Available online at www.sciencedirect.com
SCIENCE DIRECT
International Journal of Rock Mechanics & Mining Sciences 43 (2006) 512–519
International Journal of Rock Mechanics and Mining Sciences
www.elsevier.com/locate/ijrmms

Estimation of a joint diameter distribution by an implicit scheme and interpolation technique

Jae-Joon Song*

School of Civil, Urban and Geosystem Engineering, Seoul National University, San 56-1, Shilim-dong, Kwanak-gu, Seoul 151-742, Korea

Accepted 19 September 2005
Available online 2 November 2005

Abstract

A new technique to estimate the diameter distribution of a joint set from the contained trace length distribution is suggested. This technique obtains the diameter distribution directly from the sample histogram of the contained trace lengths without using any information about the trace length distribution of an infinite window. Compared with the previous method of Song and Lee [Estimation of joint length distribution using window sampling. Int J Rock Mech Mining Sci 2001; 38: 519–28], it is more accurate for small-size joint samples. To obtain more accurate estimates, we adopt an interpolation technique of B-spline to smooth out the sampled contained trace length distribution. The effect of the B-spline as a function of three kinds of predefined diameter distributions is examined by Monte Carlo simulations.

Keywords: Implicit scheme; Diameter distribution; Contained trace length; B-spline

1. Introduction

As rock mechanics and computer technologies advance, rock engineers have shown increasing interest in discontinuum models of rock mass. The success of discontinuum analysis greatly depends on how correctly in situ joints are surveyed and modeled for the analysis. From a geometric point of view, 3-D modeling of rock joint requires joint parameters such as the frequency, orientation, size, location and shape, all of which are represented by probabilistic distributions. The in situ joints are measured on scanlines or in sampling windows. The joint orientation, frequency, and size provided by field measurement are biased values or distributions due to the constrained orientations and sizes of the sampling zones. The process of removing the bias and guessing of the population values and distributions is the statistical estimation of the joint parameters.

The joint size is one of the most difficult properties to measure accurately [2,3]. When the joints are assumed to follow the Poisson disc model [4], that is, the shape of a joint is of a disc and its center is located randomly in 3D space, joint diameter can be obtained by two kinds of approaches: one, the trial-and-error method [2] and the other, mathematical inference of the diameter distribution from a sampled trace length distribution [1]. In the first approach, the type and parameters of the diameter distribution are repeatedly adjusted until the error between the sampled distribution and theoretical distribution of trace lengths becomes lower than a predefined threshold value; for this reason, this approach is called a distribution-dependent method. One of the representative techniques of the distribution-dependent method is 'forward modeling' suggested by Dershowitz [5]. This technique does not need any form of integration functions or complex mathematical conversions in the estimation process. It, however, generally yields a solution by using a parametric estimation, so it only provides the diameter distribution defined by parameters such as the mean and the standard deviation. In the second approach, the distribution-independent or distribution-free method, the trace length distribution defined in a virtual infinite sampling window is inferred from the sampled trace length distribution and

*Tel.: +82 2 880 9043.
E-mail address: songjj@snu.ac.kr.

1365-1609/$ - see front matter
doi:10.1016/j.ijrmms.2005.09.009

then, the diameter distribution is obtained from the inferred trace length distribution [6–9]. The second approach uses an integration function to estimate the diameter distribution from the trace length distribution in an infinite sampling window, which is estimated from the trace or semi-trace length distribution of a scanline sampling or window sampling [1,10].

Song and Lee [1] suggested an estimation technique of the trace length distribution of an infinite window. This technique uses a contained trace length distribution. The contained trace is a trace whose both end points are located in the sampling window [2,11]. They also estimated the diameter distribution from the trace length distribution by numerically converting the integration function of the diameter and cumulative trace length distribution suggested by Warburton [9]. Song and Lee [1] showed that the trace length distribution of an infinite window could be estimated more efficiently or accurately by using the contained trace lengths rather than the dissecting trace lengths of a window sampling or the complete trace lengths of a scanline.

This study develops a new approach for the estimation of the diameter distribution from the contained trace length distribution. With the new approach, the trace length distribution of an infinite window is not required for the estimation of the diameter distribution, but rather, the diameter distribution is directly obtained from the sample histogram of the contained trace lengths by the least square method. To obtain more accurate estimation results, we apply an interpolation technique of the B-spline to smooth the sampled contained trace length distribution.

2. Estimation of the joint diameter distribution by the least square method

2.1. Basic assumptions and definitions

Joints are assumed to be circular discs with center points randomly distributed in a 3D rock mass (Poisson disc model). All of the joints belonging to a set are parallel to each other, so their traces are also parallel. Each set is to be analyzed and estimated for its own joint diameter distribution. Sampling windows are assumed to be big enough so that censoring bias can be ignored. Remaining as future work, the censoring bias problem could be solved by using the proportions of joint trace types such as 'contained' and 'dissecting' , which play a principal role as in La Pointe et al.'s solution [12].

This study estimates the joint diameter distribution of a set. Therefore, here, only the parallel joints and parallel joint traces are investigated. For this purpose, let the contained joint trace length be sampled at a rectangular sampling window having for width and height, W and H, respectively. Let the joint traces whose length is l make an acute angle with the boundary line of the sampling window, as shown in Fig. 1.

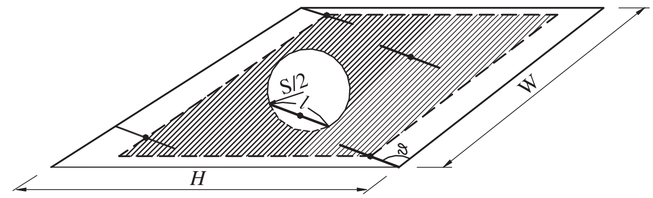

Fig. 1. Joint discs and traces in a rectangular sampling window.

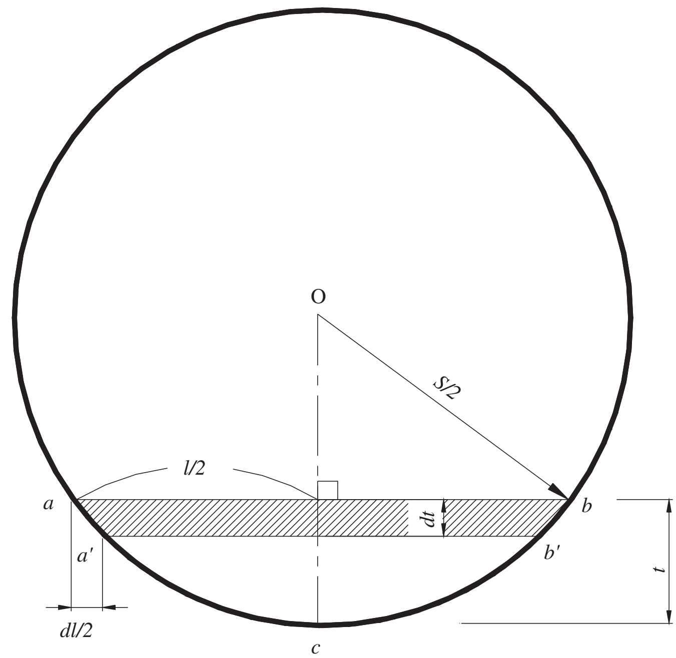

Fig. 2. Radial distance dt of a joint disc corresponding to the trace length variation of dl.

The center points of contained joint traces having a length of l can exist in the shaded zone, whose area A_l^c is obtained as follows [4].

$$A_l^c = (W - l\cos\theta)(H - l\sin\theta). \tag{1}$$

Any joint disc can make a contained trace length l in the sampling window only if its diameter is equal to or greater than l and is properly located near the sampling window. The joint disc centers are theoretically located in a rectangular plane at a certain distance from the sampling window, and the rectangular plane has the same area as the trace center zone defined by Eq. (1). In a real situation, however, it is more practical to consider the region of disc centers as a hexahedral volume rather than as a rectangular plane. This is because the trace length distribution obtained after a joint survey is not a continuous function but a histogram that has discrete length divisions. Let's consider this in more detail. Fig. 2 shows a joint disc of diameter s intersecting a sampling window and making a trace length l. A line is drawn from the disc center O to the disc boundary c intersecting the midpoint of trace $\overline{ab}$. The