2001				04:57:41.411	1116.68	471.08	4.02e+02	
39	5.4.2001	20:36:13.800	1116.255	473.837	20:36:12.689	1117.00	474.10	7.13e+03	MORC,OKC,VRAC
40	11.5.2001				06:33:59.498	1117.59	474.79	5.21e+03	
41	25.5.2001				07:20:32.160	1116.15	474.04	2.04e+03	
42	26.5.2001	14:40:55.920	1117.032	473.928	14:40:54.494	1117.44	474.84	1.17e+04	MORC,VRAC,OKC, DPC
43	31.8.2001	23:29:42.300	1115.715	473.891					MORC,OKC,DPC
44	12.12.2001	10:55:06.400	1117.026	474.801	10:55:05.074	1117.97	475.28	5.7e+03	MORC,OKC,VRAC, DPC,KHC,PRU
45	30.5.2002	17:54:07:81	1116.361	475.238					OKC
46	30.5.2002	19:28:53.600	1116.824	472.953	19:28:53.442	1116.76	474.32	1,7e+03	MORC,OKC,VRAC
47	19.6.2002	19:55:41.400	1117.483	473.309					OKC, MORC
48	20.6.2002	18:49:34.360	1116.226	473.981					OKC
49	27.6.2002	03:39:18.870	1117.342	473.237					

Location plots

The essential purpose of SP DPB array was to monitor induced seismic events within the eastern part of the Ostrava-Karviná Coal Basin. Oppositing to that the erection and operation of the SPF array since 1992 was aimed at the monitoring of expected induced seismicity due to a new mine operation which was sunk in the surrounding of Frenštát p. Radh.. Considering the mining damp-down during the last decade, sinking work and all mining activities at this locality were stopped and, therefore, any seismic induced event has not been observed.

From the point of view of both regional seismological networks, whith position a situated in geologically different background, coal fields of the mines Paskov and Staříč are situated southwest and north from SP DPB and SPF, respectively. Since the seismic rays propagate from the focal regions to particular seismological stations from different azimuths, the derived and used velocity models are somehow different (Knotek et al., 1990; Kaláb, 1992). Such differences of models (see Table 2) were subsequently reflected in the determination of the focus position using one and/or another seismological network data

Model 1 (SPF)

v_p (km/s)	h (km)
4.2	0.00
5.5	1.50
8.0	30.00
	9901
ratio v_P / v_s = 1.73	

Model 7 (SP DPB)

v_p (km /s)	h (km)	v_s (km/s)
2.518	0.00	1.948
3.285	0.195	2.183
4.194	0.355	2.244
4.300	0.905	2.354
5.008	1.374	2.811
5.780	2.500	3.710
6.105	6.840	3.835
8.000	30.00	4.620
	9901	

Tab. 2 Velocity-depth models implemented into the localization procedures at computer centres SPF and SP DPB Paskov.

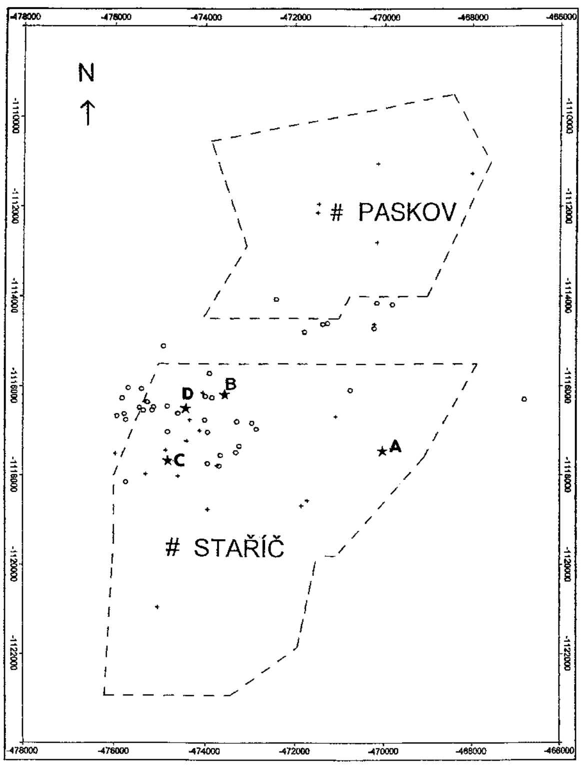

Fig. 4. Foci located separately by the SPF network (o)And /or by SP DPB (+), ★ probable focal regions A, B, C and D.

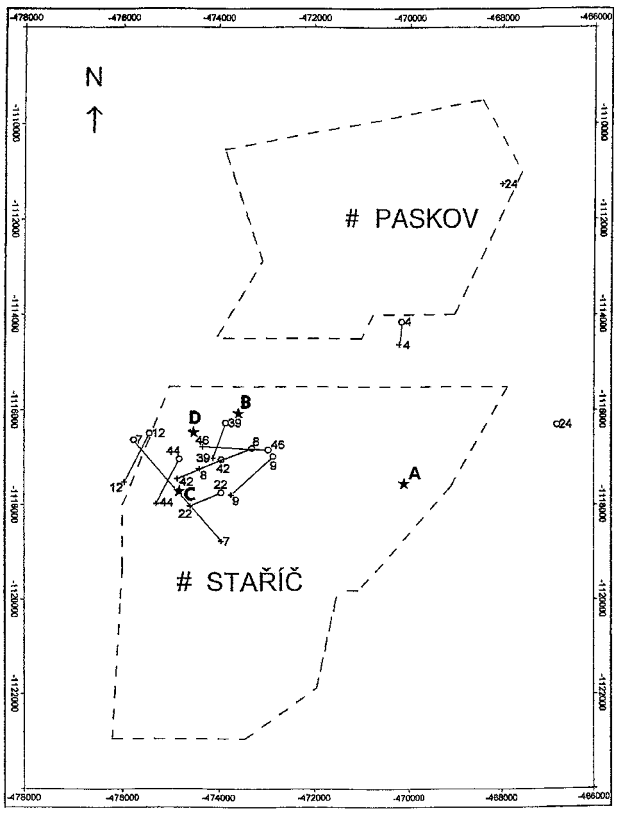

Fig. 5. Calculated focus positions of seismic events recorded simultaneously by both seismic monitoring networks. SPF (o) and SP DPB (+), ★ probable focal regions A, B, C and D.

In Fig. 4, foci of 49 seismic events located by both networks and four probable focal regions, i.e. A, B, C and D, connected with mining activity at Staříč colliery, are displayed. Some of events, either by SP DPB and/or by SPF networks, were recorded only. The eccentric position and different seismogeological conditions of these arrays with regard to the assumed position of focal regions result in an inaccuracy of the calculation of focus positions ampared with these in case of surrounding the respective focal region by a similar monitoring network with a comparable geology of the background. Table 2 represents the velocity-depth values for both models applied.

For a comparison of the differences in determining the focus positions, 11 seismic events recorded simultaneously by both seismic monitoring systems are depicted in Fig. 5. These foci are named as common seismic events with identical numbering and corresponding pairs linked up by straight lines. Mutual differences in distances of particular foci vary within the range of 0.5 – 2.8 km. Based on the focus positions determined by both networks, a mutual systematic shift of foci is obvious. Excluding the only event (No.46), all foci of common events calculated on the data of SP DPB network are shifted southwards from the foci determined according to the data of SPF network. The substantiation of discrepancy in the foci position of the event No. 24 of November 17, 1999 (Holub et al., 2002) was after the reinterpretation of records explained by an instantaneous drop-out of the time information at the SP DPB stations.

Tab.3. Testing of focus coordinates calculation using modified input data.

		SPF				SP DPB			
		model 1 (o)		model 7 (•)		model 7 (+)		model 1 (■)	
No	date	x	y	x	y	x	y	x	y
22	26.6.1998	1117.733	473.933	1116.819	474.948	1118.02	474.58	1114.557	473.053
39	5.4.2001	1116.255	473.837	1116.116	473.171	1117.00	474.10	1115.428	473.317
42	26.5.2001	1117.032	473.928	1116.817	472.990	1117.44	474.84	1115.497	473.812
44	12.12.2001	1117.026	474.801	1117.836	474.426	1117.97	475.28	1115.359	473.944
46	30.5.2002	1116.824	472.953	1117.305	472.672	1116.76	474.32	1115.559	473.651

To probable focal regions A, B, C and D then several induced seismic events recorded and located were adjoined. In the first case (focal region A) there were obviously four seismic events (Nos. 25, 26, 27 and 28) during March 2000, which occurred as a consequence of breaking-up of a small remnant pillar between the brake incline and finishing coalface No. 041525. In the second case (focal region B), the occurrence of the seismic event (No. 37) of February 7, 2001 was connected with the development of caving within longwall face No. 082621 in the Stařîč colliery. The seismic event (No. 44) on December 12, 2001 (focal region C) was connected with the development of caving in the region of longwall face No.145662 operation. The last series of seismic events (Nos. 45, 46, 47, 48 and 49) were probably caused also by breaking-up of a small remnant pillar left between the coalface No. 145673/1 and the gob of adjacent to the coalface No. 145660; the corresponding focal region was denoted as D.

As a part of the foci plot analysis, we tried also to repeat the localization procedure with modified input data. For this purpose, we used arrival times of seismic events Nos. 22, 39, 42, 44 and 46 observed at seismological stations of SPF and SP DPB as well. The trial calculation of focus coordinates was performed using thevelocity-depth model 1 (SPF) and model 7 (SP DPB), which are implemented into localization procedures in the respective computing centres. Table 3 represents the results of localization, i.e. foci coordinates for various modifications of input data. In Fig. 6, only the graphical form of the essential variant of localization is given, i.e. arrival times of these five events recorded at stations of SPF and SP DPB are applied for the calculation using both models.

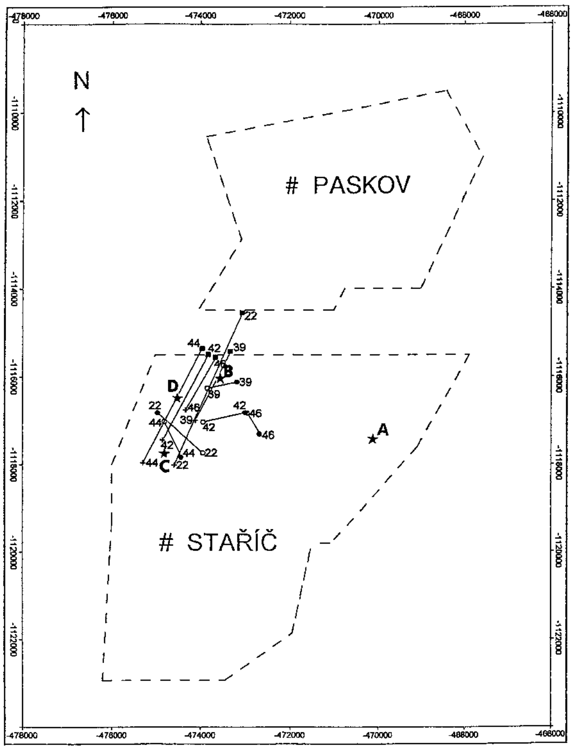

Fig. 6 Results of calculation of five focus positions using modified input data. SPF o model No. 1, • model No. 7; SP DPB + model No. 7 and ■ model No. 1, ★ probable focal regions A, B, C and D.

If we compare average value of distances between individual pairs of determined foci, the minimum average value corresponds to the variant - arrival times at SPF calculated with both velocity models, i.e. approx. 890 m, while for the variant - arrival times at SPF + model 1 and arrival times of SP DPB +, model 7 displays the average value approx. 985 m. This situation which is the essential basis of this paper, is depicted in Fig. 5.

For any other variant the average distance exceeds the value of about 1400 m up to 2400 m, which is the worst result of calculation using arrival times at SP DPB + model 1 and model 7. However, it is interesting that all foci (■) are situated in northortheastern direction from foci denoted as (+) and all connecting straight lines are almost parallel having the azimuth between 25^o-31^o, as seen in Fig. 6.

In order to ensure more reliable detection possibilities of the SP DPB, the seismic station from ČSM colliery was moved back to the previous site near Brušperk and changing of triggering conditions of the monitoring system. This decision has been approved by the increase of detected events by SP DPB since March 2001.

Conclusions

In the present paper it was demonstrated that induced seismic events within the area of Paskov and Staříč collieries could be detected not only by the seismological stations of regional seismological monitoring systems of SP DPB and SPF but also by the stations of the Czech national seismological network (CNSN), i.e. stations OKC, MORC, VRAC, DPC, PRU and KHC. With the application of data of regional networks, a location procedure of events was performed and (in several cases) it was possible to assess a mutual linking-up between the mining activity and the nucleation of such events. But such cases were very rare because seismic events which occurred during mining were relatively weak and did not cause any serious effects underground. Eccentricity of both regional networks in relation to the assumed focal region as well as models applied in location procedures affected the accuracy of the location which at mutual confrontation indicated certain differences. A maximum distance difference $r \approx 2.8$ for the event No. 7 of October 22, 1992 was observed. In the case of event No. 24 which occurred on November 17, 1999, the foci difference was calculated $r \approx 5.2$ km. However, according to the reinterpretation of recordings, time information in SP DPB data was adjoined due to a drop-out of timing. Therefore, the result of computations is incorrect. This is why a relatively great difference between the foci computed on the basis of data of both regional monitoring systems in Fig. 5 is given.

The transfer of the station from the mine ČSM to its original site at Brušperk site was proved as justified by the need for a more reliable detection of seismic events inside the area of Paskov and Staříč collieries.

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