Modelling of Fracture growth in rocks

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Introduction

The evolution of fractures in rocks is an area of active research in the department of Geology and Geophysics at the University of Edinburgh. The patterns of crack networks and crack propogation are complex and of great interest, as cracks provide pathways for fluid flow, and so predicting where cracks are is useful in areas such as determining water quality, the safety of nuclear waste disposal, and where oil is in crack reservoirs. This project seeks to advance the understanding of crack propogation by simulating the stresses on, and growth of, cracks in elastic rocks. It builds on extensive work already done by Dr Javier Sabadell [1].

Background

Dr Sabadell wrote a serial code to model the stresses round a system of cracks. His code applies boundary conditions, external and internal forces, and generates cracks and displays stresses. He then started work on a parallel code, called `elasem`. It is parallelised using a message passing interface (MPI) [2]. It reads in a grid and divides it up into elements according to the finite element method, and then uses a partitioning algorithm, METIS [3], to divide up the elements between the parallel processors. The calculations of the displacements of the nodes under an applied force are done using the *Aztec* parallel library [4], an iterative solver that simplifies the parallelisation process when dealing with linear systems of equations. Finally the code models the elasticity of a rock by displaying the displacements calculated. It was from this point that my project began.

Method

The method used is a numerical one. The `elasem` code has been extended by adding in cracks as failed elements, calculating the stresses acting on them, and eventually, showing how the cracks grow. A short script was written that could generate an input file of the correct format so that it could be read by `elasem`. The input file described a square grid, divided up into elements, with Dirichlet boundary conditions round all four edges, and forces acting vertically on the top edge. Figure 1 shows the grid used, and figure 2 shows how METIS divided it up between processors.

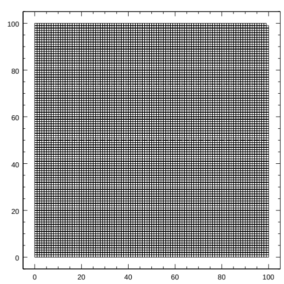

Figure 1 : The square grid.

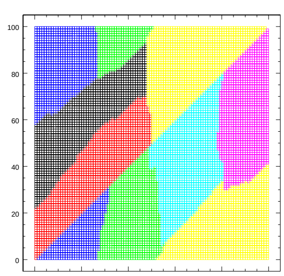

Figure 2 : Partitioned grid.

Cracks were generated by applying boundary conditions, forcing the displacements of the nodes to be zero at the points where the crack is. The code was modified to read in the start and end co-ordinates of a crack, and to apply boundary conditions at all the nodes between these co-ordinates. Thus the displacements of the cracked material under a force can be displayed. The following two figures show the output for a horizontal crack across the grid.

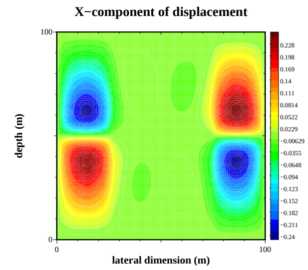

Figure 3 : x component of displacement.

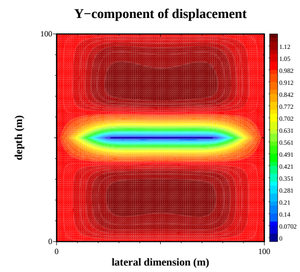

Figure 4 : y component of displacement.

Dr Sabadell is working on an additional piece of code to calculate the stress matrix using finite element method, and I have written a subroutine to calculate the stress matrix and invariants for a given gridpoint. However, my subroutine uses finite difference method, and so therefore relies on the grid being a square.

Future Developments

There are a few things that remain be done to model cracks propogating in rocks.

- The code should be modified to display the stress invariants rather than the displacements.
- The crack generating routine needs to be generalised to populate the domain with a random network of cracks. In order for the cracks to propagate naturally, a heterogeneous field strength will also have to be introduced. Then the program should be adjusted so that if the stress at the crack tip exceeded the field strength then the crack would be extended.
- The code should be modified to allow forces to have varying direction and strength, thus allowing opposing forces and forces that increase with time.

The code will be a very powerful tool for studying the fracture growth in rocks.

References

1. F. J. Sabadell. *1999 Tensile crack modelling: tests and preliminary results*, see http://www.glg.ed.ac.uk/˜sabadell/report/.
2. Marc Snir, Steve W. Otto, Steven Huss-Lederman, David W. Walker and Jack Dongarra. *MPI The Complete reference.* The MIT Press. 1996.
3. Family of Multilevel Partitioning Algorithms, see http://www-users.cs.umn.edu/˜karypis/metis/.
4. Sandia National Laboratories, see http://www.cs.sandia.gov/CRF/aztec1.html.