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Extension-fracture displacement and stress fields generated by fluid overpressure variations given by Fourier cosine series

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Many extension fractures are driven open by fluids such as ground water, geothermal water, gas, oil, and magma. These include fractures such as dykes, mineral veins, and many joints. Variations in fracture opening (aperture) commonly leads to flow channelling, which is of fundamental importance for understanding fluid transport in many reservoirs and volcanoes. Nevertheless, most analytical solutions for the apertures of fluid-driven extension fractures, and the associated displacement and stress fields, assume the fluid overpressure (the internal fluid pressure in excess of the minimum principal compressive stress acting on the fracture) to be constant or with a linear variation. While these solutions have been widely used for a variety of extension fractures, it is clear that a fluid-driven extension fractures in a heterogeneous and anisotropic rock mass is normally subject to fluid overpressure that is neither constant nor with a linear variation. We can solve some overpressure condition problems by superposition of some solutions given, for example, by a constant overpressure in range of linear elasticity because we can apply the superposition principle to the stress and displacement fields. However, difficulties arise with this method when more advanced problems (more complex overpressure conditions or host-rock properties) are treated.

Here we present new general solutions for the apertures and the associated displacement and stress fields of an extension fracture opened by an overpressure that varies

irregularly along the fracture walls but which variations can be given by the Fourier cosine series. We decided to derive analytical solutions in order to be able to solve advanced problems of extension fractures subject to complex overpressure variations without superposition. The solutions are two-dimensional and consist of the two displacement components and the three stress components. Each solution has two terms. The first term gives the displacement and stress fields generated by the average overpressure acting inside the extension fracture. Here, “average” means the average of overpressure values acting inside the fracture and is given by the initial term of the Fourier coefficients expressing the overpressure variation. The second term gives the displacement and the stress fields caused by differences between the average overpressure value and the actual overpressure variation. The differences between the average value and the actual overpressure variation are given by the general terms of the Fourier coefficients expressing the overpressure variation. The solutions given here can be used to estimate the displacement and stress fields around any type of fluid-driven extension fracture, as well as its aperture variation, so long as the (sometimes highly irregular) variation in overpressure inside the fracture can be described by Fourier series. We believe that the results have wide implications for better understanding flow channelling, as well as local stresses, displacements, and crack-crack interactions in fractured reservoirs, geothermal fields, fault zones and volcanoes.