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Investigation of fractal distribution law for the trace number of random and grouped fractures in a geological mass

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ABSTRACT

A fractal study method of the number of geological mass fractures is introduced in detail in this paper. Three main aspects of the problem were studied: (1) The random distribution of fractures in a geological mass was in good agreement with the fractal law. The size scale of the studied geological mass ranged from 2400 m to 1 mm for the length of each side, and the geological mass samples were taken from 13 coal areas in China. (2) The geological mass fractures were evidently directional and anisotropic, having originated from tectonic movement. Observation and statistics for the data from the Xuangang, Fenxi and Dongshan coal areas in Shanxi, China, demonstrated that the fracture distribution of each group, classified by the strike of the strata, still follow the fractal law, even though the fractal dimension varies to a certain extent with different strikes. (3) The sedimentary strata containing the coal seams, as a geological mass, underwent almost similar tectonic movements in their geological history. The mechanical experiments on geological mass samples from Fenxi and Jiexiu in Shanxi demonstrated that the fractal dimension of the number of fractures in the same strata is in good power function with the product of strength and elastic modulus. The larger the product of the strength of the elastic modulus is, the larger is the fractal dimension, and vice versa.

1. Introduction

Is there a law on geological mass fracture distribution? What law does it follow? Is the law consistent for different geological masses of different sizes? These are questions that need to be answered by means of geophysics and geological mass mechanics.

Distribution of rock fissures, cracks, and fractures is an important subject for geology and geological engineering. A great deal of research has been done in the international community, including spacing, density and random distribution of fractures and cracks, e.g., Rabinovitch et al. (1999), Priest (2004), Lu and Latham (1999), Mauldon (1998), Mauldon et al. (2001), Song and Lee (2001), Song (2006), Zhang and Einstein (1998); Kulatilake et al., 1993.

After the birth of fractal geometry (Mandelbort,1982), many scholars widely studied the distribution of geologic bodies and their fractures, fissures and cracks on the basis of their similarities and on the principle of fractal geometry and the application of fractal geometric methods. The distribution and scale of fissures and cracks in such rock were revealed. These studies provided a greater understanding of some of these laws of nature (La Pointe, 1988; Hirata, 1989; Turcotte, 1989; Amitava et al., 1993; Xie, 1993; Boadu and Long, 1994; Ankur et al., 2007).

Barton and Larsen (1985) and Aviles et al. (1987) studied the pattern of distribution of natural geological cracks and fractures. However, the number of fractures with changes of scale had seldom been studied or described. In this study, fractures and cracks in geological sequences were grouped, including those in the main groups and subgroups. So what is the law concerning the number of cracks and fractures with scale distribution in each group? We know that the fractures were caused principally by tectonic movement. The question is, whether or not the number of fractures and fissures are in scalar distribution with some of their mechanical features in the same rock strata. These are urgent issues that need to be researched.

Since 1990, systematic research of the distribution and number of geological fractures was carried out by the Taiyuan University of Technology for more than 20 coal zones (Kang et al., 1995; Zhao et al., 2002, 2005; Song, 2006). The fractal law for the number of fissures in different-scale coals and enclosing strata, with the scale distribution, was revealed. Further research shows that the number of large-scale geological cracks, faults and fractures still follow the fractal distribution according to trend groups and non-conditions. Through mechanical testing of fractured rock, fractal distribution from a few integrated drilling cores, the number of fractures, the fractal dimension and the strength of the rock modulus were studied in the different lithologies of the same rock sequences. These laws are of considerable significance and are valuable as reference resources for forecasting the number of rock fissures, fractures and faults, with their distribution scales, for geological research and engineering design. More details will be given in succeeding sections.

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Table 1
Number of fracture traces and fractal dimensions of in situ coal mass.

Samples	Original scale L_0(m)	Specimen numbers	Fractal dimension	Std.	Dev
Working face 8902,Xin Zhou Yao Colliery	0.5	7	1.6973	0.1514	0.0892
2341 working face, Feng Huang Shan Colliery	0.5	8	1.5820	0.0778	0.0492
8701 working face, the first colliery of Yang Quan	1.0	6	1.6640	0.0335	0.0201
6111 working face, Wang Zhuang Colliery	0.5	6	1.6130	0.1175	0.0728
6102 lane, Shui Yu Colliery	1.0	7	1.4828	0.071	0.0479

Table 2
Fracture number and fractal dimensions of coal samples accounted in laboratory ($L_0 = 100$ mm).

Sample	Specimen number	Fractal dimension (D)	Std.	Dev.
Coal #11, Xin Zhou Yao Colliery, Da Tong	9	1.4502	0.1577	0.1087
Coal #3, Bao Dian Colliery, Yan Zhou	12	1.4049	0.1057	0.0765
Coal #3, Yong Hong	9	1.6380	0.0935	0.0571
Coal #3, Nan Tun, Yang Zhou	9	1.3813	0.1028	0.0744
Coal #3, Xing Long Zhuang Colliery, Yang Zhou	13	1.4390	0.1618	0.1125
Coal #3, the first colliery, Yang Quan	6	1.4490	0.1269	0.08758
Coal #12, the third colliery, Wu Da	12	1.6500	0.2434	0.1475
Coal #10, Shui Yu Colliery, Fen Xi	9	1.4590	0.1357	0.09298
Coal #8, Xi Ming Colliery, Xi Shan	9	1.6585	0.0957	0.0577
Coal #3, Wang Zhuang Colliery, Lu An	9	1.6920	0.1192	0.07045
Coal #3, Dong Tan Colliery, Yang Zhou	14	1.3272	0.10598	0.0833
Coal #8, Xi Qu Colliery, Xi Shan	12	1.7574	0.1175	0.0669
Coal #3, Gushuyuan Colliery, Jin Cheng	9	1.6826	0.1294	0.0769
Coal #1, the fifth Colliery, He Bi	12	1.6826	0.1391	0.0827
Coal #1, Bai Long Colliery, Huo Xian	10	1.6825	0.1163	0.0691
Coal #9, Guan Di Colliery, Xi Shan	9	1.7990	0.1366	0.076
Coal #2, Jia Le Quan	9	1.6043	0.1911	0.1192

2. Fractal study method of fracture traces with distribution numbers

The number of fractures in different-scale gridding can be interpreted by the 2D box counting method in fractal geometry (La Pointe, 1988). The observation, counting and analysis method can be summarized briefly as follows. For the measured geological mass, an area must be chosen with an original scale L_0 to observe and count the number of fractures whose length is larger than or equal to L_0 in the area. This work then would be repeated in a quarter of the original area with a length of $L_0/2$, observing and counting the number of fractures whose length is larger than or equal to $L_0/2$ in the area. Next, iteratively observe and count the number of fractures whose length is larger than or equal to $L_0/2^{n-1}$ in all the square grids of the $L_0/2^{n-1}$ scale. The relationship between the fracture trace number (N) in a certain scale grid and the grid scale (L) is

$$N = N_0 L^{-D}. \quad (1)$$

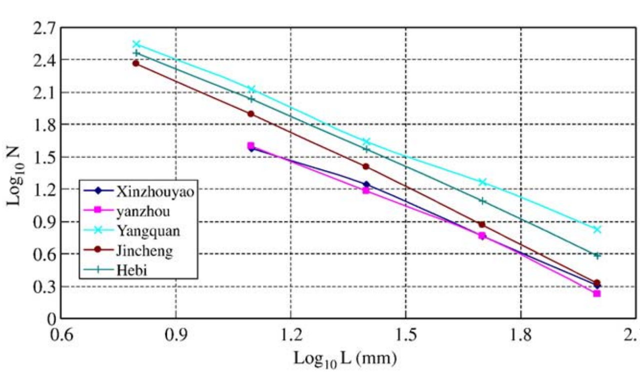

Fig. 1. Fracture number and fractal dimensions of a coal sample ($L_0 = 100$ mm), based on Table 2.

where N_0 is the original value of the fracture number distribution and D is the fractal dimension, meaning the number of fractures in the geological mass of unit scale. For convenient discussion, the following conception and definition are introduced. The fracture distribution in a certain scale of geological mass can, in fact, be determined by four parameters: fracture number, fracture length, definite position and fracture direction. The fractal law of fracture traces of the distribution number actually describes only the relationship between the number of fractures and the scale of the geological mass, but the position and the direction of the fractures still are not obtained. In nature the fracture strike can be determined by tectonic grouping; however, the definite position of the fracture is still hard to determine. Thus the following two situations are considered: (1) If both the position and the direction of the fracture follow random distribution, this is termed heavy random fracture distribution. (2) If the strike of the fracture can be grouped by geological observation, and its position only randomly distributed, this is termed weak random fracture distribution. In rock mass engineering, following the concept of fracture fractal distribution, the original value N_0 is significant: the original value of N_0 and the fractal dimension D together determine the fracture-trace-number distribution. For the sake of discussion, the original scale L_0

Table 3
Statistics of micro-fissures in coal specimens and fractal dimension of ($L_0 = 1$ mm).

Coal specimen	Specimen numbers	Fractal dimension	Std.	Dev.
#11, Datong	5	1.4074	0.0035	0.0025
#8, Zhenchengdi	3	1.7333	0.0731	0.0420
#8, Xiqu	4	1.6340	0.0110	0.0064
#3, Yangquan	5	1.6005	0.1804	0.1127
#2, Hebi	6	1.5181	0.040	0.0264
#8, Ximing	7	1.6335	0.0634	0.0388
#15, Yinying	4	1.8449	0.0211	0.0114
#3, Tangan	4	1.3659	0.0280	0.0265
#3, Yonghong	5	1.4471	0.1484	0.1026
#3, Jincheng	5	1.2752	0.0142	0.1110