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CONVERGENCE MEASUREMENT ON THE MINE MAYRAU

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ABSTRACT. The submitted article contains measurement results of the convergence of mine openings on the mine Mayrau (Kladno coal district), carried out in connection with the research of induced seismic phenomena. Potentiometric distance sensors were used for the measurements and the measured data were recorded on a surface PC. Two measurement sites were used to check the convergence rate and value and namely their affecting by induced seismic events, recorded by the local seismic network. A very pronounced effect of significant seismic phenomena, on the course of convergence, could be established. However, the convergence measurement results did not have any prognostic character, because they were affected always simultaneously with the occurrence of a seismic event. However, these measurements enable the correctness of the determination of location of induced seismic event foci to be confirmed or, eventually, they may draw the attention to eventual errors in their location.

KEYWORDS: measurement, convergence, deformation, induced seismic event, focus, coal mine

When investigating the properties and behaviour of a rock massif affected by mining activities, several experimental methods are used in the area of geotechnics. One of them, which might contribute to the knowledge of rock mass properties and could eventually predict its behaviour, is the observation of convergence. This is usually measured as the relative displacement of two observed points in the direction of their momentary connecting line. The size and the time behaviour of convergence are closely connected with the stress–strain condition of the rock massif or its parts, resp., and constitute an important criterion for the evaluation of the effect of mining activities.

The submitted contribution deals with first results and information obtained from the evaluation of more than 5 months' convergence measurement on the Mayrau mine in the Kladno coal district. Measurements were carried out there as a part of a complex of methods within the grant of GA CzR No. 105/96/1065 "Mining induced seismic events".

Measurement of convergence was primarily aimed at the study of effects of sudden stress changes within the rock massif, on the deformation size and rate, namely in relation to induced seismic events, which occur at the Mayrau mine and have been recorded there by the local seismic network installed in this mine.

1. Method of Measurements

The method of convergence measurements of mine openings, by IRSM, has had a long tradition, including measurements at the location of the Mayrau mine (Roček et al., 1973; Roček et al., 1974; Roček and Skála, 1978). However, in all hitherto realized measurements, mechanical unit–built convergometers of the KR series or electromagnetic convergometers KRE with remote data recording, developed and in the past also manufactured in IRSM, have been used (Roček and Pulchart, 1985). Measurement outputs from both instrument types yielded records (curves) of deformation changes on a recording paper band. Such a record had a characteristic saw–tooth character, due to regular zero setting of the recorder within a selected time interval. Thus, the measurement range could be enlarged with maintaining the sensitivity and the given width of the record paper. It was necessary, for further computer processing of the measured data, to form a cumulative curve from this record and transform it into a digital form.

For these reasons, a new convergence measurement method by means of potentiometric distance sensors with data transfer directly to a PC, situated on the surface, has been tested. Potentiometric distance sensors Megatron RC 130 (Germany) (Fig. 1), with constant current supply, have been used.

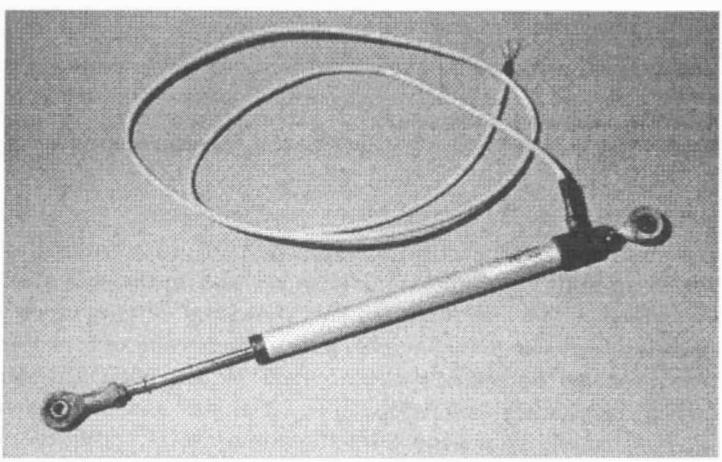


Fig. 1. Potentiometric distance sensor RC 130 (Megatron)

Sensors were incorporated directly between bars (rods) of the measurement base, anchored between the end points, in the mine opening's profile. The signal was transferred by cables into the seismic station on the surface, where data were accumulated (across a converter) in a PC. Data collection program GEMON, created in IRSM by B. Růžek was used for recording into a data set. The time dependence of the deformation was observed by continuous recording of convergence with the interval of 1/2 h (interval of computer disc records). The precision of the mentioned measurement and recording method was 0.01 mm and values were recorded directly in mm.

2. Measurement Site and Time

As already mentioned above, convergence measurements were carried out in the coal mine Mayrau of the Kladno coal district, where – during the year 1997 – only residual reserves, contained in the protective shaft pillar, were drawn. The mining object was here, like in other parts of this deposit, the Main Kladno Seam with the average thickness of 8.6 m. The mining and all other activities in 1997 took place only at the 10^{th} level of the mine, at the depth of 490 to 540 m below surface. A more detailed description of geological conditions and mine situation is described by the author in (Živor, 1994; Živor et al., 1995).

All mining activities in the shaft pillar of the Mayrau mine ended by 30.6.1997 and only liquidation works continued after this date, which culminated in the fall 1997 by the total liquidation and closing of the mine. Continuous convergence measurements were carried out during the period from February 18 to July 31, 1997 and covered thus the last period of mining activities in this mine. Measurements in July recorded the development of convergence, which was no longer affected by the proper coal mining. It's a pity that this period had to be terminated prematurely due to the destruction of convergence measuring stations during the mine liquidation.

For convergence measurements, two stations – S1 and S2 – whose mutual distance was 208 m, were established in the shaft pillar. Due to the fact that the main stress orientation within the rock massif, which would enable the precise bearing of the measuring system to be carried out, was not known, the main convergence measurement were orientated in vertical direction. This choice of orientation was supported by the assumption of the mostly vertical strain function considering the depth of stations below surface and practical experience with the concentration of foci of induced seismic events mainly to overlying layer between elevations of 200 and −100 m above sea level.

The station S1 was established in a no more used small niche (stable hole) and a blind cross cut "Západní lanovka", 110 m NW from the Mayrau shaft. This station was situated at the elevation of −167 m a.s.l., i.e. about 520 m below surface. Measurements were realized in vertical direction and the length of the measurement base was 1.3 m. The upper end point of the base was anchored deeper into the rock mass of the niche's roof, the lower one in a massive concrete block in the footwall. The access gateway and the stable hole (niche) itself were reinforced by the steel–arch support with wooden casings. As to the geological conditions, the station was situated in the basal part of coarse–grained sandstones in the hanging wall of the Main Kladno Seam, above the position of the claystone (so–called "mydlák" – soapstone).

The station S2 was situated at 90 m NE from the Robert shaft, at the crossing of the entry Ch3111 with the drift Ch3118. It was located directly in the Main Kladno Seam at the elevation of −174 m a.s.l., i.e. 527 m below surface. The convergence measurement at this station was carried out in two directions, the vertical and horizontal ones. The vertical sensor was installed directly into the profile of the Ch3111 drift and the length of its measurement base was 2.0 m. The horizontal

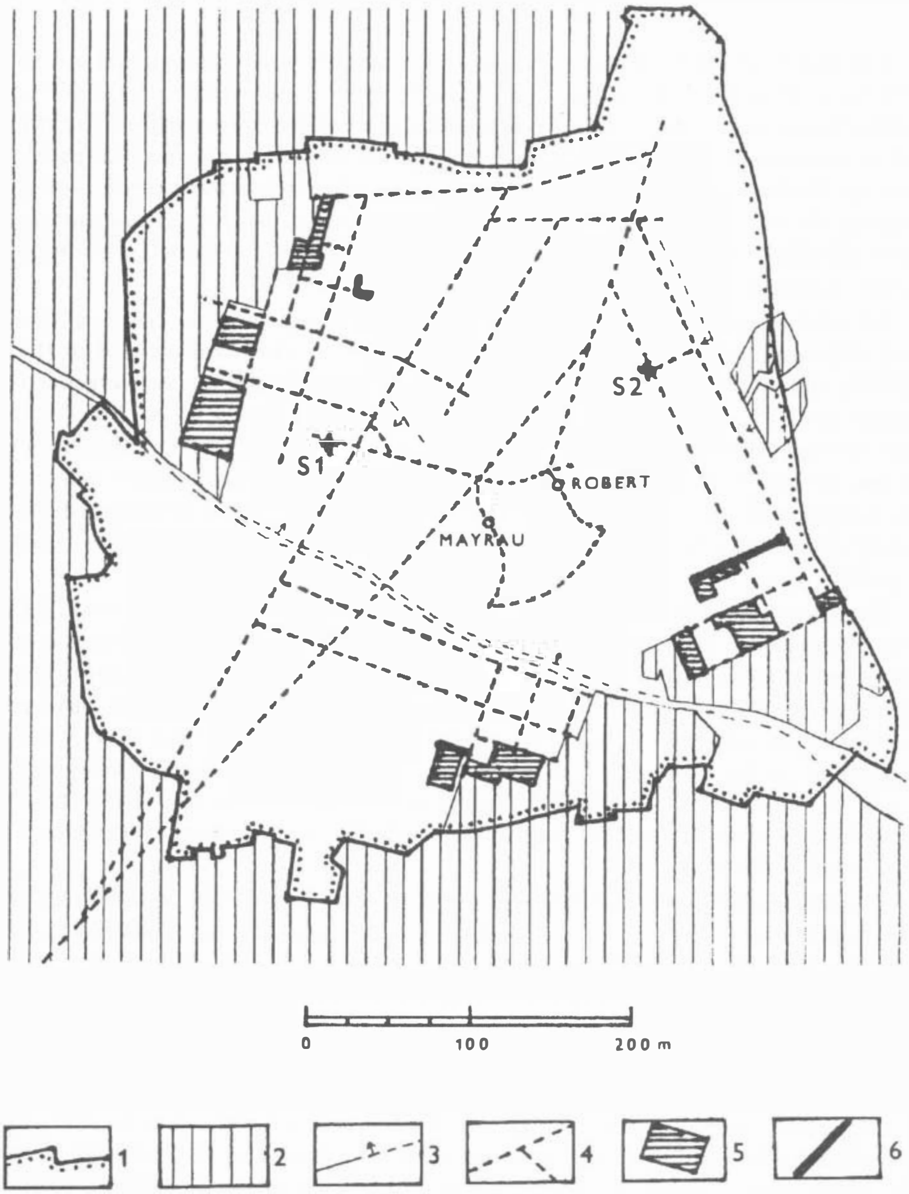


FIG. 2. Mining situation within the shaft pillar of the Mayrau mine
1 – original limits of the shaft pillar, 2 – extracted parts of the mine space, 3 – faults, 4 – accessible mine entries, 5 – coal getting during measurements, 6 – entry drifting during measurements

sensor had the base length of 3.3 m and was installed in a small niche at the crosscut of the mentioned entries. Both end points of the horizontal measurement base and the upper end point of the vertical base were attached to the support at the working face, the lower part of the vertical base was fastened to a steel anchor driven–in deep in the footwall. This drift too, together with the niche, was reinforced with steel–arch support with wooden casings.

The choice of measurement sites was considerably affected by mine–operation conditions and possibilities and thus did not agree with ideal conditions according to research requirements and conceptions. However, this reality has to be taken in account during in–site research at mine operation conditions.

The mining situation in the shaft pillar and the location of convergence measuring stations is reviewed schematically by the mine map (Fig. 2), where all accessible mine entries and the extracted parts of the mine space are illustrated. Specially set off (in the map) are parts of the shaft pillar mined during the convergence measurements and the sections of entries drifted during the same time period.

3. Mining Activities during Measurements

It is evident, from Fig. 2, that all mining activities during the convergence measurement period were concentrated to three mutually remote areas of the shaft pillar.

The first one is the NW part of the shaft pillar, formed by three independent mining blocks at the distance of 80 – 130 m from the convergence measuring station S1. In addition to that, two short entry sections were drifted in the area in February, 90 – 100 m off the S1 station.

The second area is found in SE part of the shaft pillar, 130 – 170 m off the convergence measuring station S2. It includes 4 partial mining blocks and an opening drift driven in months February through May.

The third area is constituted by practically continuous mining blocks and an opening drift in the southern part of the pillar. Owing to the location behind an important tectonic fault and to considerable distance from both convergence measuring stations (210 – 230 m from S1, and 250 – 280 m from S2), a significant effect of this area on the course of convergence is not assumed.

Tab. 1 reviews the coal extraction volume (expressed in the worked–out surface area) and drifting of entries within the shaft pillar in individual months. It includes both the total size of worked–out areas and drifted entries within the entire pillar, and the partial values of extraction and drifting from mentioned areas in the neighbourhood of stations S1 and S2 and from the southern part of the shaft pillar.

4. Results of Convergence Measurements

The main scope of convergence measurements was, above all, the observation of changes of the magnitude and rate of deformation. The total convergence for the entire measurement time, i.e. from 18.2. to 31.7.1997, amounted to 69.5 mm at the station S1. The vertical convergence at the S2 station, for the same time

TAB. 1. Volume of extraction and drifting of entries within the shaft pillar of the Mayrau mine

	Total		Area S1		Area S2		Southern pillar part	
	extracted area [m²]	entry drifting [m]	extracted area [m²]	entry drifting [m]	extracted area [m²]	entry drifting [m]	extracted area [m²]	entry drifting [m]
February	547	39	285	19	179	17	83	3
March	677	40	336	0	230	23	111	17
April	472	0	232	0	46	0	194	0
May	508	18	203	0	99	18	206	0
June	769	0	232	0	235	0	302	0
July	0	0	0	0	0	0	0	0

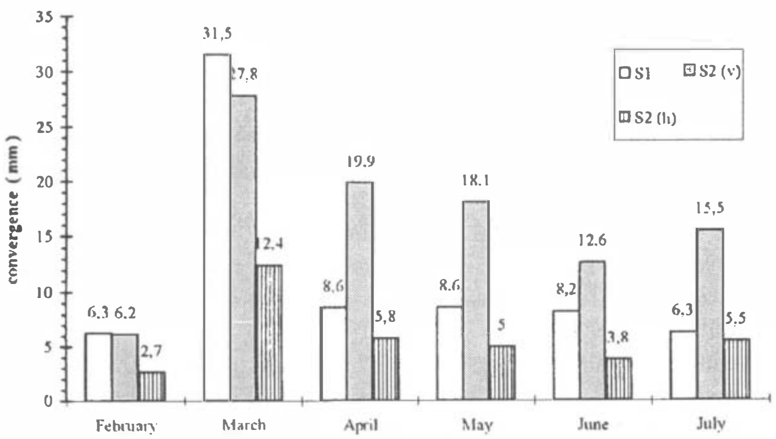


FIG. 3. Monthly values of convergence

period, amounted to 100.1 mm and the horizontal one to 35.2 mm. Values of the total convergence for individual months are illustrated in Fig. 3.

An important criterion for the evaluation of the deformation of the rock massif due to the mining operations is the convergence rate of rock layers, which can be defined as the ratio between the increment (drop) of convergence $\triangle c$ and the number of time units t, during which the increment (drop) took place (Roček, 1973):

$$v = \frac{\triangle c}{t} .$$

Average values of the convergence rate (in mm/day), computed from the total course of convergence, are graphically illustrated in Fig. 4.

To the illustrated total values of convergence size and rate contribute, of course, all factors affecting the course of deformation:

– rheological behaviour of the rock massif

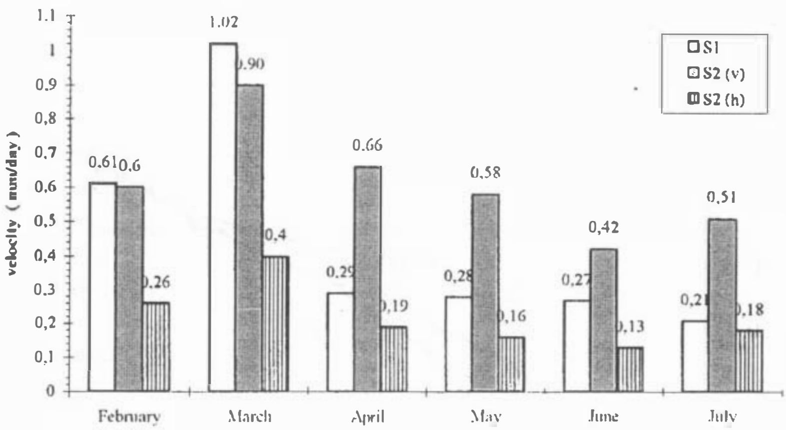


FIG. 4. Total average convergence rates

- advance rate of mining works
- stress rearrangements due to induced seismic phenomena.

The convergence behaviour during individual months is illustrated in Figs. 5 to 10, showing convergence results for individual months February through July 1997 from stations S1 and S2. The figures illustrate well the significant effect, on convergence, of several induced seismic events, whose occurrence is graphically marked by short vertical lines above the time axis. The solid line marks all seismic events with the magnitude exceeding 1.5, occurring within the horizontal distance lower than 100 m from one of the convergence measuring stations S1 or S2. The broken line marks all seismic events with magnitude lower than 1.5, which, however, affected significantly the course of convergence due to their short distance from one of the S1 or S2 stations. A more detailed analysis of induced seismic events and their effects is quoted below.

After subtraction of the effect of identified seismic events illustrated in Figs. 5 through 10, which affected significantly the course of convergence, an idea can be figured of the convergence rate for periods between the occurrence of such events – see Fig. 11. Convergence rates were established as mean values of the daily convergences excluding the periods of occurrence of induced seismic events in the neighbourhood.

The illustrated convergence rates include the effect of the rheological behaviour of the rock massif and the effect of advancing mining works. The effect of a large quantity of weak induced seismic events, which are unable to be individually distinguished in convergence records and which appear summarily by a gentle increase of the deformation value, cannot, of course, be eliminated.

The effect of the rheology of the rock massif on the course of convergence was studied, in the past, in a mine, where induced seismic events and rock bursts did not occur. In cases, where the convergence measurements are realized at a site without any mining activity, the acting stress can be considered constant and the form of

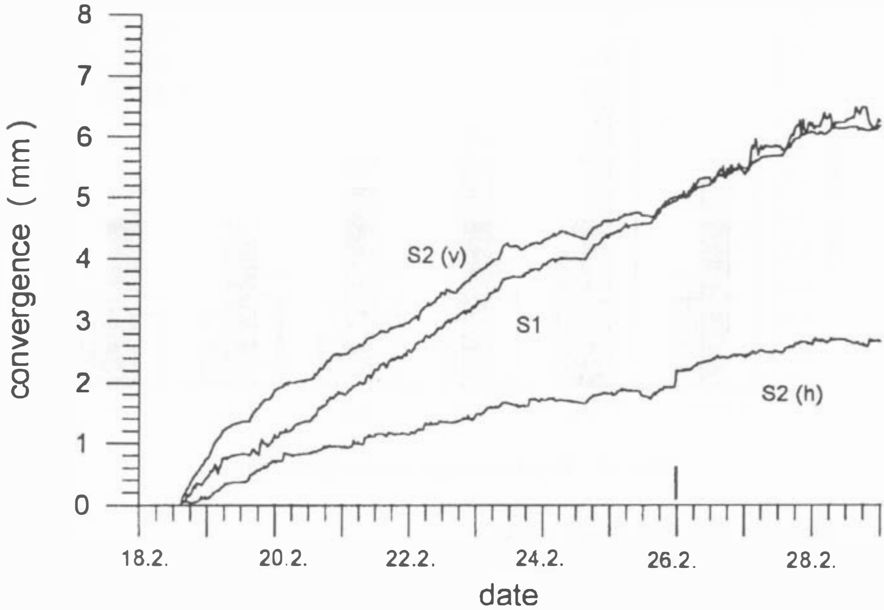


FIG. 5. The course of convergence in February 1997

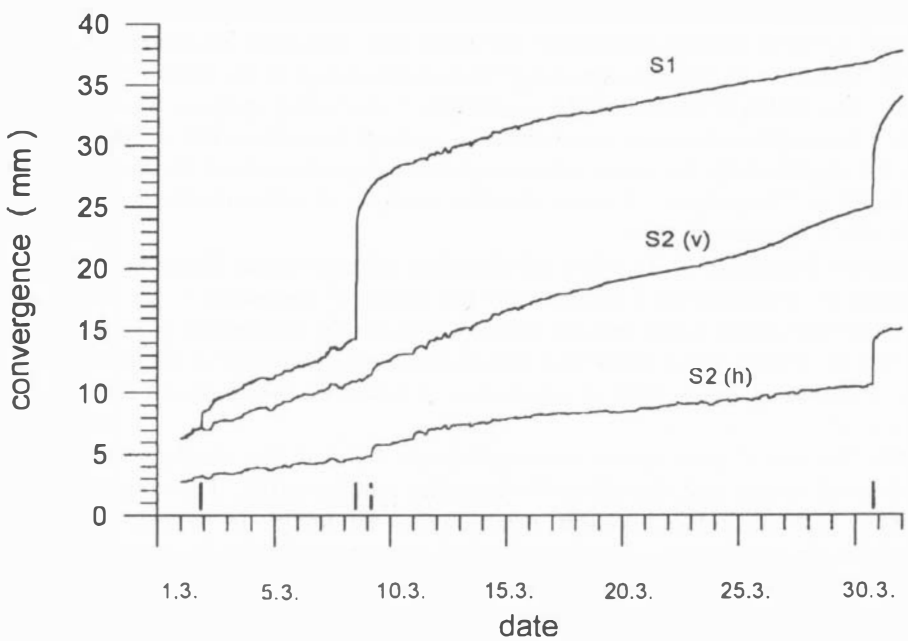


FIG. 6. The course of convergence in March 1997

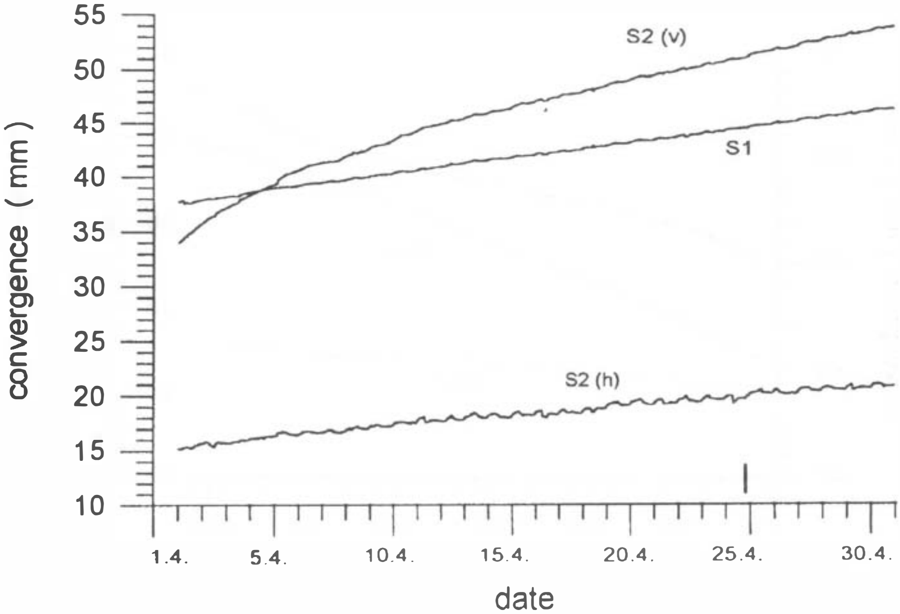


FIG. 7. The course of convergence in April 1997

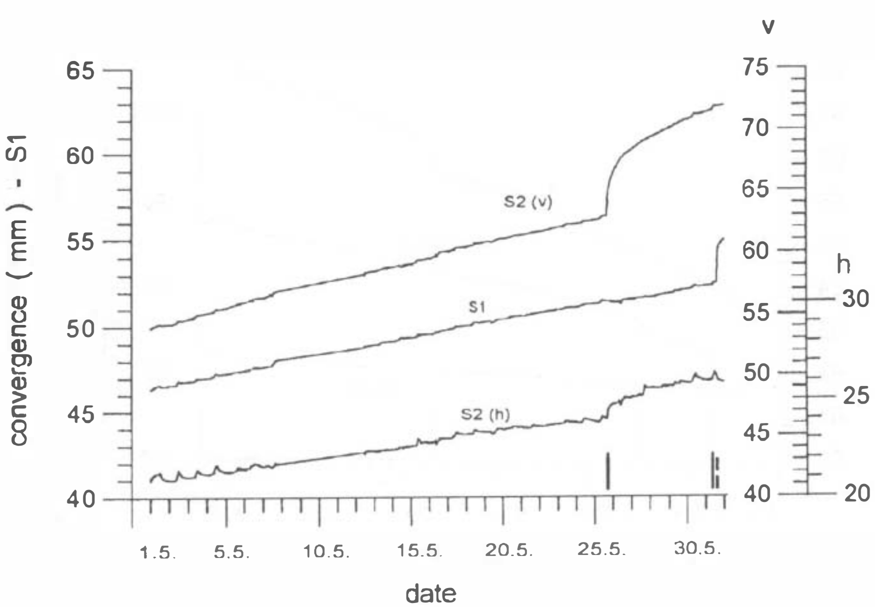


FIG. 8. The course of convergence in May 1997

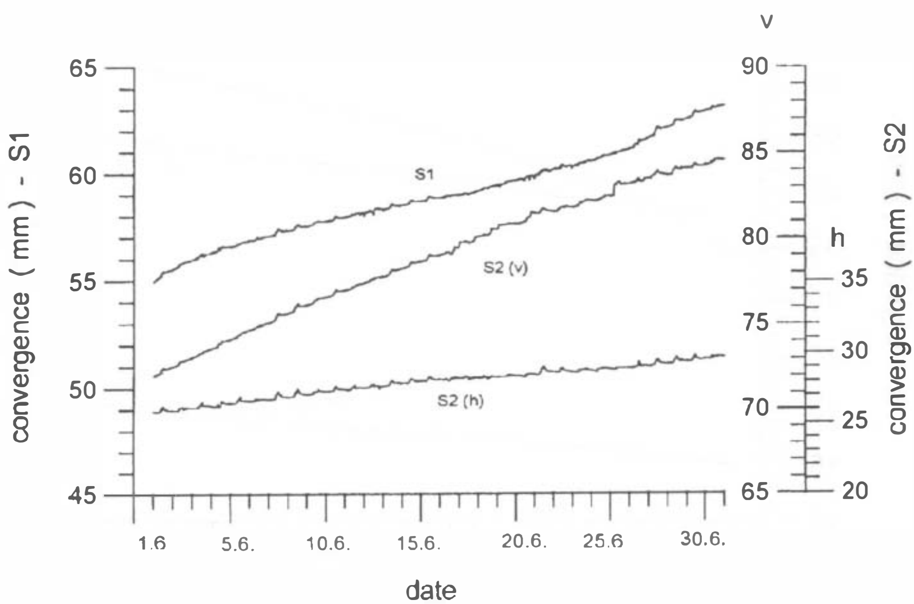


FIG. 9. The course of convergence in June 1997

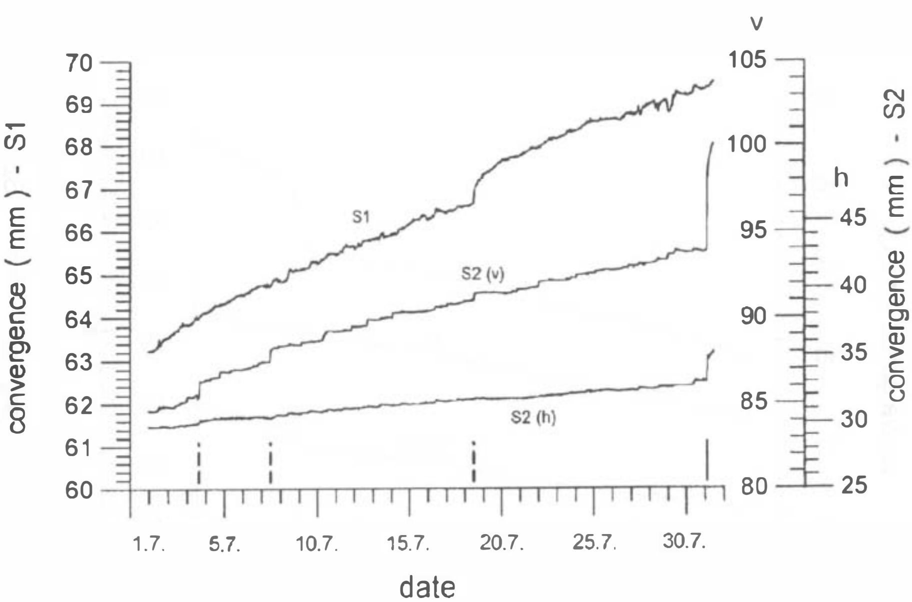


FIG. 10. The course of convergence in July 1997

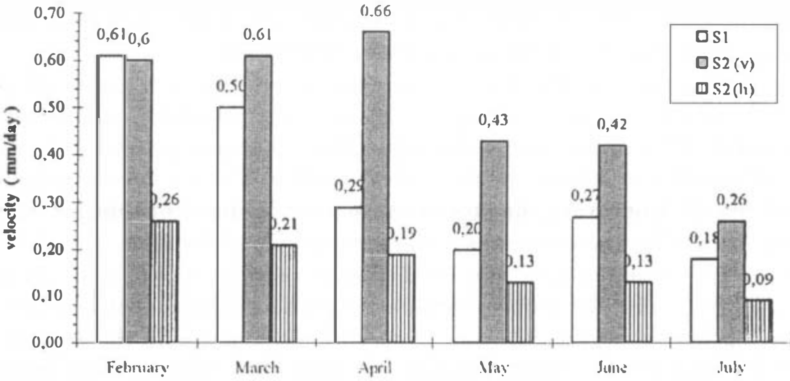


FIG. 11. Average convergence rates without effects of induced seismic events

the deformation (stress–strain) curve corresponds to the rheological model for an elastic–viscous (Kelvin's) substance (Skořepová and Roček, 1980). This condition is mostly approached by convergence rate values for the month of July, where the measurement stations were no longer affected by mining activities. However, neither in this case, the partial (above mentioned) effect of a quantity of weaker seismic events, whose number was already considerably reduced, though, can be excluded. The difference of values of vertical convergence rates at stations S1 and S2 should be attributed to the differing rheological behaviour of the rock massif as affected by the different geological environment of the location of stations.

A more important effect, on the course of convergence, has the advance of mining works, which is the higher, the shorter is the distance of these works from the measurement site. It has been established, during precedent research in the region of Kladno mines, that the magnitude of convergence and the frequency activity of seismic events are much more affected by the drifting of opening entries in the neighbourhood than by the intensity of the proper mining works (Roček and Skála, 1978). This relationship agrees, according to authors, with the primary stress state of the massif, which is close to the ultimate strength of rocks. When driving the mine entries, the loosened zone is not yet formed in the close neighbourhood of the opening, unlike the stopes, where larger exposed faces are formed by rock breaking with slower advance, so that a loosened vault, which reduces the effects of seismic events, has time enough to be formed. In the case of the discussed measurements in the shaft pillar of the Mayrau mine, the effect of mining works will probably be very small, due to relatively long distance of these works from measurement stations. When measuring the convergence on the non–bursting mine Nejedlý 2, the effect of mining works on the course of deformation could not be detected but after the approach of mining face to less than 80 m (Roček and Skořepová, 1979). This assumption is also confirmed by the fact that a direct relationship between the convergence rates from Fig. 11 and volumes of extraction works, quoted in

Tab. 1, could not be established unambiguously. Relatively high convergence rates, recorded in April, are probably still a consequence of an anomalous quantity of induced seismic events during the month of March, 1997.

When evaluating results of the convergence measurements, great attention was paid to the effect of induced seismic events as to the possibility of their prediction. The research of the deformation changes of mine openings proved that, within the period of significant seismic events, which result in a stress rearrangement within the rock massif, important changes of convergence of mine openings take place.

Data concerning the occurrence time, intensity and location of foci of induced seismic events obtained from the local seismic network of the mine Mayrau, are taken as objective for the scope of evaluation of their effect on convergence. During the convergence measurements, i.e. from 18.2. to 31.7. 1997, the seismic network recorded, within the Mayrau shaft pillar, altogether 382 induced seismic events. Out of this quantity, 45 % were very weak, with magnitudes < 0.5. Only 53 events had magnitudes exceeding 1.0, including 12 of them stronger than 1.5. The histogram of the sum of magnitudes of 210 induced seismic events with M exceeding 0.5 is illustrated, for individual months, in Fig. 12. Unlike the convergence, there is an evident interdependence between the occurrence of seismic events with the progress of mining works, namely with the volume of drifting of the opening entries, which agrees well with the above quoted dependence.

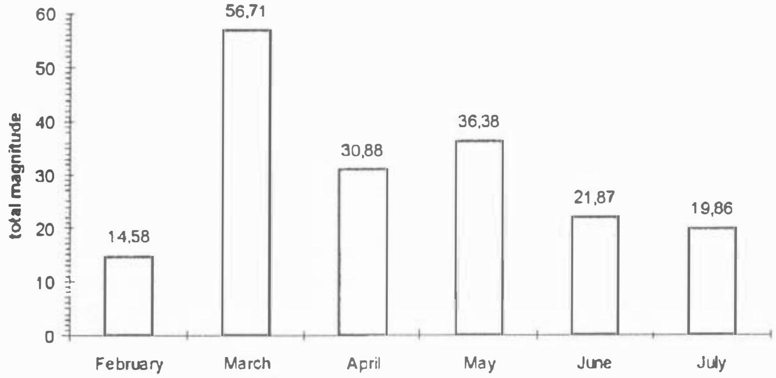


FIG. 12. Total sums of magnitudes of induced seismic events with $M > 0.5$

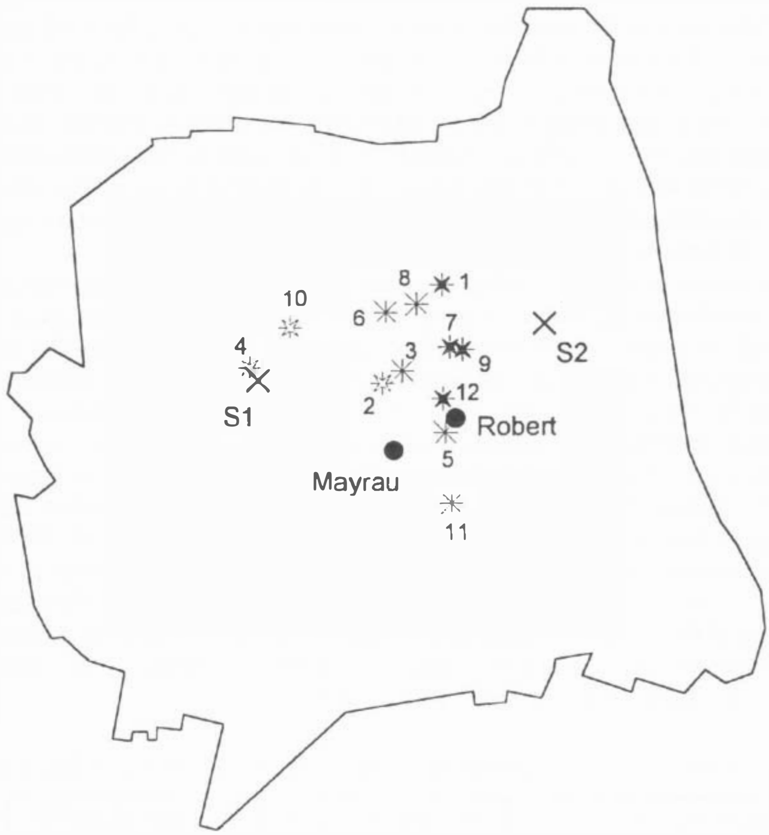
5. Discussion of Results

As it is evident already from Figs. 5 to 10, among the total number of 210 seismic events with magnitude exceeding 0.5, the convergence measurements recorded only 12 of them, which manifested themselves by a strong increase of the convergence rate. Among these 12 recorded induced seismic events two of them were doubled, because within the chosen half–hour recording interval of convergence data two seismic events occurred, which shared their effect on the course of convergence. Out of the total of 14 recorded events, 7 were reliably recorded with magnitudes exceeding 1.5 and in remaining 7 cases they concerned weaker events, whose effect on the course of convergence is sometimes not unambiguous. In addition to this number, there exist many smaller partial anomalies, which correlate in time with the occurrence of some seismic events though, but cannot be reliably differentiated because their values do not exceed the disturbing background noise affecting the course of convergence curves, which is probably affected by the electric signal noise during the data transmission from the mine to its surface.

None of the recorded 14 seismic events (including the strongest ones) has been sensed simultaneously on both measuring stations S1 and S2, but just at one of them. The fact that – according to the established coordinates – the foci of recorded events coincide with the neighbourhood of the station, which recorded this event, confirms the relatively correct location procedure of foci. As the distance of stations was 208 m, it means that convergence measurements cannot cover seismic events, whose foci are at a horizontal distance of more than 100 m from the measurement site. This information agrees exactly with the value quoted by other authors and established during preceding measurements (Roček and Skořepová, 1982). This is clearly documented also by Tab. 2, which reviews all 12 induced seismic events with magnitudes exceeding 1.5. This table quotes also horizontal and absolute (spatial) distances of foci of these events from both convergence measuring stations S1 and S2, and the station is mentioned, which recorded the seismic event. The layout of these events is illustrated graphically in Fig. 13.

TAB. 2. Review of induced seismic events with M exceeding 1.5

induced seismic event				distance from S1 [m]		distance from S2 [m]		registered by station
No.	date	time	M	hori-zontal	abso-lute	hori-zontal	abso-lute	
1	25.2.1997	23:47:23	1,62	148	274	78	250	S2
2	1.3.1997	21:23:49	1,86	89	340	123	357	S1
3	4.3.1997	18:30:20	1,65	103	278	107	286	—
4	8.3.1997	12:35:27	2,07	11	202	212	298	S1
5	24.3.1997	22:14:33	1,79	139	341	105	335	—
6	26.3.1997	3:32:02	1,65	103	255	113	265	—
7	30.3.1997	18:58:48	1,78	139	323	69	307	S2
8	24.4.1997	20:47:25	1,84	126	336	92	352	—
9	25.5.1997	17:55:33	1,67	148	302	61	278	S2
10	31.5.1997	9:46:28	1,91	44	325	181	376	S1
11	25.6.1997	5:32:46	1,66	164	290	145	286	—
12	31.7.1997	3:54:11	1,54	133	262	90	250	S2



Foci of mining tremors with M >1.5 :

- registered on convergence station S1
- registered on convergence station S2
- nonregistered on any convergence stations

FIG. 13. Layout of foci of induced seismic events with M exceeding 1.5

The table shows that the convergence measurements recorded practically all induced seismic events with M exceeding 1.5, whose horizontal distance from the measuring station does not exceed the mentioned 100m. An exception in this respect is the seismic event from 24.4.1997, which was not recorded and whose focus is situated closely below that limit. In the case of weaker events with magnitudes below 1.5 is the situation more complicated, because – in addition to the considered recorded seismic events – there occur several nearer and stronger events, which did not affect the course of convergence. These circumstance can suggest either a non–unambiguous interpretation of convergence data in relation to seismic events (if the seismic data would be considered fully objective) or they can point to eventual mistakes in the location of the focus or the assessment of magnitude.

When estimating the effect of the absolute distance of a seismic event focus from the convergence measuring station on the course of deformation, it results from Tab. 2, that this factor is not as limiting as in the case of the horizontal distance. Some events from this group did not affect the deformation course at all, although their absolute distance to the measurement site was shorter than for some other recorded seismic events. Thus, the position above the measurement site is, for the behaviour of convergence, much more important than the absolute distance of the focus from the measurement site. This circumstance is connected with the vertical measurement orientation of the main convergence. At a relatively small absolute distance, but a long horizontal distance, the main deformation (strain) acts in another direction than is the setting of the measurement system.

In evaluating the results of convergence measurements, special attention has been paid to the detailed analysis of the time dependence of deformations on seismic events. The following three cases can be found in this connection (Skořepová and Roček, 1980):

a) The convergence curve does not exhibit any perceptible changes, which means that the seismic event did not affect significantly the deformation at the measurement site. Such a condition was encountered most frequently and can be caused by some of the already mentioned reasons:

- the distance of focus is such that it does not affect the deformation state at the measurement site,
- the energy of the induced seismic event is very small,
- the geological structure of the environment prevents the deformation changes to be shown at the measurement site,
- the deformation acts in another direction than that to which is set the measurement system.

b) The significant deformation change occurs simultaneously with the inception of an induced seismic event or as its consequence with a certain delay. Such a situation was met in 13 cases out of the 14 recorded seismic events. A strong deformation increase was observed immediately during the half–hour interval of data recording (where the seismic event occurred), latest within a few minutes. An interesting deformation development is shown in the course of seismic activities on 31.5.1997. Simultaneously with a strong seismic event ($M = 1.91$), the convergence rate increased from 0.01 mm/h to 0.1 mm/h. A very strong increase upto 1.8 mm/h took place simultaneously with the occurrence of a double of seismic event at 15:07 h ($M = 1.02$ and 0.85), the focus of the weaker one being located very close to the measurement station S1. The horizontal distance amounted only to 6 m with absolute distance of 115 m.

c) Significant deformation changes occur already before the induced seismic event with a time advance of even several hours. Such cases occur either in consequence of stress increase in proximity of the measurement site or of a very high stress increase in more distant areas. This group of the time behaviour is most interesting, because these are cases, where convergence measurements could be used for prognostical purposes or, at least, for rendering the prognostical elements more precise in combination with further rockburst prediction methods. However, prognostical information obtained by convergence measurements in the past, could not prove positive in this respect. The only case, when a perceptible change of the course of convergence occurred already before the inception of the induced seismic event, was shown by measurement results of a seismic activity on 1.3.1997. The average convergence rate increased, 2.5 hours before the occurrence of the seismic event, from 0.01 mm/h to 0.13 mm/h and later, simultaneously with this event, rose strongly to 1.2 mm/h.

Within the measurement of the vertical and horizontal convergence at the station S2, an evaluation has been carried out of the promising information on the prediction possibility of induced seismic events from the mutual ratio of horizontal to vertical deformation. Some earlier measurements suggested that in the time period preceding a seismic event, the deformation ratio H/V decreases significantly (increased vertical deformation), while after a rockburst (bump), this value increases several times for the benefit of the horizontal deformation (Roček and Skořepová, 1979). However, this prognostical character couldn't be confirmed, not even by new measurements. Admittedly, during measurements the horizontal/vertical deformation ratio varied, but it differed from each other and, due to the number of recorded events, it was impossible to draw, from these data, some generally valid prognostical conclusions. More important changes of the H/V ratio, quoted in (Roček and Skořepová, 1979) were not established during these convergence measurements.

6. Conclusions

The measurement of convergence by means of potentiometric distance sensors proved successful at the Mayrau mine and brought new information and experience. It turned out that this measurement method is applicable and it in many respects exceeds the convergence measurement methods by mechanical or electromechanical devices used by IRSM in the past. A great advantage is, above all, the continuous recording of deformation changes within the arbitrarily chosen time interval directly on the computer disc, which enables the immediate processing of measured data by a graphic or tabular editor to be carried out. The method is adequate and fully functional pro classic convergence measurements.

Like the first application of every new method, also the described measurement method showed some weak points and imperfections, which will have to be removed in further applications. They all result from the electrical data transmission, susceptible to inducement. Among them, the probable data distortion in mine's cable lines, drawbacks of the software GEMON, which did not enable data recording on computer disc, and introduction of disturbing anomalies into the data-base set at a repeated program starting, may be quoted. All mentioned drawbacks are removable, though, or can be eliminated by increasing the precision and sensitivity of the method. Measurements on the Mayrau mine (within the mentioned grant) could not be continued due to the premature termination of mining activities in this mine.

Measurements aimed at the determination of seismic event precursors in rockburst–prone mine have shown that convergence measurements did not have any prognostical character. However, they could be used to make the determination of focal parameters of induced seismic events more accurate and to point to some errors in their determination. For these reasons, I consider the new convergence measuring method a prospective one which would be suitable and appropriate for further development and refinement.

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