Paper 103, CCG Annual Report 12, 2010 (© 2010)

Relating Different Measures of Fracture Intensity

Eric B. Niven and Clayton V. Deutsch

An important parameter in fracture modeling is fracture intensity. In this paper, measures of fracture intensity are reviewed. A methodology for calculating 3D fracture counts from 1D fracture counts is presented. In addition, an algorithm for converting 1D fracture count to volumetric fracture intensity, P32, is discussed. Computer programs to perform these calculations are presented.

1. Introduction

Fracture patterns are described in terms of distributions for orientation, size, shape, spatial location and intensity. Fracture intensity refers to the amount of fractures in a given rock mass and is often used because terms such as 'fracture spacing' ignore issues of orientation bias, spatial arrangement and discontinuity size (Golder Associates 2010).

Dershowitz and Herda (1992) define a class of fracture intensity measures in one, two and three dimensions. Dershowitz and Herda classify fracture intensity measures based upon the dimension of the measurement region and the dimension of the fracture. Modern fracture modelers generally characterize fracture intensity in one of the following ways:

- P_{10}: Lineal fracture intensity, expressed as the number of fractures per unit length (L^{-1}).
- P_{20}: Areal fracture intensity, expressed as the number of fractures per unit area (L^{-2}).
- P_{30}: Volumetric fracture intensity, expressed as the number of fractures per unit volume (L^{-3}).
- P_{21}: Areal fracture intensity, expressed as length of fracture traces per unit area (L^{-1}).
- P_{32}: Volumetric fracture density, expressed as the area of fractures per unit volume (L^{-1}).
- P_{33}: Fracture porosity, expressed as the volume of fractures per unit volume of rock (dimensionless).
- Fracture Counts: The total number of fractures. Can be measured along a line, in an area, or in a volume.

The letter 'P' refers to the term persistence and the subscripts refer to the dimensionality of the region and the fractures, respectively. Thus, P32 is the area of fractures (2nd dimension) per unit volume of rock (3rd dimension.

P10, P21 and P32 are scale and orientation independent, and for that reason, are preferred for modeling purposes (Dershowitz and Herda 1992, van Dijk 1998, Zhang and Einstein 2000, Makel 2007). Dershowitz and Herda (1992) also develop relationships between the intensity measures based on methods of stochastic geometry.

2. Calculating 3D Fracture Count from 1D Fracture Count

Fracture intensity is often measured in one dimension from a bore hole. However, in order to simulate a three-dimensional DFN, a three-dimensional fracture count is required. With knowledge of the number of intersections on a 1D borehole (a 1D fracture count) and some knowledge of fracture size, the 3D fracture count can be determined. Figure 1 shows an example of a fracture network intersected by a vertical borehole. The modeling grid cell is 80 distance units long and there are 10 fractures, which are all 20 distance units long contained within the grid cell. In this case, the borehole intersects 2 fractures.

Imagine drawing several vertical scan lines at random locations through the grid cell shown in Figure 1. Any such scan line would intersect between zero and five fractures. If enough scan lines were drawn we could determine an estimate of the average number of intersections.

Figure 2 shows the same modeling grid cell and fracture set. However, here the number of fracture intersections by vertical scan lines is noted at the bottom of the figure and it is also color coded such that darker shading equaling more fracture intersections.

If the number of fracture intersections is integrated over the length of the modeling grid cell, the average number of fracture intersections can be calculated as 2.2 intersections. This means that any grid cell that has a borehole intersecting 2 fractures, where the fractures are the same orientation as Figure 1 and the fracture size to grid size ratio is 0.25, should have a little less than 10 fractures.

A new fracture network can be created with more or less fractures, and for each one, the average number of intersections by vertical scan lines can be calculated. This results a curve, such as shown in Figure 3.

Not only can the number of fractures be varied, but their size and orientation can be varied as well. Essentially, this results in a simulation study.

The algorithm is as follows:

1. Start with some fracture intensity.
2. Start with some fracture length.
3. Simulate a DFN.
4. Choose a randomly located sampling line that runs parallel to the average fracture pole orientation. The sampling line will intersect some number of fractures, which are recorded. Then the average fracture spacing along that line can be calculated as the distance between those fractures that are intersected by the sampling line.
5. Many sampling lines may be needed to ensure smooth results. The number of lines requires depends on the size and amount of fractures. The number of sampling lines required is roughly inversely proportional to the size of the fractures. The smaller the fractures, the more sampling lines that are required to obtain a representative distribution of intersections for the DFN.
6. Go to 2, incrementally increasing fracture length.
7. Go to 1, incrementally increasing intensity.

The program `FIConvert` has been created using this algorithm to allow estimation of three-dimensional fracture count from one-dimensional fracture count. The result is a surface such as is shown in Figure 4.

For example, say that 40 horizontal fractures are measured along a 10 m borehole and assume we wish to simulate fractures in a 10 m cubic box. The fracture intensity is varied between 10 and 200 fractures (in the 10 m cubic box) in increments of 10 fractures. The fracture length is varied between 1 and 20 m, in increments of 1 m. The program requires that a normal distribution for the orientation of the fracture poles is specified. Since horizontal fractures are measured in the borehole, only horizontal fractures are used in the example. The result is shown in Figure 4. The legend refers to the one-dimensional fracture count, while the y-axis refers to the three-dimensional fracture count. The x-axis refers to the ratio between the size of the fractures and the size of the grid. Thus, if we assume that the average fracture size is 8 m and the domain size is 10 m, the ratio is 0.8. As is shown on the chart, this means that in order for a random borehole to intersect 40 horizontal fractures in the 10 m cubic domain of interest, there needs to be approximately 100 fractures, if the fractures are 8 m square.

3. Converting Grids of 1D Fracture Count to 3D Fracture Count

The above mentioned program, `FIConvert`, has the advantage that it can be used to determine a range of likely 3D fracture counts for a range of fracture sizes. However, the program is not suitable for converting realizations of 1D fracture count into 3D fracture count.

The program, `FC1Dto3D`, has been constructed to convert realizations of 1D fracture counts to 3D fracture counts using the same principles as above.

4. Converting from 1D Fracture Count to P_{32}

Many fracture modelers prefer to build fracture networks by matching the P_{32} fracture intensity. The P_{32} has the advantage of being scale independent. The program, `FC1DtoP32`, has been created to convert realizations of 1D fracture counts to volumetric fracture intensity. The algorithm is the same as above, except that the P_{32} is known instead of the 3D fracture count. Since fracture networks are simulated, the number of fractures simulated, their size and the size of the modeling grid block are all known. Thus, 3D fracture count and the P_{32} are also both known.

5. Conclusions

Fracture data comes in many varieties. Often times, fractures may be measured in one or two dimensions (P_{10} or P_{21}), while modeling is conducted in 3D. It may be useful to estimate either 3D fracture counts or volumetric fracture intensity (P_{32}) from the one or two-dimensional data. Three programs have been created, which rely on simulation of known fracture networks to estimate the three-dimensional parameters from their lower dimensional input data.

References

Dershowitz, W.S. and Herda, H.H. 1992. Interpretation of fracture spacing and intensity. *In* 33rd US Symposium on Rock Mechanics, Santa Fe, NM, pp. 757-766.

Golder Associates. 2010. FracMan7: Interactive discrete feature, data analysis, geometric modeling and exploration simulation. Golder Associates, .

Makel, G.H. 2007. The modelling of fractured reservoirs: Constraints and potential for fracture network geometry and hydraulics analysis, Geological Society, London, Special Publications, **292**(1): 375-403.

van Dijk, J. 1998. Analysis and modeling of fractured reservoirs. *In* SPE European Petroleum Conference, Hague, Netherlands, Vol. SPE 50570.

Zhang, L. and Einstein, H.H. 2000. Estimating the intensity of rock discontinuities, International Journal of Rock Mechanics and Mining Sciences, **37**(5): 819-837.

Figures

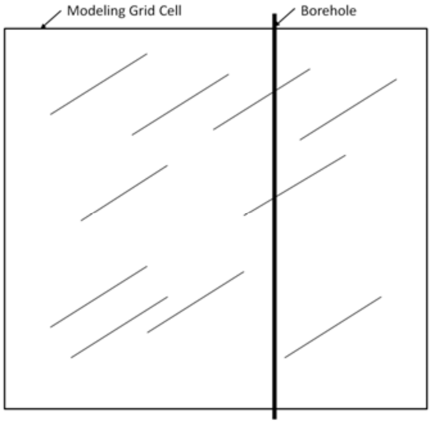

Figure 1: Estimating the amount of fractures in a modeling grid cell based on the number of intersections at the borehole, and an assumed fracture size distribution.

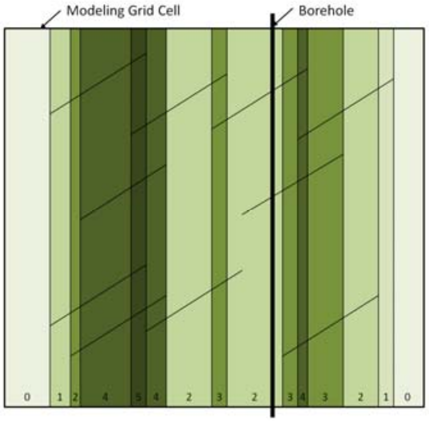

Figure 2: The modeling grid cell is color-coded to indicate the number of fracture intersections by a vertical scan line (the number of intersections are also indicated with numbers at the bottom of the figure).

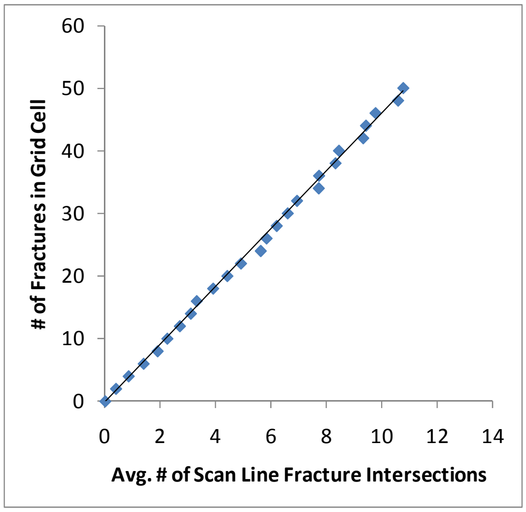

Figure 3: Number of fractures in a grid cell vs. average number of fracture intersections from a vertical grid cell.

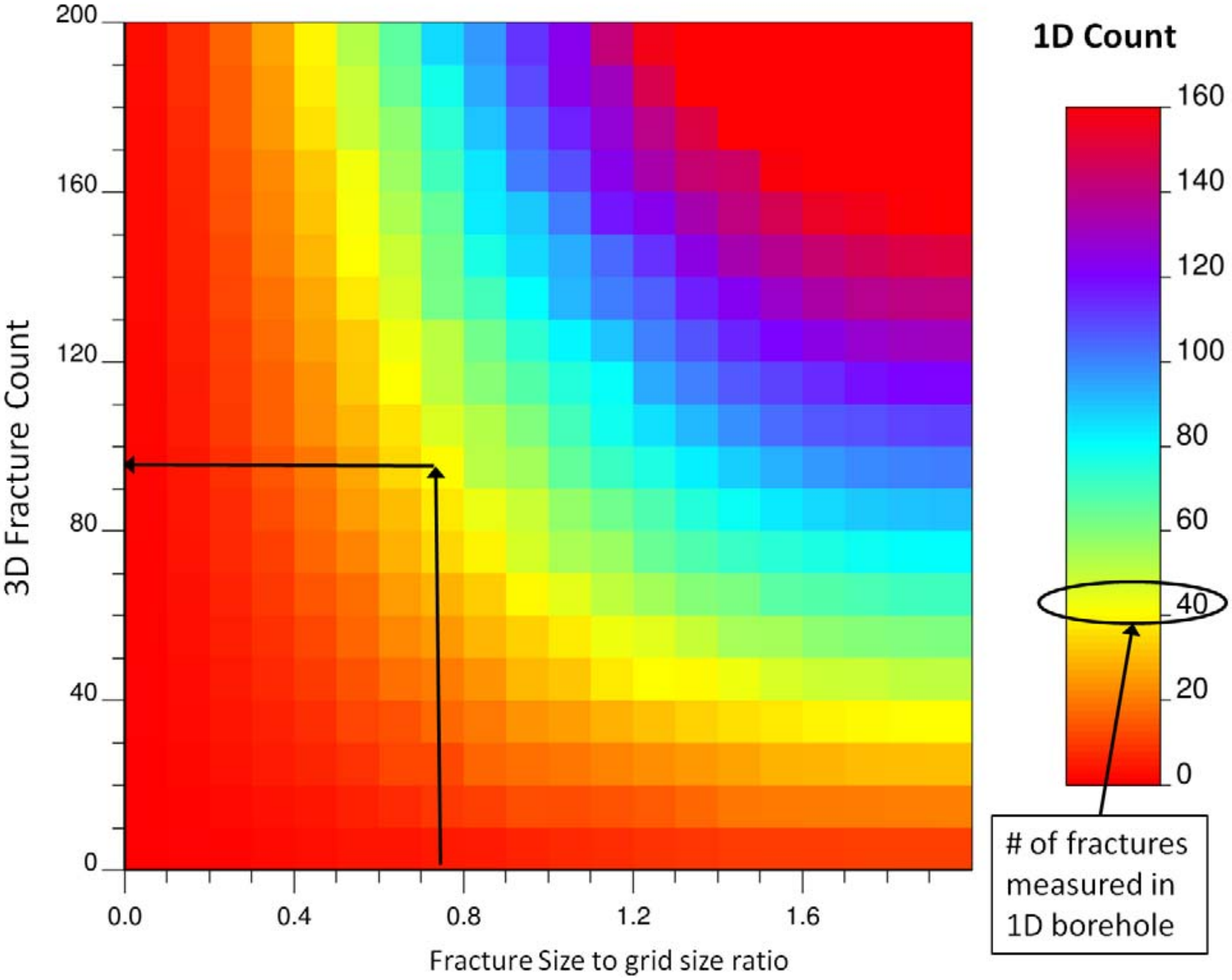

Figure 4: Estimating 3D fracture count from 1D fracture count.