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Fractal character of lenticles and its influence on sediment state in tailings dam①

JIANG Wei-dong(蒋卫东)[1,2]

(1. School of Resources and Safety Engineering, Central South University, Changsha 410083, China;
2. School of Business, Central South University, Changsha 410083, China)

Abstract: The distribution of tailings lenticles reflects the sediment state of tailing dam, and has a great influence on the stability of the dam. In order to disclose the distribution law of tailings lenticles in theory, 12 geological cross-sections, including 7 cross-sections of tailings dam constructed by the upstream method and 5 cross-sections by the middle line method, were analyzed with box dimension method. The results show that the distribution of tailings lenticles has better fractal character with box dimension from 1. 290 7 to 1. 513 6. The box dimension of the tailings dam constructed by upstream method is nearly 1. 50 and that by middle line method is 1. 30. Thereby the values of lenticles dimension have obvious relation to the method of constructing dam, and reflect the sediment state of tailings dam with the rule that smaller value means better state.

Key words: tailings dam; box dimension; fractal; tailings lenticles

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1 INTRODUCTION

Under the influence of the various factors, such as a series of tailings with different particle's diameters and tailings disposal, the process of tailings sediment is very complicated. The arsenic disposal practice of the metallurgical industry and the sediment of the disposed arsenic compounds were reviewed by Riveros et al[1]. Wind-wave-induced suspension of mine tailings in disposal pond was studied by Lawrence et al[2] with implicit finite difference. Samad et al[3] used linear wave theory and countercurrent flow profiles to obtain the total bottom shear stress, which was then compared with the critical shear stress of the tailings to predict the onset of erosion and resuspension and to compute the resulting mass of suspended tailings. Tailings sedimentation was studied by Consoli[4] applying implicit finite difference. Tailings cohesiveness and compression, which are influenced by the change of chemical hydrogeology, were researched by Cao et al [5]. Tailings lenticles can be formed in different shapes in the tailings dam inevitably for there is a complex sediment process in tailings.

The presense of tailings lenticles has brought about negative influence on the stability of the tailings dam and the circumstance of the tailings reservoir under which seepage in tailings dam is affected and the pore water pressure transmission is changed inhomogeneously[6-9]. As to the distribution of tailings lenticles, there is no good research method except drilling so far, therefore, Blight[10] thought that the research of the mechanism of tailings sediment is very important to tailings dam. In this paper, based on engineering geological principal sections of tailings dams in No. 2, No. 4 of Dexing Copper Mine, Yongping Copper Mine, Yingshan Pb-Zn Mine, Dongxiang Copper Mine, Wushan Copper Mine and an Anhui Copper Mine, the distribution rule of tailings lenticles was studied by fractal geometry.

2 BOX DIMENSION

Box dimension is also called Minkowski dimension, capacity dimension[11].

The box dimension of a set S contained in n is defined as follows: For any $\varepsilon>0$, let $N_\varepsilon(S)$ be the minimum number of n-dimensional cubes, side-length ε needed to cover S. If there is a number D, such that

$$N_\varepsilon(S)\sim 1/\varepsilon^D \quad \text{for} \quad \varepsilon\to 0$$

We say that the box dimension of S is D, and denote this by $S=D$.

Note that the box-counting dimension is D if and only if there is some positive constant k such that

$$\lim_{\varepsilon\to 0}\frac{N_\varepsilon(S)}{1/\varepsilon^D}=k \qquad (1)$$

Since both sides of Eqn. (1) are positive, it will still hold if we take the logarithm of both sides to obtain

$$\lim_{\varepsilon\to 0}(\ln N_\varepsilon(s)+D\ln\varepsilon)=\ln k \qquad (2)$$

Solving D gives

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Correspondence: JIANG Wei-dong, PhD, Senior engineering; Tel: +86-701-3777340; E-mail: w. d. jiang@163. com

$$D=\lim_{\varepsilon\to 0}\frac{\ln k-\ln N_\varepsilon(\varepsilon)}{\ln\varepsilon}=-\lim_{\varepsilon\to 0}\frac{\ln N_\varepsilon(S)}{\ln\varepsilon} \qquad (3)$$

Note that the term $\ln k$ drops out because it is a constant while the denominator becomes infinite as $\varepsilon\to 0$. Also, since $0<\varepsilon<1$, $\ln\varepsilon$ is negative, so D is positive as we expect.

3 BOX DIMENSION CALCULATION OF TAILLING LENTICLES

12 engineering geologic sections of tailings dam in No. 2, No. 4 of Dexing Copper Mine, Yongping Copper Mine, Yingshan Pb-Zn Mine, Dongxiang Copper Mine, Wushan Copper Mine and Anhui Copper Mine were investigated. The results show that all tailings dams were constructed by the upstream method except the tailings dam No. 4 by the middle line method。 The tailings lenticles in the engineering geologic investigation sections were speculated by combining their explored length from drill hole with their changed characteristics which can reflect the space shape of tailings lenticles, and we can analyze these sections. The tailings lenticles in the engineering geologic investigation sections have a reference to the sampling intervals and assessing standards. It is difficult to get the fractal characteristics which come from different sampling intervals or different clay layer's assessing standards. The same sampling interval and assessing standards above mentioned engineering geologic investigation sections of tailing dams are adopted by and large. Fig. 1 shows the typical engineering geologic investigation sections of tailings dam which are constructed by the upstream method and the middle line method, respectively. In the common investigation section, the horizontal and vertical scales are different. In order to calculate the fractal dimension of the tailings lenticles, the scales must be changed into the same。

Fig. 1 is overlaid by the gridding in r dimension to count the gridding amount of tailings lenticles for getting $N(r)$. And then, we minish r according to multiple of 1/2, and get corresponding $N(r)$. Furthermore, calculating with Eqn. (3), the results are shown in Fig. 2.

According to calculating results, there exits self-similarity in Fig. 2, and the tailings lenticles have fractal character. The values of the dams constructed using upstream method are got as follows: principal section of tailings dam No. 2 in Dexing Copper Mine is 1.502 4, $E-E'$ section 1.504 6, principal section of tailings dam in Yongping Copper Mine 1.453 1, principal section of tailings dam in Yingshan Pb-Zn Mine 1.492 8, principal section of tailings dam in Dongxiang Copper Mine 1.466 7, principal section of tailings dam in Wushan Copper Mine 1.513 6, principal section of tailings dam in an Anhui Copper Mine 1.483 6, $A-A'$ section of tailings dam No. 4 in Dexing Copper Mine 1.335 1, $B-B'$ section 1.313 1, $C-C'$ section 1.296 4, Ⅲ-Ⅲ′ section 1.308 1, Ⅳ-Ⅳ′ section 1.290 7.

Through separating the tailings by adopting the cyclone, the middle line method improves the sediment state of tailings dams and is better than the upstream method. The fractal dimensions of

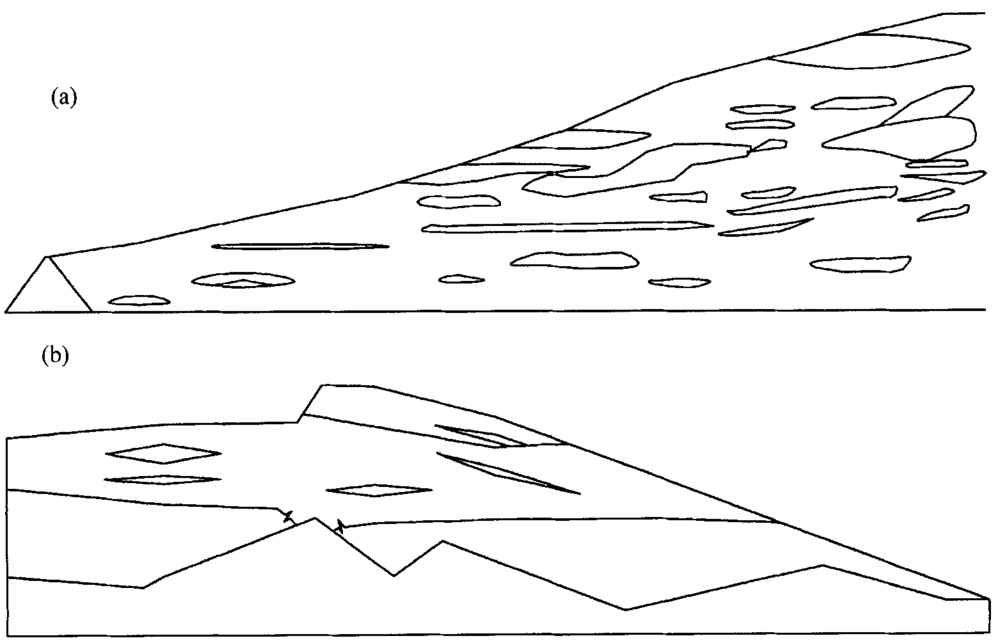

Fig. 1 Distributing state of lenticles
(a)—Principal section of tailings dam No. 2 in Dexing Copper Mine;
(b)—$A-A'$ section of tailings dam No. 4 in Dexing Copper Mine

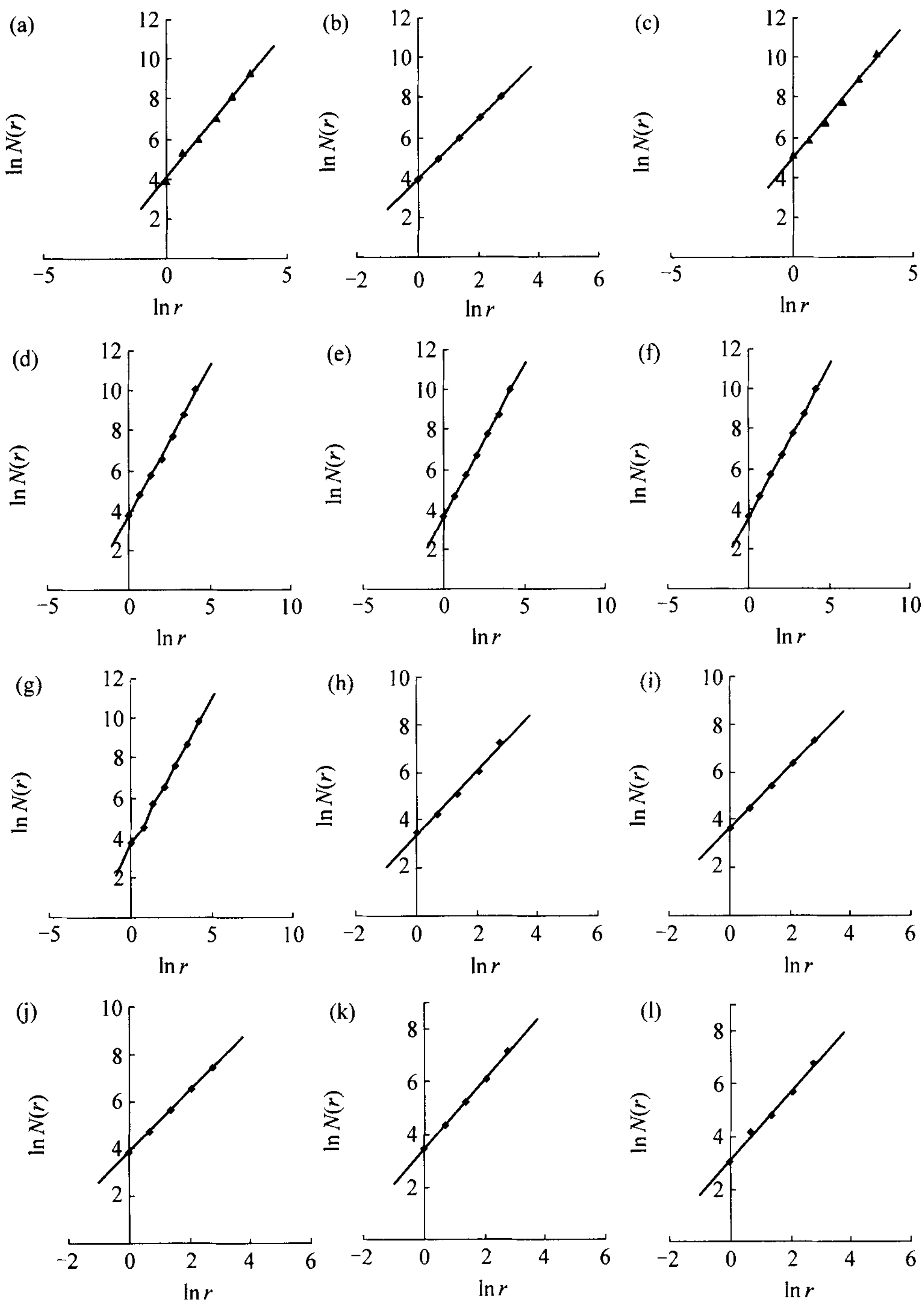

Fig. 2 Calculating results of box dimension
(a)—Principal section of tailings dam No. 2 in Dexing Copper Mine;
(b)—E-E' section of tailings dam No. 4 in Dexing Copper Mine;
(c)—Principal section of tailings dam in Yongping Copper Mine;
(d)—Principal section of tailings dam in Yingshan Pb-Zn Mine;
(e)—Principal section of tailings dam in Dongxiang Copper Mine;
(f)—Principal section of tailings dam in Wushan Copper Mine;
(g)—Principal section of tailings dam in Anhui Copper Mine;
(h)—A-A' section of tailings dam No. 4 in Dexing Copper Mine;
(i)—B-B' section of tailings dam No. 4 in Dexing Copper Mine;
(j)—C-C' section of tailings dam No. 4 in Dexing Copper Mine;
(k)—Ⅲ-Ⅲ′ section of tailings dam No. 4 in Dexing Copper Mine;
(l)—Ⅳ-Ⅳ′ section of tailings dam No. 4 in Dexing Copper Mine

the 5 tailings lenticles sections by the middle method are less than those of the 7 sections by the upstream method. The sediment state of the tailing dam shows that smaller value means better state.

In the traditional stability evaluation of tailings dam, the experience and numerical computational method are often used. The stability of dam is evaluated by analysis of the engineering geologic investigation data including the distributing state of tailings lenticles. There are more errors in the analysis method and cannot discover the engineering geologic investigation data scientifically. But being analyzed by box dimension method, the tailings lenticles distribution rule is discovered from physical nature. The relation between the fractal dimension of tailings lenticles and the sediment state of tailing dam may have significant meaning for survey, management, design, and evaluation in tailings dam.

4 CONCLUSIONS

1) The distribution of tailings lenticles has fractal character. The values of lenticles box dimension are between 1.290 7 and 1.513 6. The value of the tailings dam constructed by upstream method is close to 1.50, and that by the middle line method close to 1.30.

2) The values of lenticles box dimension have relation with the construction method, and reflect the sedimentation state of tailings dam with the principle that the higher value means the better sedimentation state.

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