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LEVELLING AND SEISMIC REFRACTION MEASUREMENTS OF GROUND SUBSIDENCE IN A MINING AREA

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ABSTRACT

Surface deformations are one of the most disadvantageous effects resulting from coal mining exploitation. Changes of stress in rock mass causing such deformations have a significant impact on variations in values of physical parameters of rocks. In these cases applying some geophysical methods seems to be very useful and practical.

The analysis of two-year cyclic levelling and seismic refraction measurements carried out in area of mining exploitation is presented in this paper. The application of complex researches and the detailed study of head wave velocity and mining subsidence allowed to describe much more accurately the deformation process occurring in a shallow subsurface.

KEYWORDS: subsiding trough, levelling, velocity of head wave, seismic refraction

1. INTRODUCTION

Surface deformations resulting from mining exploitation are reckoned among the most disadvantageous and dangerous hazards particularly in those regions which are inhabited and industrialised. Geodesic and geophysical methods can be successfully applied to estimate such deformations in rock mass. As well as the standard geodesic methods, the use of satellite lets researchers accurately calculate the values of parameters of deformations. Similar results can be obtained using tensometric research (Kanciruk et al.). To estimate spatially the values of subsidence radar satellite interferometry (InSAR) is successfully used (Perski, 1999). This also allows to make an investigation in the relatively large area included in the satellite photograph. The accuracy of this method is less than in the case of application of other geodesic methods.

The above-mentioned methods can provide some general information about the process of displacement of measured points on the surface.

Geophysical researches, including seismic prospecting (Schwarz, 1990;Johnston and Carpenter, 1998), gravimetry (Szczerbowski, 2001), geoelectric (Kaczor, 2003) and electromagnetic methods are used to monitor the process of deformation in rock mass, as well as to indicate the zones which might be under threat of deformation. However, seismic methods have been applied predominantly because of the fact that the velocity and attenuation of seismic waves are closely connected with stress and fracture in rock mass. Geophysical methods also allow to observe the variation in values of physical parameters at different depths. Applying both geophysical and geodesic methods seems to be very useful in better recognising the process of formation of subsiding troughs on the surface resulted in mining exploitation.

2. DESCRIPTION OF AREA UNDER STUDY

The area, which was chosen for this study, is a typical example of deformations occurring in the Upper Silesia Coal Basin (South Poland) due to underground mining exploitation. It is situated between two cities - Katowice and Chorzów - and includes the coal fields of the Katowice-Kleofas Coal Mine (Fig 1). During the time the measurements were conducted, the A-4 motorway was simultaneously being built in the vicinity of the region assigned for scientific research. The geological structure of the area consists of Carboniferous sandstone, mudstone, schist and coal beds covered with a four-meter layer of clay. The roof of the Carboniferous consists of about a one-meter-thick weathered coal bed interbedded with schist. The surface deformation process of rock mass resulting from mining exploitation of the 510 coal bed deposited at a depth of 700 meters was studied. During the research period the longwalls No. 201 and No. 202 were driven using the fall of roof method. The thickness of the exploited layer was 2 meters.

In the past in the region under study, above-lying coal beds had been exploited several times. This is why the rock mass is considerably disturbed at present. The rate of the longwall exploitation is illustrated in Fig. 1

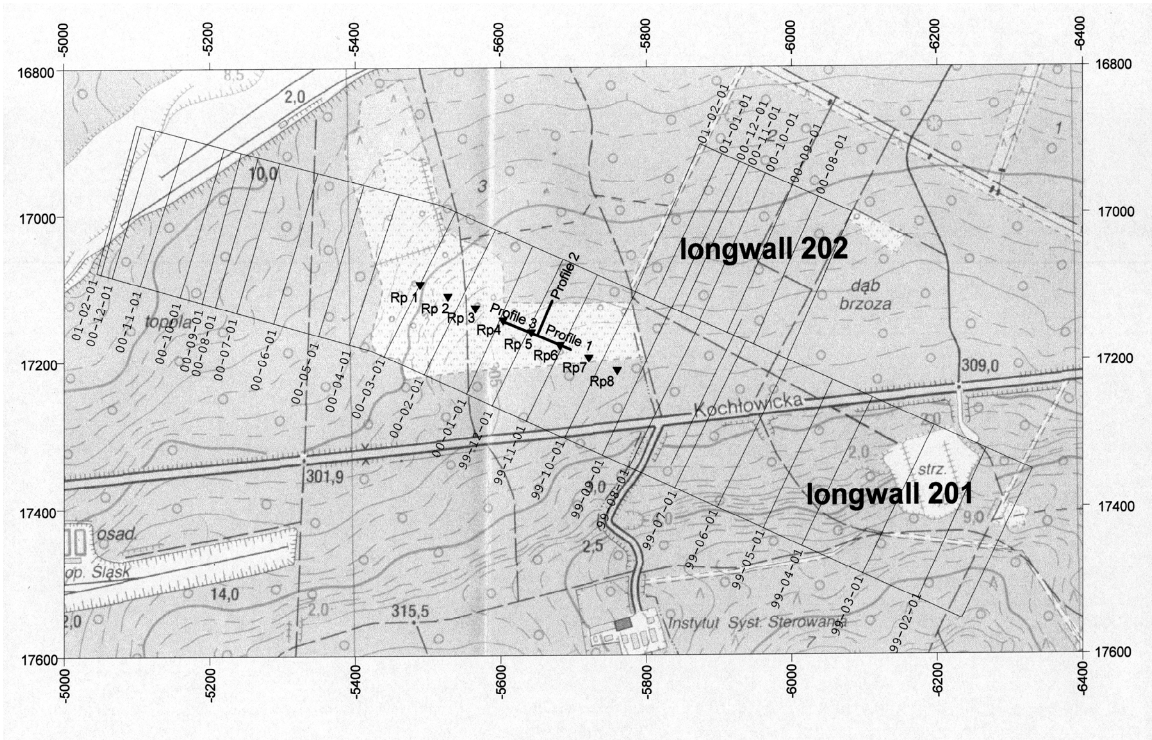

Fig. 1 Scheme of research area with surface projection of exploited longwalls in consequent time period (coordinates in Sucha Góra Reference Frame in meters).

3. METHODS

3.1. ENGINEERING LEVELING

Level benchmarks Rp 1 – Rp 8 (Fig. 1) were located every 40 meters in the middle part of the longwall. The benchmarks were attached geodetically to the benchmark number Ps 14, which pertained to the level circuit running along the motorway under construction. Cyclic measurements in the Ps 14 benchmark point were conducted throughout the whole research period. The levelling error of closure was lesser than 4 mm. Levelling survey was carried out in the region of an intensive mining exploitation. The leveling instrument was applied with measurement accuracy of 2 mm per km.

Unfortunately, the horizontal displacement components, more useful in state of deformation analysis, were not measured.

3.2. SEISMIC MEASUREMENTS

To conduct the seismic measurements an MK6 TERRALOC device was employed. The investigations were carried out along three oriented profiles using the forward and reverse traverse method (Fig. 1). Each seismic spread contained 12 geophones placed at four-meter intervals. Shot points were located 4 meters in front of the first geophone and 4 meters behind the last one. Because of the fact that the refraction interface was horizontal the intercept time method was used in this case. Seismic data were interpreted using the Seismic Unix and Viewseis computer programmes.

4. RESULTS

4.1. SEISMIC MEASUREMENT RESULTS

A two-layer velocity model of the rock mass and horizontal refraction interface was obtained. The first layer, consisting of clay, was about 4 meters thick and its velocity averaged 550m/s. The values of the velocity changed insignificantly during the two-year period of the researches. The layer lying beneath the clay was composed of weathered Carboniferous rocks. Its velocity averaged 1290 m/s. The velocity of head wave in brittle Carboniferous rocks in profiles No. 1, No. 2 and No. 3 (Fig. 1) were illustrated correspondingly in Fig. 2, Fig. 3 and Fig. 4. The observed values of head wave velocity can be changeable up to 200 m/s. In profiles No. 1 and No. 2 one can notice considerable variation in values, nevertheless they oscillate around the average. In profile No. 3 significant trends of increasing and decreasing in values of head wave velocity are observed which might be connected with alternating periods of compression and tension of the rock mass due to underground mining exploitation, whose direction was in accordance with the one of profile No. 3.

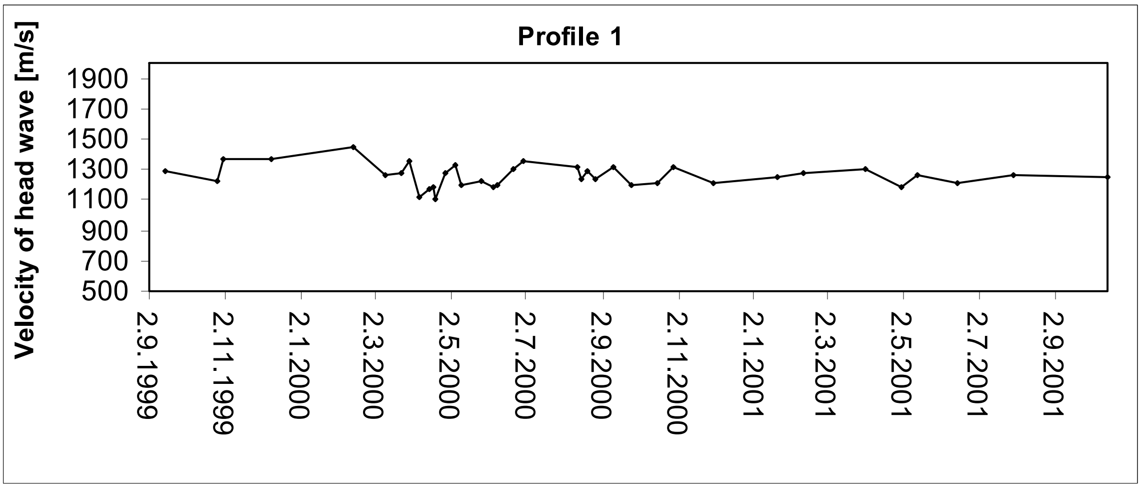

Fig. 2 Variation in velocity of head wave in profile No.1 in accordance with the direction of exploitation.

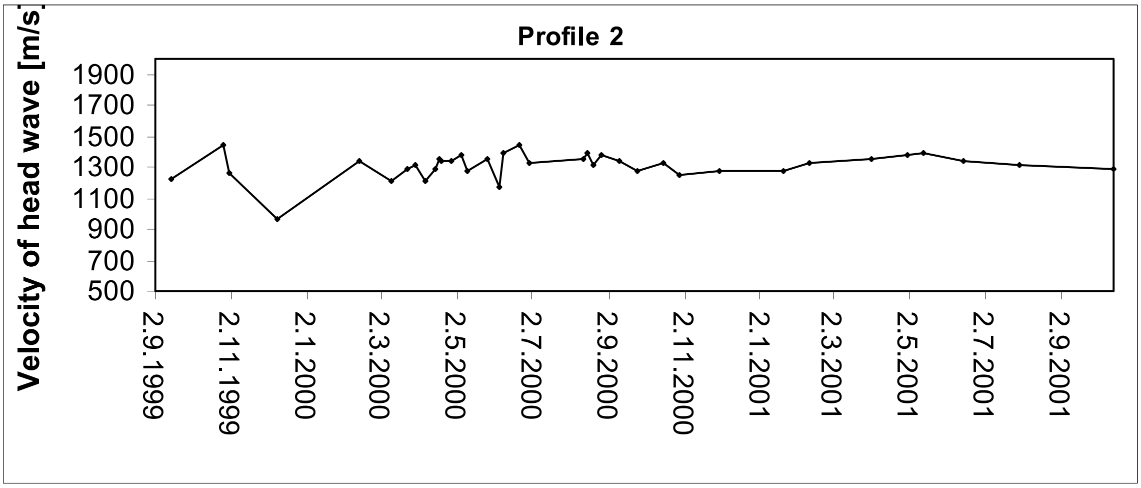

Fig. 3 Variation in velocity of head wave in profile No.2 perpendicular to the direction of exploitation.

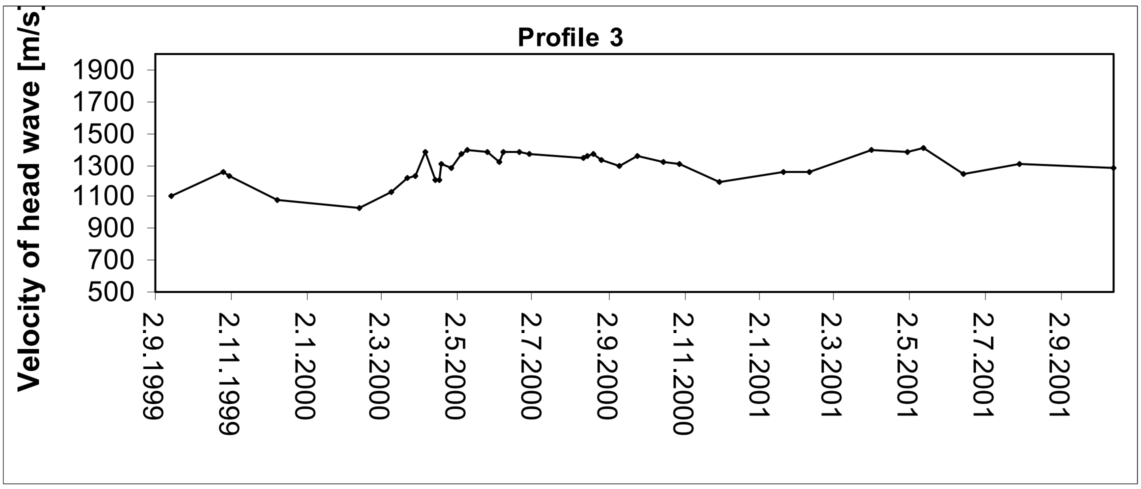

Fig. 4 Variation in velocity of head wave in profile No. 3 in accordance with the direction of exploitation.

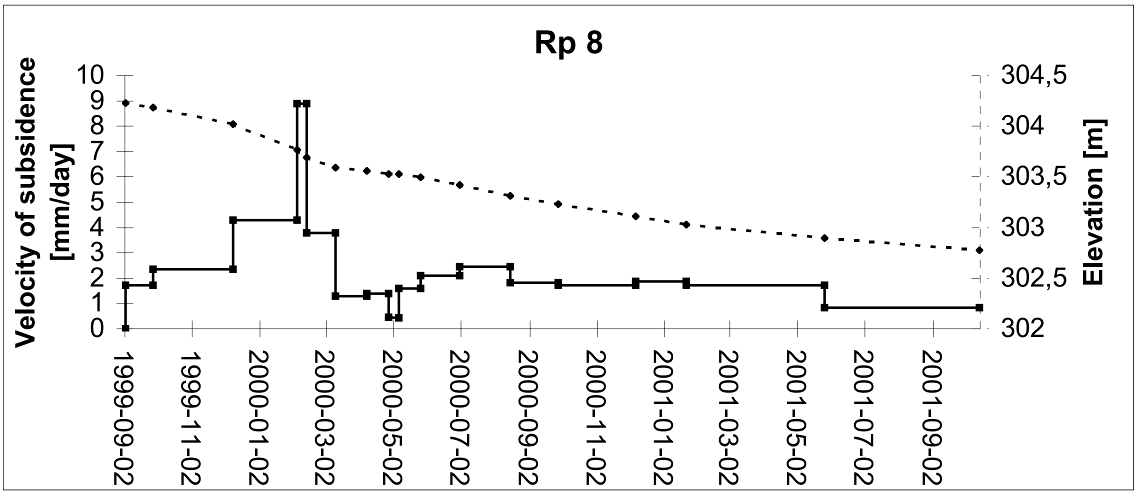

Fig. 5 Subsidence measured at benchmark Rp 8.

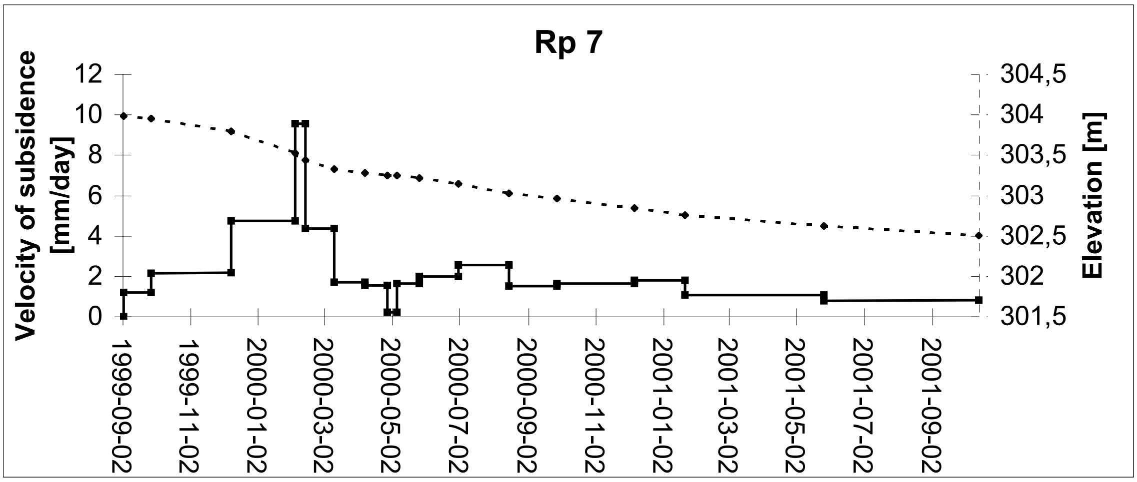

Fig. 6 Subsidence measured at benchmark Rp 7.

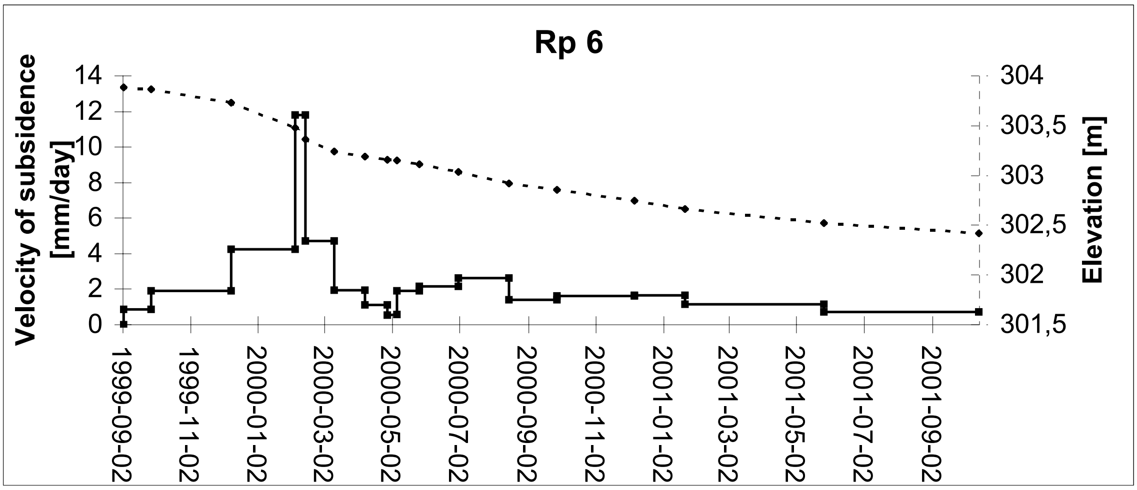

Fig. 7 Subsidence measured at benchmark Rp 6

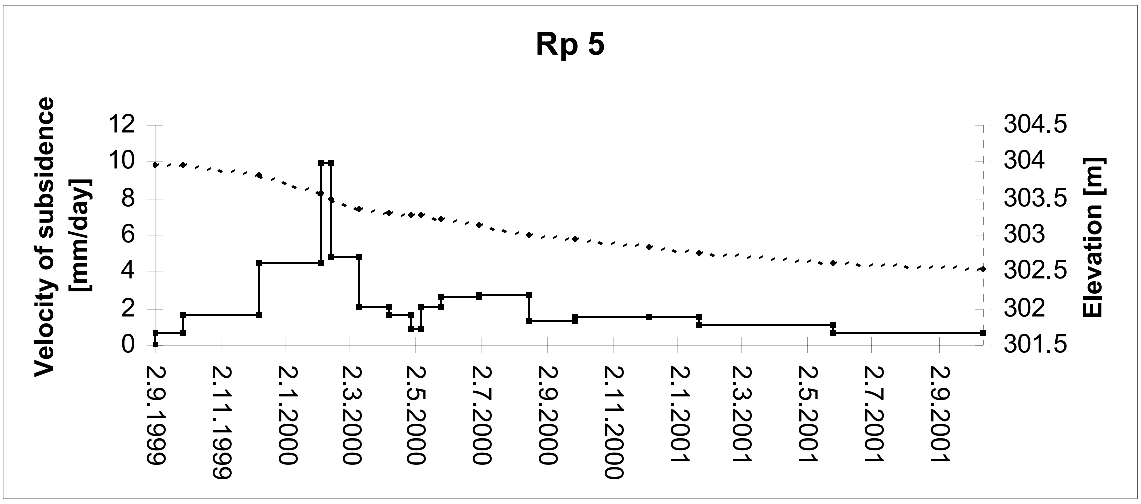

Fig. 8 Subsidence measured at benchmark Rp 5.

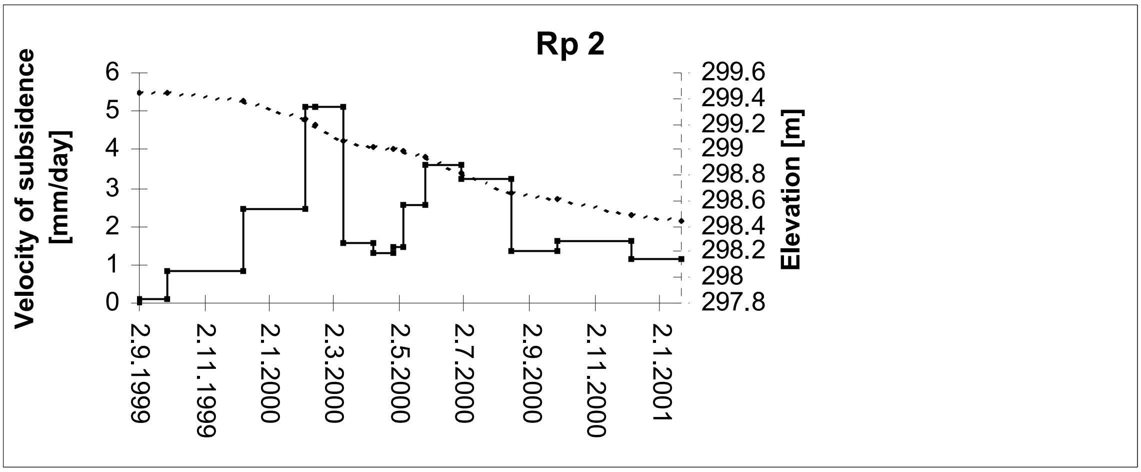

Fig. 9 Subsidence measured at benchmark Rp 2.

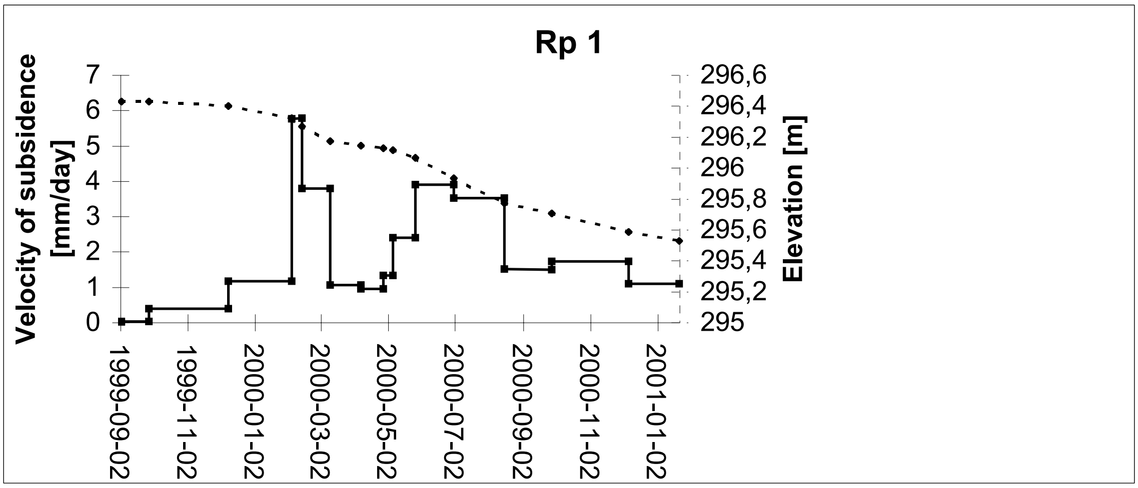

Fig. 10 Subsidence measured at benchmark Rp 1.

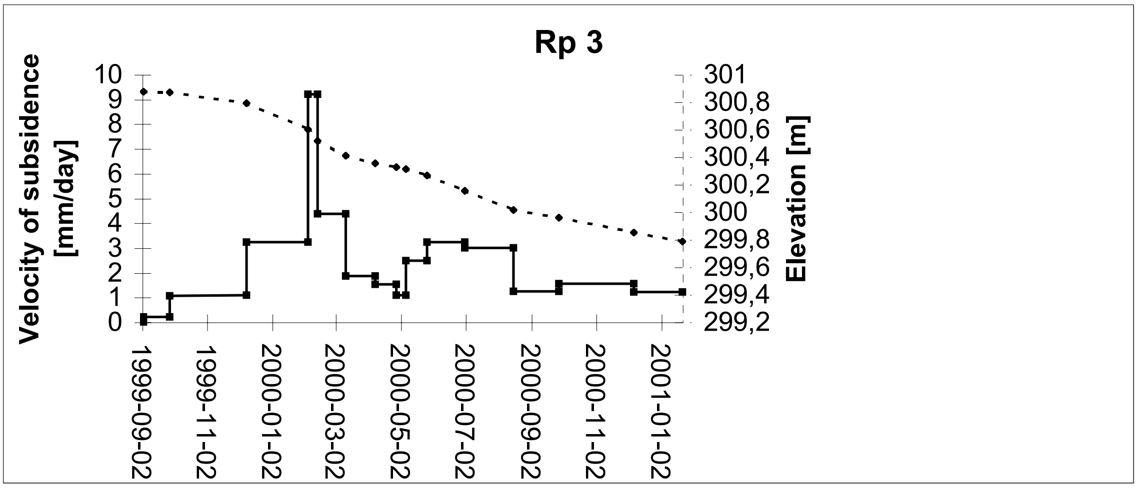

Fig. 11 Subsidence measured at benchmark Rp 3.

4.2. ENGINEERING LEVELLING RESULTS

The data obtained from benchmarks Rp 1 to Rp 8 allowed analysis of the subsidence process occurring in the area in which the scientific researches and the underground mining exploitation took place simultaneously. The subsidence was spatially diversified. The values measured at benchmarks Rp 8 – Rp 5 were almost identical during the whole period of observations (Figs. 5, 6, 7, 8). From the beginning of researches the velocity of subsidence increased up to the maximum value of 10 mm per day in February 2000, whereas in period of June – August 2000 the value was lesser and averaged 3 mm per day, from October 2000 to February 2001 about 2 mm per day.

The velocity of subsidence at benchmarks Rp 1 – Rp 2 was characterised by a different course of events (Figs. 9, 10) which was as follows: the maximum velocity of subsidence reached 5 mm per day during the period of February to March 2000 and the one with the value of 4 mm per day appeared from June to July 2000. The benchmark Rp 4 was destroyed at the beginning of scientific research and benchmarks Rp 1-Rp 3 were banked with earth in February 2001.

The velocity of subsidence at a benchmark No. 3 (Fig. 11) showed indirect characteristics among other groups of benchmarks mentioned above.

5. CONCLUSION

The analysis of values measured at benchmarks allowed the area being under study to be divided into two groups: the first one includes benchmarks Rp 8 – Rp 5 and the other is connected with Rp 2 - Rp 1. These two zonations indicate that the process of subsidence in the region ran in the form of block subsidence. Seismic research confirmed this conclusion. In profile No. 1 and No. 2 the significant temporal variations of the head wave velocity responding to periods of continuous tension and compression in the shallow subsurface were not found corresponding with. In profile No. 3, situated between zones with different subsidence regime, the periods of a gradual increase and decrease of the head wave velocity were clearly noticed.

There were no more advanced statistic methods applied to the interpretation because of the fact that the number of seismic measurements (about 40) exceeded considerably the number of levelling survey (about 16). Moreover these two types of measurements could not be performed simultaneously for various reasons including labour absorbing seismic measurements as well as a change in weather conditions.

The values of head wave velocity showed a tendency to return to their initial values. This might be connected with the change of stress in the rock mass (Figs. 2, 3, 4). This could suggest that the change of stress in the shallow subsurface of the rock mass resulted in compression and tension of formerly existing fractures rather than in creating new ones.

Mining documentation was analysed and it was found that the number of faults occurring in the studied area did not exceed those in its vicinity. Considerably larger amplitude variations of the head wave velocity were observed concurrently with significant changes in the subsidence rate.

Geophysical measurements carried out simultaneously with geodetic ones allow to better recognise the process of subsidence caused by underground mining exploitation.

The results presented in the paper point to a certainty that geophysical measurements carried out together with measurements of the horizontal components of ground displacements give more information about mining-induced rock mass subsidence than research based on measurements of vertical displacements only.

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