SOTELO GAMBOA Edith (2023): Seismic reflectivity of fractures in low permeability rocks : the impact of poroelastic effects associated with damage zones

ABSTRACT

Large fractures tend to dominate the mechanical and hydraulic properties of the affected rock masses and, thus, their characterization is essential for a wide variety of subsurface applications. The strong mechanical contrast that large fractures often present with regard to their embedding backgrounds lends itself to the application of the seismic reflection methods for their detection and characterization. Recent work has shown that poroelastic effects between a large fracture and its permeable background can increase the normal compliance of the former and, thus, its reflectivity. However, many fractured settings of interest are associated with background rocks deemed impermeable for the seismic frequencies. There is, however, evidence to suggest that the prevalence of damage zones associated with large fractures can provide the necessary hydraulic communication for such poroelastic effects to prevail. This, in turn, signifies the plausible enhancement of the seismic visibility of large fractures, which, otherwise, could be undetected in these largely impermeable environments. To test this hypothesis, I investigate the impact that these poroelastic effects have on the compliance of large fractures and on their seismic reflectivity. To this end, I use a model that consists of a poroelastic homogeneous layered medium embedded in elastic half-spaces, where the layers represent the fracture-damage zone system and the half-spaces the embedding impermeable background, respectively. This modeling approach allows for the direct use of semi-analytical plane-wave solutions to compute both the normal fracture compliance and the reflectivity response of the fracture-damage zone system. The results show that there is an increase of the normal compliance and the reflectivity response of the fracture with respect to its hydraulically isolated reference as the result of poroelastic effects associated with the porous damage zone. On the other hand, damage zones are highly heterogeneous consisting of network of fractures at different scales. A heterogeneous porous medium can be described by a viscoelastic equivalent behavior, which results from poroelastic effects. Consequently, an efficient way to study the seismic response of highly heterogeneous porous media is to use their viscoelastic equivalents. Nevertheless, classical poroelastic-to-viscoelastic homogenization methodologies require the existence of a periodic hetii erogeneous structure and, thus, are not readily applicable to porous media that do no comply with this requirement as it is the case of fracture-damage zone systems embedded in a largely impermeable background. In this scenario, the estimation of the equivalent moduli is inherently affected by the boundary conditions associated with the embedding background. Thus, I have developed a methodology that naturally incorporates these boundary conditions. The proposed method focuses on the homogenization of porous seismic thin layers with non-periodic internal stratification embedded in largely impermeable backgrounds. I validate the proposed approach by considering a porous thin layer composed of two sandstone strata with different fluids embedded in impermeable shale. The results show that the viscoelastic equivalent closely reproduces the reflectivity response of the original porous thin layer. I apply a slightly modified version of the proposed homogenization method to extend the studies of poroelastic effects associated with damage zones surrounding large fractures. To achieve this, I consider a model consisting of a large fracture connected to secondary ones embedded in impermeable background, where the secondary fractures can be, for instance, part of the adjacent damage zone. I use this modeling approach to evaluate the impact on the seismic properties of the main fracture due to poroelastic effects associated with variations in the secondary fracture properties. I accomplish this goal as follows. First, I find the viscoelastic plane-wave modulus pertaining only to the main fracture by applying, as stated, a modified version of proposed homogenization method. Then, I use this modulus to estimate the main fracture compliance and its reflectivity response. The results show that the poroelastic effects associated with the secondary fractures increase the normal compliance and the normal-incidence PP reflectivity response of the large fracture from its hydraulically isolated reference. The results also show that variations in the secondary fracture properties affect in different degrees the seismic properties of the large fracture. Overall, these results suggest that connected secondary fractures can enhance the seismic visibility of a large fracture compared to its isolated counterpart.