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The stochastic modelling and simulation of fractures in rock masses

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This lecture covers research in the stochastic modelling and simulation of fractures in rock masses conducted over the past 15 years at the University of Leeds and the University of Adelaide.

Rock fracture networks are the most significant means of fluid transport through rock masses, especially those at significant depths in the subsurface of the Earth. There are many important existing and emerging technologies that require accurate characterisation of such rock masses for the modelling and prediction of fluid flow and/or for associated risk assessment. These include hot dry rock geothermal projects in which artificial reservoirs must be created by stimulating fractures to enable geothermal flow; and the evaluation and construction of underground repositories for the safe storage and disposal of hazardous wastes for which potential contaminant flow through surrounding natural fractures must be quantified. Rock fractures and fracture networks also play a very significant role in many engineering applications involving rock masses. Examples include underground water transport through aquifers in hydrogeological engineering; movement of oil and gas in reservoirs in petroleum engineering; the production of gas from unconventional reservoirs; stability of slopes and underground openings in civil and mining engineering; cavability assessment in block caving mining applications; and the in situ recovery of mineral resources.

A fracture is a discontinuity in a rock mass. Characterising rock mass discontinuities is an extremely difficult problem, not least because accurate field measurement of a single discontinuity is difficult and measurement of all discontinuities is impossible. For these reasons, there is no observable reality on any meaningful scale and the only realistic approach is via a stochastic model informed by sparse data and/or by analogues; in this approach the presence and properties of discontinuities are interpreted as spatial random variables. The widely used deterministic approaches to the mapping of fractures in a rock mass at best provide only a partial solution and, at worst, give misleading solutions, as for example when discontinuity models are used for the assessment of fluid flow through rocks.

Data, from which model parameters can be derived, normally come from surveys of analogues, such as rock outcrops, or from direct or indirect observations of the rock mass such as drill cores, borehole imaging, geophysical surveys or seismic monitoring during fracture stimulation. A systematic and consistent means of integrating these various types of data is required.

As the fracture networks cannot be directly observed on any scale relevant to the applications there is no direct means of validating models. However, a form of indirect validation is to subject a proposed fracture model to a simulated process and compare the outputs to the response of the real fracture network to the actual process. For example, subject a fracture network model of a geothermal reservoir to fluid flow and heat extraction and compare the outputs to measured flow rates and steam production from the reservoir. Another option is to create a three-dimensional laboratory-scale ground-truth fracture network from which samples can be taken on a specified grid (fractures observed on a specific scale) and the data used to simulate (or estimate) the entire fracture network; each simulation or estimation can be compared with the ground truth, which comprises the entire known fracture network.

This lecture covers a range of methods for fracture modelling and simulation including truncated plurigaussian simulation; Markov Chain Monte Carlo optimisation; spatial clustering; random sample consensus (RANSAC); and point and surface association consensus (PANSAC). It also includes a public domain, ground-truth data set for validating models and an overview of a software package that implements all of our methods and is available to the research community under a free licence.

The methods are illustrated by applications to fracture network modelling and fracture propagation in hot dry rock geothermal reservoirs.