A MODIFICATION OF THE RANDOM MIDPOINT DISPLACEMENT METHOD FOR GENERATING ROCK FRACTURE SIMILAR SURFACES

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ABSTRACT

Many phenomena of interest in rock mechanics and rock engineering have a strong dependency on the geometry of fractures inside the rock. The long term goal of this project is to develop a better understanding and prediction of grouting results. As a part of that, the mechanical and fluid mechanical processes inside inaccessible rock fractures needs to be modelled to raise the understanding of the processes involved and the parameters controlling these processes.

Measurements from a replica of a fracture at the Äspö hard rock laboratory in Sweden has been used as references while designing an algorithm that outputs geometries that could be used in simulations.

A method for generating self affine geometries statistically similar to rock fractures is proposed. This method is an isotropic modification of the random midpoint displacement method. The proposed method outputs geometries with properties similar of the measured surfaces.

The proposed method allows generation of geometries for simulation of rock fracture flow and stiffness and the results of some initial diffusive flow simulations are presented in this study.

1 INTRODUCTION

In the Nordic countries and in other countries with high quality hard crystalline rock, grouting is a commonly used method when sealing tunnels and other underground constructions. Grouting is an old and established method that in many cases provides an acceptable result. For constructions in urban areas or areas with sensitive environment or complicated geology, the reliability of current grouting methods is not high enough to conform to the higher sealing requirements. Uncontrolled grout spreading, hydraulic jacking and insufficient sealing are problems that are unacceptable in more advanced building projects. Grouting in rock and flow in rock is highly governed by the fracture density and the fracture properties (Fransson, [1]). Generally, flow in fractured rock is a widely studied area and specifically flow in fractures (Tsang & Tsang, [2]; Zimmermann & Bodvarsson, [3]). Concerning grouting several approaches to study flow in fractures have been presented (Hässler [4], Eriksson [5]).

In order to better understand and evaluate different grouting strategies it is important to understand how different fluids flow inside fractures and in what way real fractures differ from the fracture models used today. The usage of grouting pressure that exceeds the in situ stress in the rock might enable mechanical interaction between fractures in close proximity. In order to accurately describe these processes a realistic model of the fracture void and surfaces is needed. It is the long term goal of this project to develop that level of understanding.

The geometry of a fracture is a result of several parameters that are difficult to measure, such as the composition of the rock and its history of movements. In order to describe a fracture and its void its tortuousity, matedness, roughness and amplitude needs to be described as well as the geometry and frequency of any contact surfaces (Hakami [6]). The fracture can also be filled with fluid or clastic material from the rock or its surroundings. One approach to describe the geometry of fractures is to use self-affine geometries. There are several indications that the fractures can be described as fractal, self affine geometries (Fardin [7], Lanaro [8]). The measured values of the fractal dimension vary from study to study (Walsh et al [9]).

2 METHOD

The most commonly used method to generate self-affine geometries is the Random Midpoint Displacement Method, RMD (Miller, Gavin [10]) which is a method commonly used for landscape generation for movies and computer graphics. The RMD method starts with a simple geometry like a line or a plane and recursively adds random details to the geometry (Figure 1). When implementing the method in several dimensions it displays anisotropic artefacts. Since a rectangular mesh is used some directions become dominant. In such geometries vertical, horizontal and diagonal structures are overrepresented (Figure 2).

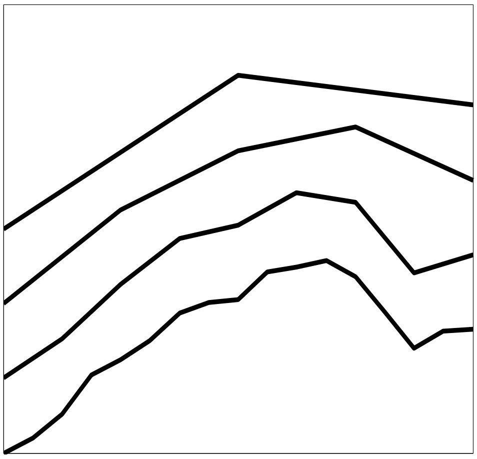

Figure 1: Four steps of the RMD method. The lines consists of 2^n elements with n=1 to 4 for the four lines.

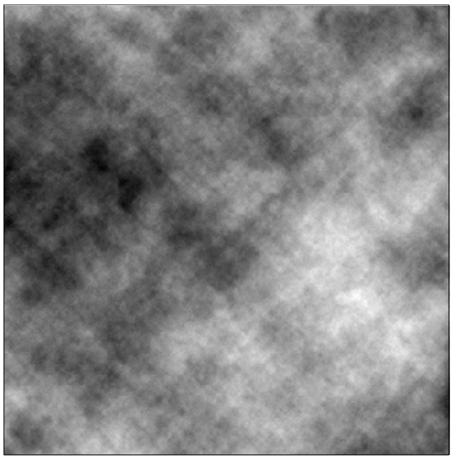

Figure 2: A height field generated by the 2-dimensional RMD. The structure has a strong influence of diagonal lines.

A new method for generating fracture similar geometries is proposed. This method is an isotropic modification of the RMD Method. Measurements that emanates from a exposed rock fracture surface at the Äspö Hard Rock laboratory is used as reference in this study. A silicon replica, 1000mm x 1000mm, was made and was used to make several concrete replicas of the fracture surface. These replicas where scanned with high precision in a 3D laser scanner. The work is thoroughly described in Fardin [11].

2.1 The box-counting dimension

If a surface's geometry is fractal it does not let itself to be described properly as surface nor a volume. By measuring the volume of the surface with increasing accuracy and observing by which manner the value of its volume converges the fractal nature of the surface can be measured. Such a measurement is called a box-counting measurement and is often associated with implemental difficulties. The box-counting dimension is often used as an approximate measure of the fractal dimension. No geometry existing in the nature lends itself to measurements with arbitrary precision why a box-counting measurement only describes how fractal a surface seems in limited scales.

2.2 Random field aggregation method (RFA)

In order to avoid the anisotropic problems with the RMD but still maintain the control of scale properties the method provides a modified random method has been developed. The proposed method does not base the generation of geometries on a regular rectangular mesh and it is not recursive.

For every level of scale the method generates a random unstructured mesh and every node in the mesh is assigned a random value, interpreted as the height in the same manner as the RMD method. When all nodes are assigned a value the mesh is triangulated by DeLaunay triangulation algorithm. If necessary the mesh is then interpolated to a rectangular mesh. The algorithm generates several of these random meshes with varying number of nodes and amplitude and sums them together. The result is a geometry with interesting properties. The algorithm can be described in the following steps.

1. Generate a irregular mesh with number of nodes N_i
2. Assign each node a height value from a normal distribution with the variance σ_i
3. Triangulate the geometry
4. If necessary, interpolate to a rectangular mesh
5. Repeat steps 1-4 the requested number of steps
6. Add the meshes together.

The fourth step is necessary only if the output of the algorithm is going to be used in an algorithm that requires the input to be defined on a rectangular mesh, it also facilitates step six. Figure 3 shows eight random fields with different scales before step 6 is performed. The average distance between a node in a mesh and its closest neighbour is proportional to the length of the side of the mesh divided with the square root of the number of nodes in the mesh $l_i = L / \sqrt{N_i}$. By choosing a variance σ_i, that is a direct function of the distance l_i to the power of a parameter H, a self affine structure with properties similar to that of the RMD method.

3 RESULTS

3.1 Box-counting-measurements

The box-counting dimension for the rock samples was measured to approximately 2.2. It is however not constant over all scales. It varies from roughly 2.5 for scales over 100 mm and drops to values closer to 2.0 for scales lower than 0.1 mm. The measurements give an indication of what scales the rock fracturing mechanisms are correlated

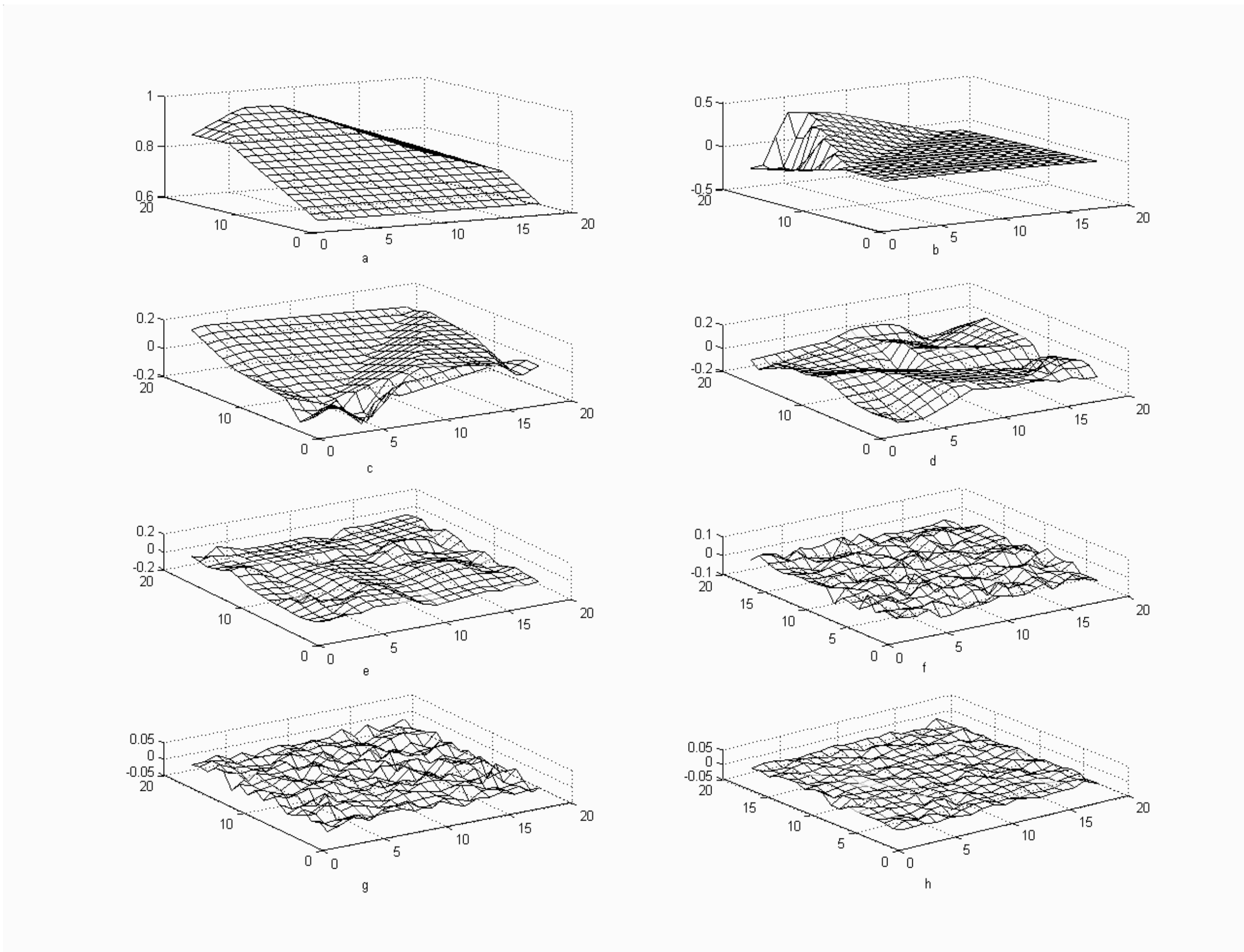

Figure 3: Eight different layers, each with increasing complexity and decreasing amplitude.

3.2 Fracture and transmissivity simulations

The RFA method was used to generate a void with similar box-counting dimension and amplitude as one of the measured surfaces. One realisation of a fracture based on the box-counting dimension 2.2 is presented in Figure 5. A naïve dimensionless transmissivity field simulation was performed to calculate the grout take of the fracture subjected to a grouting attempt in the centre of the fracture. The results can be seen in Figure 5. In Figure 4 the corresponding presentation for the measured data is shown. The simulated fracture has a slightly different behaviour at small scales which has yielded a somewhat denser pattern.

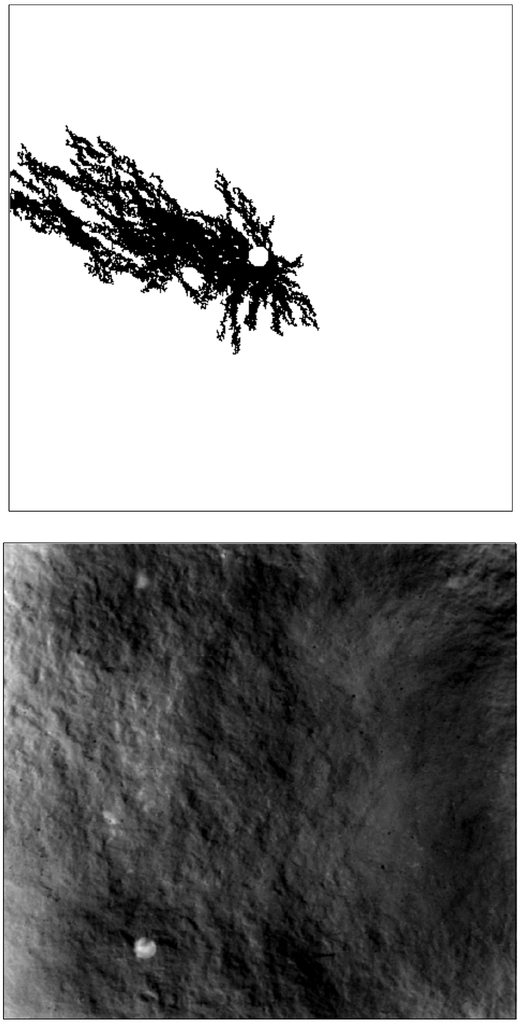

Figure 4: A measured fracture void and its corresponding simulated grout penetration pattern (above).

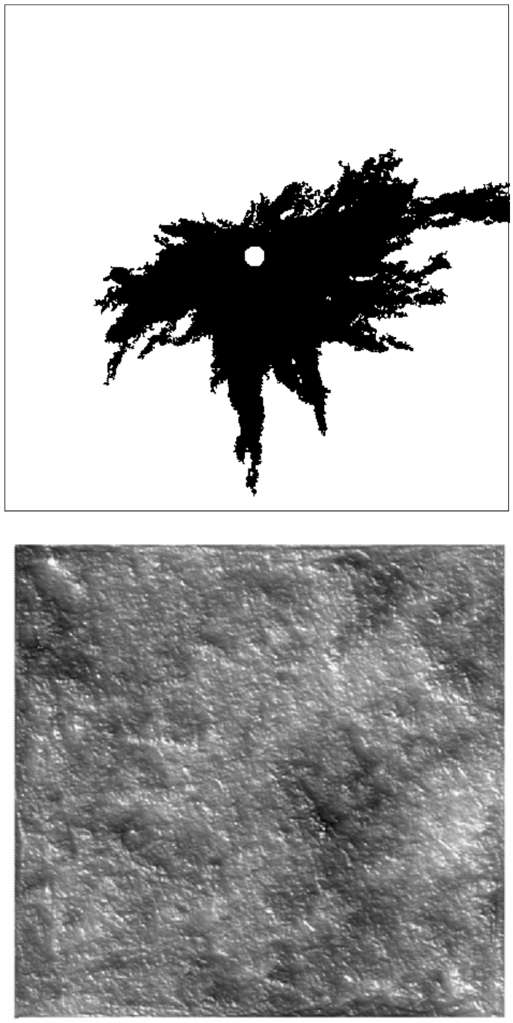

Figure 5: A simulated fracture void with similar aperture. Its simulated grout penetration pattern (above).

4 CONCLUSIONS

Artificial generation of fracture voids gives the possibility to simulate interesting rock mechanical phenomena and investigate their dependence on specific geometric parameters. Transmissivity field simulations of fluid flows inside fractures gives the possibility to better understand the hydro mechanical properties of the rock mass. The RFA method has shown promise of suitable character as a source of geometries for these kinds of simulations. The method indicates suitability for generating large amounts of data for Monte Carlo simulations of different parameters influence on grout flow and other rock mechanical processes.

5 ACKNOWLEDGEMENTS

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