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VARIATIONS OF THE FRACTAL DIMENSION OF EPICENTRE DISTRIBUTION IN THE MINING–INDUCED SEISMICITY

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ABSTRACT. Epicentre distribution in the mining–induced seismicity is analysed for individual longwalls of some mines of the Upper Silesia Coal Basin. The fractal nature of this distribution has been stated.

Time variations of the fractal dimension, calculated by means of box–counting method, are correlated with other geophysical parameters related with induced seismicity of the exploited area.

At the same time methodology of the fractal dimension calculations is analysed.

1. INTRODUCTION

The fractal nature of natural and mining–induced seismicity has often been the object of studies for the last several years. Papers concerning the field deal with the number–magnitude relation, faults or fracture geometry and time–space distribution of the seismicity. Basic papers are those of Mandelbrot [Scholz, Mandelbrot 1989], Turcotte [Turcotte 1992], Xie [Xie 1993] and Hirata [Hirata 1989]. Data from Polish mines were analysed by e.g. [Marcak 1994] and [Idziak, Zuberek 1994].

The presented studies concern global nature and time variations of epicentre distribution of mining–induced seismicity for some mines of the Upper Silesia Coal Basin for particular longwalls. Calculations by means of box–counting method serve the purpose of estimating the usefulness of the fractal dimension as a characteristic parameter of the distribution with a structure not having a description in the sense of classical geometry and as the precursor of large tremors.

The closest to this study are the analyses of the rock noise location in [Xie 1993] and [Trifu 1993]. In those papers it was shown that the distribution of the epicentres of mining–induced seismicity is fractal – has statistical self–similarity.

In the first case the fractal dimension D of seismic noise was calculated with the use of a number – radius method, the so–called cluster dimension. For the data from two mines a decrease in the fractal dimension prior to major rockburst was observed in spite of relatively high seismic activity.

In the second case the fractal dimension was calculated as correlation dimension D_2. This dimension, calculated separately for two perpendicular directions, had a drop of value several days before major rockburst and at the completion of the aftershock sequence. There was no correlation between the D_2 dimension and the value of Gutenberg b coefficient. The authors concluded a lack of self–similarity between large and microseismic events.

The conclusions of different authors disagree with one another, but the optimism concerning the fractal dimension position in major rockburst prediction predominates.

Our research based on significant statistics does not confirm this opinion. The fractal dimension is, however, the parameter essentially changing in time. So the presented paper is the first stage of its analysis.

2. THE DATA AND METHODOLOGY OF CALCULATIONS

The distributions of mining seismicity in relation to longwall position were examinated in various time periods for mines: Katowice, Szombierki, Wesola, Bobrek and Pokoj. The epicentres from the field of 400 m × 400 m around the longwall centre, as directly related to local changes of rock–mass caused by exploitation, were analysed.

A number of $N(r)$ squares with side r, covering given distribution, for several values of r from 20 to 133 m were calculated by means of box–counting method. The linearity of $\log N(r) - \log r$ relation proves fractality of the set. The slope of the log – log plot is directly the value of fractal dimension D, according to the definition [Turcotte 1992]:

$$N(r) \approx r^{-D}$$

denotation as above.

The fractal dimension is defined in several ways. The above used, called box–counting dimension or box dimension, is consistent with the Kolmogorov or Hausdorff definition and corresponds to capacity dimension frequently denoted by D_0. For $r \longrightarrow 0$ capacity dimension D_0 is equal to information D_1 and correlation exponent D_2 dimensions (e.g. [Xie 1993]).

3. RESULTS

In every case the fractal character of epicentre distribution was confirmed. This is shown in Figs. 1 and 2 in which log – log relation of number $N(r)$ squares of side r vs. value r are presented for significantly different number of events.

The relation in Fig. 1 concerns the set of seismicity data for the region of 532 longwall in the Katowice coal mine from April 1985 to October 1986, Fig. 2a from September 4–28, 1985 for the same region, Fig. 2b for the region of longwall 12 in the Szombierki coal mine from February 3–17, 1987. The linearity of the plot proves statistical self–similarity of events – the dimension is different.

The methodology of the fractal dimension calculation i.e. the interdependence of the D value from the time period of sampling, the quantity of samples and so on was also analysed.

The value of the fractal dimension depends, among others, in such cases, on the number of analysed tremor sets.

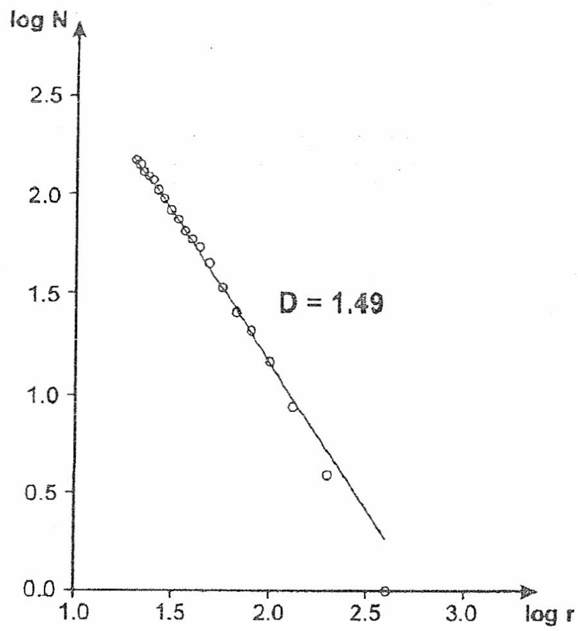

FIG. 1. The fractal analysis of seismicity space distribution for the Katowice Coal Mine, longwall 532, $n = 1494$ events

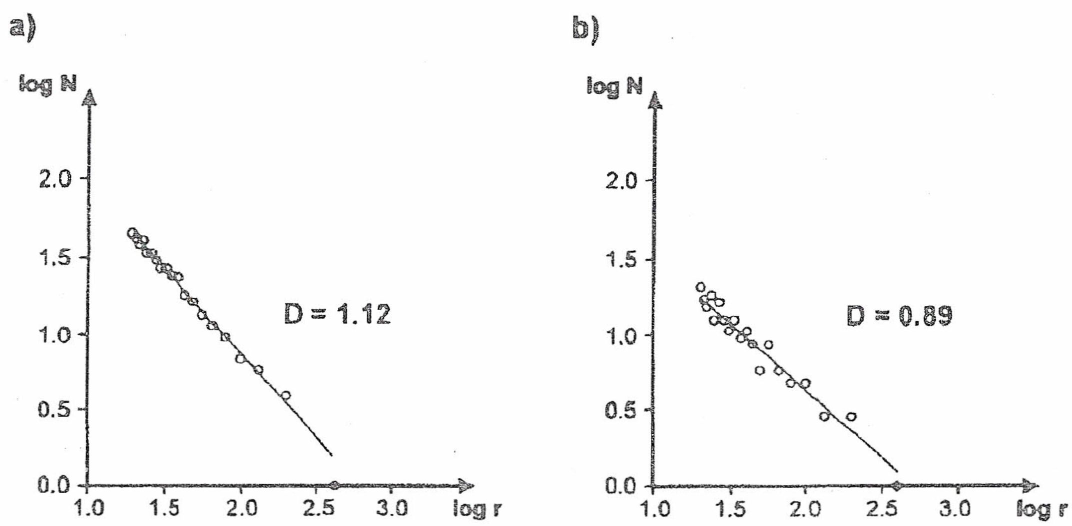

FIG. 2. The fractal analysis of seismicity space distribution for $n = 100$ events
a) the Katowice Coal Mine longwall 532
b) the Szombierki Coal Mine longwall 12

For large sets (range to two thousand events) some kind of "glut" was observed – further increase in the number of events caused only a slight increase in D dimension or did not change it. It may be assumed that the D value is a constant, characteristic for a given region. In every case it was an individual marking. For different regions of mines, with the same number of tremor sets, the D values may vary significantly and stabilize with a different number. As an example in Tab. 1 the variation of D parameter vs. number of set are juxtaposed for two different regions.

TABLE 1. The effect of the fractal dimension D stabilizing with increasing number of tremor set.

The Katowice mine

N	794	1000	1273	1500	1627	1876	2374	2623	2864	3044
D	1.59	1.60	1.62	1.63	1.64	1.65	1.67	1.68	1.67	1.70

The Szombierki mine

N	794	1043	1293	1541	1793	2042
D	1.11	1.07	1.17	1.21	1.20	1.20

The value of fractal dimension was also examined in different energetic intervals. In Table 2 there are juxtaposed values of fractal dimension of seismic event epicentre distribution, from various time intervals, for different energetic ranges for individual longwall regions of several mines of the Upper Silesia Coal Basin.

TABLE 2. The fractal dimension of the seismic event epicentres for individual longwalls of the Upper Silesia Coal Basin mines

The mine Longwall/ seam	The number of days	The n number of events	The D dimension	$E < 4 \times 10^4$ J		$E > 10^4$ J	
				n	D	n	D
Katowice							
532/510	1408	3044	1.70	2943	1.70	160	1.24
533/510	1288	2577	1.64	2414	1.63	163	1.23
537/510	218	883	1.40	840	1.39	40	0.90
Szombierki							
12/510	294	2042	1.20	1886	1.18	156	1.08
Bobrek							
11/510	290	317	1.38	112	1.03	205	1.29
Wesola							
65/510	589	432	1.37	413	1.36	19	–
Wujek							
5a/510	274	362	1.40	358	1.42	4	–
a3a/510	274	155	1.31	138	1.25	17	–
Pokoj							
708/507	658	1243	1.75/1.40	1094	1.72/1.33	149	1.46/1.8

The values vary significantly and fluctuate from 1.20 to 1.74 in the open interval of energy. For small events, of energy lower than 4×10^4 J the differences in D value are meaningless except for the Bobrek coal mine. It is probably related to the dominant number of large tremors in this case.

The results from the Pokoj coal mine are worth a special notice. Unlike in the remaining cases the $\log N - \log r$ relation plot is clearly a broken line, giving different fractal dimensions in two different intervals. This is shown in Figs. 3 and 4. The breakdown occurs for the r value at about 35 m. It may be assumed that this is the limit of self-similarity of epicentre distribution. For the remaining cases there was either no change in the line slope or the change was insignificant – the D value variation was of several decimals range. The same result was obtained while analysing total events from the region of the Wujek coal mine.

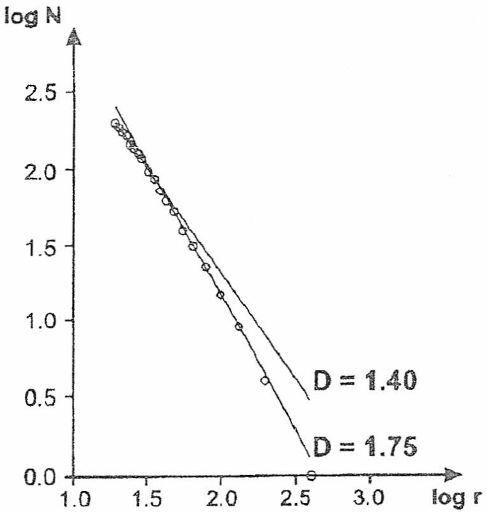

FIG. 3. The fractal analysis of seismicity space distribution for the Pokój Coal Mine, longwall 738, $n = 1494$ events

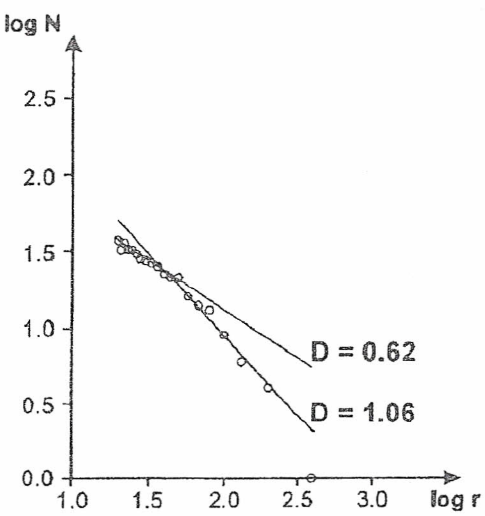

FIG. 4. The fractal analysis of seismicity space distribution for the Pokój Coal Mine, longwall 708, $n = 50$ events

The time variation of fractal dimension for individual longwalls was examined in different time intervals and for different sampling sizes. Fig. 5 presents the changes of the value of fractal dimension for seismicity from the region of longwall 532a Katowice from May 1, 1985 to June 30, 1986. In that time a period high microseismic activity and a great number of large tremors were observed. The fractal dimension obtained for data subsets of a constant size or from a sequence of equal time intervals and seismic activity and large tremors are juxtaposed. Time changes of D value for size samples 100, 50 and 25, and the tremors of energy greater then 10^5 J are compared in Fig. 6.

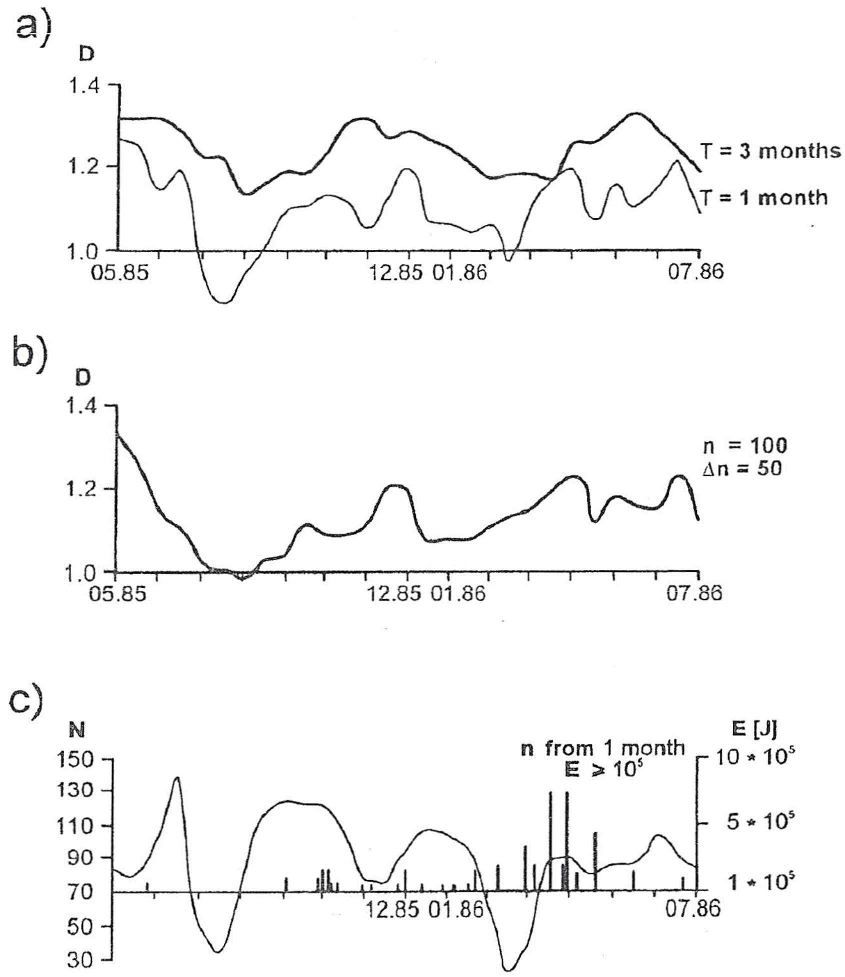

FIG. 5. The seismicity fractal dimension time changes for data from the Katowice Coal Mine, longwall 532

a) 3 months and 1 month time gate respectively with half of month shift

b) Samples of 100 events overlapping by 50 events

c) Monthly activity rate. Bars mark events of energy $E \geq 10^5$ J.

The presented plots demonstrate that for the analysis of the mining seismicity fractal dimension changes only samples of equal size may be applied. The number of events ought to be the smallest possible to characterize the distribution from a small time interval but big enough to be representative. The box–counting method requires rather large size sampling.

There is an evident essential change in the time of D value. In Fig. 6 the anomalous change of D before large events can be identified. This suggests a potential usefulness of fractal analysis for the prediction of rockbursts.

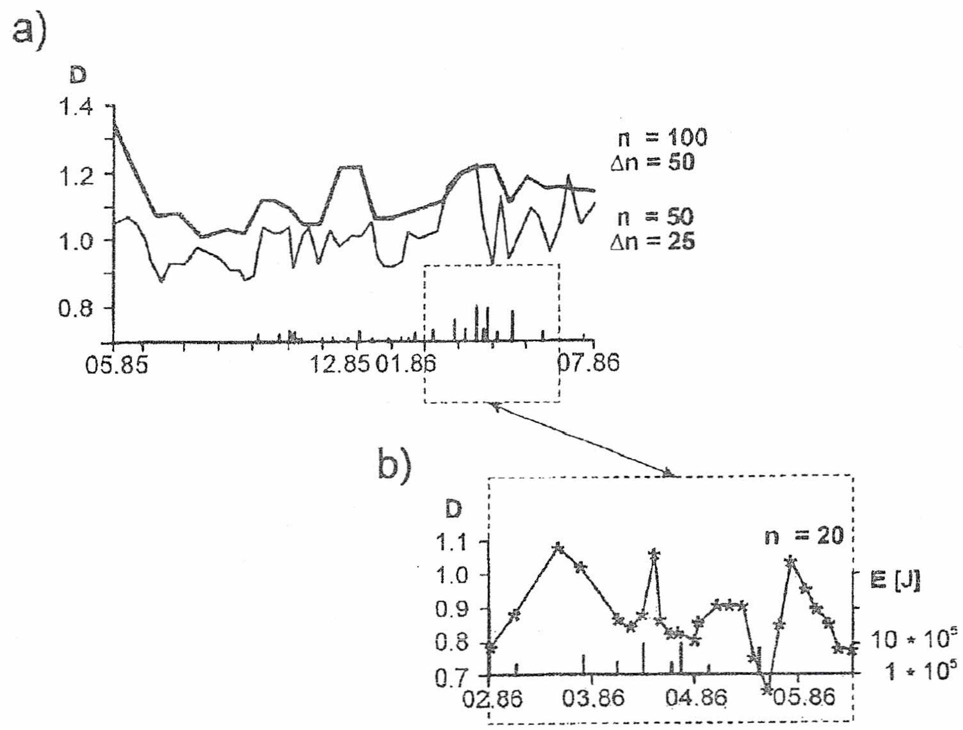

FIG. 6. The seismicity fractal dimension time changes for data from the Katowice Coal Mine, longwall 532

a) Samples of 100 events overlapping by 50 events
b) Samples of 20 events overlapping by 10 events
Bars mark events of energy $E > 10^5$ J.

To verify this hypothesis the time variation of fractal dimension, for individual regions, was correlated with the seismic activity, the total energy released in a given time interval, the number of large tremors, the sum of energy of large tremors and the estimates of the Gutenberg b coefficient and maximum energy.

Nonparametric correlation analysis was applied to the sequences of samples, size 100 and 50, for mines from Table 2 and for the case from Fig. 6 for size 25.

The significant values of correlation coefficient occur only now and then for the relation D – seismic activity. They were observed for the region of longwall 532a in the Katowice coal mine for not overlapping sequences of samples, size 100 and

50, imposing limitation on the time length of sampling which removes periods with low seismic activity – stoppage of working face.

For the Szombierki mine a significant relation was also observed (size samples of 50 events) but both cases differ in the sign of correlation coefficient. The correlation does not appear with every choice of the starting point of the sequence of not overlapping samples.

When the same relation for samples of size 100 taken every half of a month is examined:

- for the region of longwall 532a it appears with an analogous limitation in the duration of sampling,
- for the region of longwall 533 it is also observed without limitation in the duration of sampling.

In both cases the correlation is positive.
No correlation was obtained for the Pokoj coal mine.

4. DISCUSSION OF THE CORRELATION ANALYSIS

Fractal analysis of induced seismicity is meant to describe a statistical self-similarity. One expects that strong tremors and seismic events genetically related to them, preceding and following them, will distort the self-similarity and will cause characteristic changes of the fractal dimension. This phenomenon is probably covered and influenced in a way difficult to predict by numerous events due to the normal fracturing process accompanying mining works.

In order to achieve a reliable estimate of the box-counting fractal dimension D used in the presented studies one needs a considerable number of events i.e. the events which usually occur during a considerable time interval. It is likely that a preparatory time period before a strong event is often much shorter than the sampling period to evaluate D. This effect should be eliminated when one applies the number-radius fractal dimension or the correlation dimensions since their requirements concerning the sample size are less considerable.

5. CONCLUSIONS

The box-counting fractal dimension of epicentre distribution of local mining-induced seismicity turns out to be a good parameter characterizing local features of the tremor generating-process. Its values are specific for both the whole mine region as well as the area of individual excavation.

The fractal dimension significantly varies in time when evaluated from seismic events which occur in a direct vicinity of mining works. However, an estimate of the box-counting fractal dimension is strongly biased and a considerable sample size is required to make it reliable. Therefore its suitability to monitor changes related to strong tremor occurrence is doubtful.

At present we are extending the presented analysis to other self-similarity parameters namely to the number-radius fractal dimension and the correlation dimension.

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REFERENCES

Hirata T. (1989), *A Correlation Between the b Value and the Fractal Dimension of Earthquakes*, J. Geoph. Res. **94**, no. B6, 7507–7514.

Idziak A., Zuberek W.M. (1995), *Fractal analysis of mining induced seismicity in the Upper Silesian Coal Basin*, In Mechanics of Jointed and Faulted Rock, Rossmanith (ed), Balkema.

Marcak H. (1994), *Zastosowanie wielofraktalnej, pasmowej analizy do badania struktury zbiorow sejsmicznych wywolanych eksploatacja gornicza*, In Tapania'94 Sympozjum naukowo–techniczne, Rozwiazania inzynierskie w problematyce tapan, Ustron 1994, wyd. GIG Katowice.

Scholz C.H., Mandelbrot B.B. (eds) (1989), *Fractals in Geophysics.*

Trifu C.J., Urbancic T.I., Young R.P. (1993), *Non–similar frequency–magnitude distribution for $M < 1$ seismicity*, Geoph. Res. Lett. **20**, no. 6, 427–430.

Turcotte D.L. (1992), *Fractals and Chaos in Geology and Geophysics*, Cambridge University Press.