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STUDIES OF FRACTALITY OF EPICENTRE DISTRIBUTION GEOMETRY IN MINING INDUCED SEISMICITY

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Abstract. Epicentre distribution around the longwall centre, as directly related to local changes of rock–mass caused by exploitation, was analysed for some mines of the Upper Silesia Coal Basin.

Time variations of the fractal dimensions:

- capacity dimension, calculated by means of the box–counting method,
- clustering dimension, calculated by means of the number–radius method and
- correlation exponent dimension, calculated by means of the pair–radius method,

are correlated with other geophysical parameters related with induced seismicity of the exploited area.

The fractal dimension significantly varies in time when evaluated from seismic events which occur in the direct vicinity of mining work.

The fractal structure of temporal seismicity distribution for the whole mine region and for shorten samples has also been found.

1. Introduction

Fractal geometry seems to be natural for the description of some geophysical event distributions. Fractal statistics has been confirmed in many geophysical relations. In some cases this is directly connected with chaotic, non–linear behaviour of particular phenomena. A collection of articles on the subject is presented, e.g. in [Scholtz, Mandelbrot 1989], [Sammis, Saito, King 1993] and [Barton, La Pointe 1995]. In the last paper the fractal analysis methodology also is discussed.

The fractal approach to mining induced seismicity, in analogy with natural seismicity, has been applied for the last several years. For Polish coal mines it has been done, e.g. by [Marcak 1994], [Idziak, Zuberek 1995], [Idziak, Teper 1995], [Mortimer, Lasocki 1995] and [Mortimer, Marchewka 1996]. For local seismicity, the authors tend to study self–similarity of spatial (e.g. [Xie 1993], [Stewart, Spottiswoode 1993], [Mortimer, Lasocki 1995]) and/or temporal (e.g. [Coughlin, Kranz 1991], [Mortimer, 1996], [Mortimer, Marchewka 1996]) distributions of seismic or microseismic activity and relate changes of fractal properties with development of the rock–burst generating process. It is expected that the fractal dimension ought to account for the epicentre geometry modification preceding a strong event.

The important problem in investigations of fractal properties is a selection of methodology of the analysis (mono– or multifractality, self–similarity or self–affinity, time series, power spectrum and so on) and the method of determining of appropriate parameters, as each method provides some special problems and errors.

2. Methodology of the Analysis

Presented studies examine fractality of local mining induced seismicity with relation to the rock–burst generating process. We analyse the epicentre distribution connected with particular longwalls, in some of Upper Silesia Coal Mines. For this reason only epicentres from the square of 400×400 m around the longwall centre are taken into account. The position of epicentres is evaluated respectively to the position of the longwall centre. This is especially important when the sample number is large – time period more than few days. For the small sample number, when longwall movement was less then $1 - 2$ meters, such assumption does not influence results.

Our previous research [Mortimer, Lasocki 1995] of the spatial epicentre distribution by means of the fractal box–counting method provides:

- the confirmation of fractality in the examined ranges of space and time scales,
- the specific changes in time of the fractal dimension,
- the sensitivity of the fractal dimension on the range of the sample number,
- the lack of evident correlation with a strong event occurrence which we explain by the different factors biasing analysis, containing too great sample number.

Now, for the spatial epicentre distribution, we examined three most popular methods of the fractal dimension determination.

In the box–counting method, i.e. one of the most popular methods, the epicentre distribution is covered by grids of squares and the number $N(r)$ of the nonempty boxes, for different sides r, is calculated. If the relation:

$$N(r) \cong r^{-D} \qquad (1)$$

is confirmed, the slope of the $\log N(r) - \log r$ curve, in particular ranges of magnitudes, provides so–called box dimension.

The next method we studied is evaluation of the fractal clustering dimension, called the number–radius or mass–radius method [Xie 1993]. In this method, the number $M(r)$
"centre of mass" of distribution is calculated. The slope of the $\log M(r)$
plots gives the clustering dimension D according to the relation:

$$M(r) \cong r^{D} \qquad (2)$$

The correlation exponent dimension [Grassberg, Procaccia 1983] is calculated by the counting number $N(r)$ of the pairs of points with the distance less than r for different r values. The slope of the $\log N(r)$ vs. $\log r$ plots provides the D – the fractal correlation exponent dimension, according to the relation:

$$N(r) \cong r^{D} \qquad (3)$$

In some notations the fractal correlation dimension is denoted as D_2. It is obtained for the parameter $q = 2$ in the multifractal approach.

For the epicentre temporal distribution only the last method has been used. In this case r in the formula (3) denote a time interval between events.

3. RESULTS

The local mining seismicity epicentre spatial distribution.

As an example, the results of the fractal analysis of seismicity, recorded in the area of the longwall a3a/510 the Wujek Coal Mine, are presented in the fig. 1 The correlation dimension D_2, according to the formula (3) is 1.78.

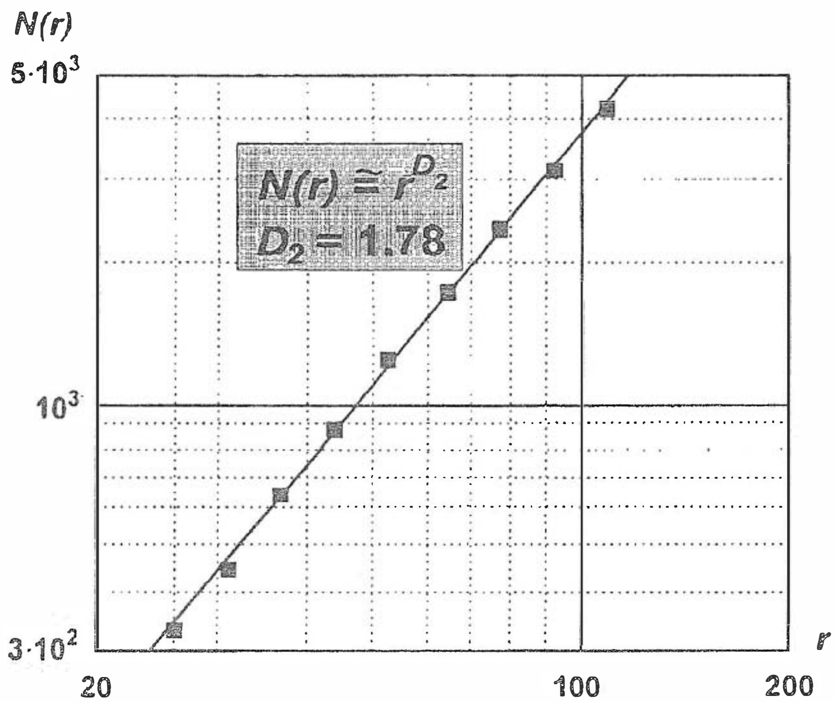

FIG. 1. The fractal analysis of the epicentre spatial distribution of 154 events, recorded in the area of the longwall a3a/510 the Wujek Coal Mine, during 274 days.

For every method fractality of the local epicentre spatial distribution is confirmed in the scale range of 20 to around 100 meters, proving a self–similarity of this distribution.

Such conclusion seems to be contrary to the calculations of [Idziak, Teper 1995] who claimed that epicentre fractality breaks in the magnitude scale less than 500 m. It is not so, as their analysis deals with global features of mining seismicity connected with redistribution of stresses induced by mining on previous existing faults or zones of weakness. Absolute values of epicentre co–ordinates used in such analysis are influenced by a movement of the longwall, so the epicentre fractality breaks.

From the point of view of local seismicity related directly to the current mining work on the longwall only the distribution from the closest neighbourhood ought to be analysed. The position of epicentres is evaluated respectively to the position of the longwall centre. Fractality of this distribution may be related to the rock–burst process not to the pre-existing fault system.

Comparing three methods of the fractal dimension determination the following conclusions are obtained:

- the D value in the box–counting method for large box sizes r is strongly biased by the selection of grid dimensions and its orientation, so some authors advise to rotate nets [Pruess 1995] and to average results. Nevertheless in our studies this method does not seem to be useful as it needs rather a fairly large number of events (like in microseismicity).
- for the clustering dimension the pitfall is similar to the previous one – position of circles centres strongly influenced by individual distant events biases the results. So the random walking of this centre and averaging the results are recommended but, at the same time fairly large number of events is required.
- the correlation exponent dimension seems to be in our case the most useful as it needs the less sample number and is not influenced by the position of grids or circles.

In the fig. 2 the comparison of the time variations of the box dimension and correlation dimension for the events from the Katowice Coal Mine longwall 532 match the energy of strong events $E \geq 10^5$ J.

The time changes of the fractal correlation dimension D_2 and other geophysical parameters related with the tremor generating process for samples from the longwall 532 the Katowice Coal Mine in the fig. 3 are presented.

In some cases the anomal change of D before large events may be thus identified but in our analysis it was not a rule.

The local epicentre temporal distribution.

The fractality of this distribution has been confirmed in time ranging from a few to a few hundred days. In the fig. 4 the $\log N(r)$ vs. $\log r$ plot is presented for the longwall 532 from the Katowice Coal Mine.

The time changes of the fractal correlation dimension D_2 for the epicentre temporal distribution are also confirmed.

Looking for parameters describing an evolution of the rock–burst generating process – according to the knowledge of the multifractal behaviour – fractal correlation dimension D_2 reflects a dense clustering. Gaps or seismicity silent intervals are better shown by dimensions D_q with the negative q parameter. Our next research will follow this line. The presented analysis allows us to understand better and select methodology of calculations.

4.

In every case the fractal character of the epicentre distribution was confirmed, the linearity of the plot proves the statistical self–similarity of events.

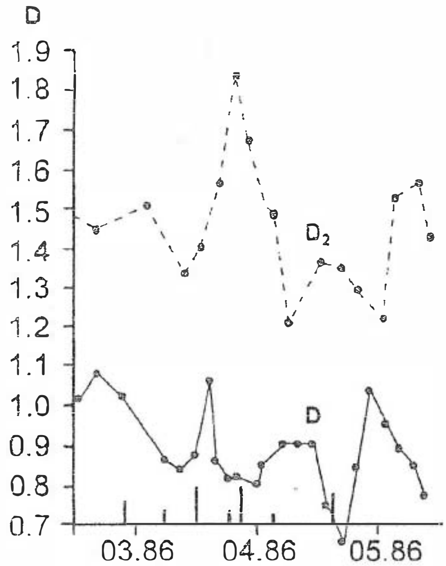

FIG. 2. The time variations of the box dimension and correlation dimension of the epicentre spatial distribution for the 20 event samples from the Katowice Coal Mine longwall 532 match the energy of events E, $E \geq 10^5$ J, the bars heights proportional to the energy of events.

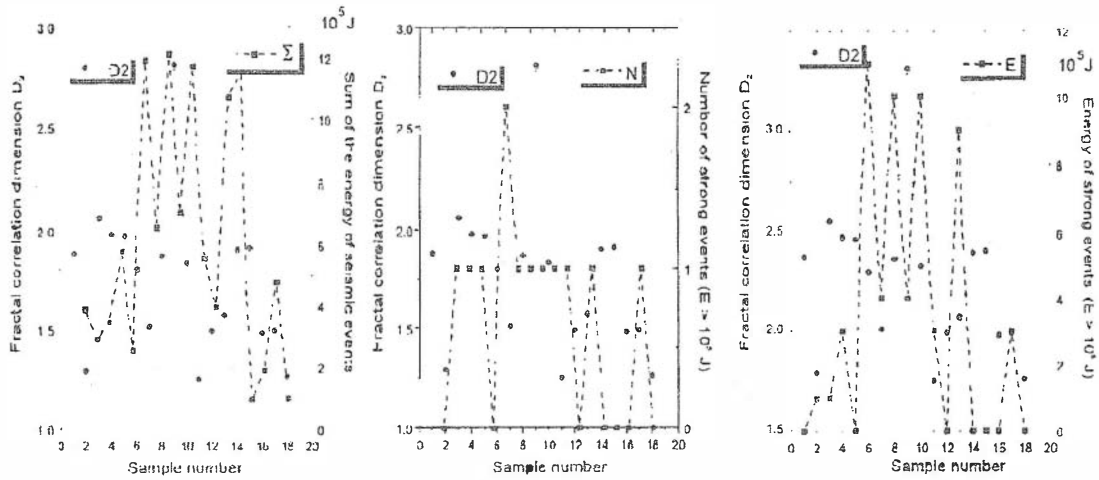

FIG. 3. The time changes of the fractal correlation dimension D_2, the sum of the energy of seismic events Σ, the number N and the energy E of strong events vs. the sample number for samples of 20 nonoverlapping events, from the longwall 532 the Katowice Coal Mine.

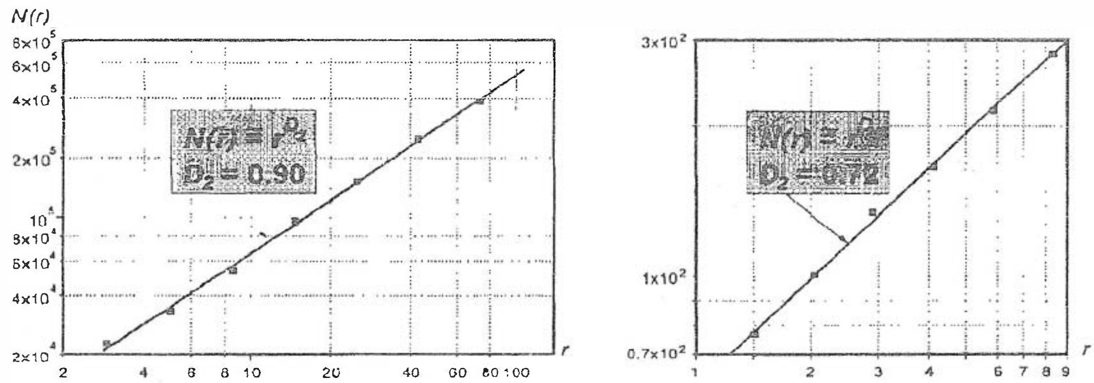

FIG. 4. The fractal analysis of the epicentre temporal distribution for the Katowice Coal Mine, longwall 532, for the sample of a) 1500 events (10 months), b) 20 events (12 days).

The value of the fractal dimension D depends on the time period of sampling and the quantity of samples.

The correlation exponent dimension D_2 seems to be in our case the most useful.

There is an evident essential change in the time of the D value. In some cases, the anomal change of D before large events may be thus identified but so far no significant correlation with these changes and strong events for whole analysed data has been found. We think that it is of rather technical not essential nature.

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