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Unusual properties of high-compliance porosity extracted from measurements of pressure-dependent wave velocities in rocks

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Conventionally the interpretation of wave velocities and their variations under load is conducted assuming that closable cracks have simple planar shapes, like the popular model of penny-shape cracks. For such cracks, the proportion between complementary variations in different elastic parameters of rocks (such as S- and P-wave velocities) is strictly pre-determined, in particular, it is independent of the crack aspect ratio and rather weakly dependent on the Poisson's ratio of the intact rock. Real rocks, however, contain multitude of cracks of different geometry. Faces of such cracks can exhibit complex modes of interaction when closed by external load, which may result in very different ratios between normal- and shear compliances of such defects. In order to describe the reduction of different elastic moduli, we propose a model in which the compliances of crack-like defects are explicitly decoupled and are not predetermined, so that the ratio q between total normal- and shear- compliances imparted to the rock mass (as well as individual values of these compliances) can be estimated from experimental data on reduction of different elastic moduli (e.g., pressure dependences of P- and S-wave velocities). Physically, the so-extracted ratio q can be interpreted as intrinsic property of individual crack-like defects similar to each other, or as a characteristic of proportion between concentrations of pure normal cracks with very large q and pure shear cracks with $q \to 0$. The latter case can correspond, e.g., to saturated cracks in which weakly-compressible liquid prevents crack closing under normal loading. It can be shown that for conventional dry planar cracks, the compliance ratio is $q \sim 2$.

The developed model applied to the data on wave-velocity variations with external pressure indicates that elastic properties of the real crack-like defects in rocks can differ considerably from the usually assumed ones. Comparison with experimental data on variations P- and S-wave velocities with hydrostatic compression of different dry and saturated rocks (sandstones, Westerly granite and Webatuck dolomite, etc.) shows that our model is accurate in a wide range of pressures with constant (i.e., pressure-independent) values of parameter q. Furthermore, the determined values of the latter are considerably different from those of conventional cracks. In particular, although all saturated samples have values $q < 1$, the simplified approximation q=0 (i.e., the absence of normal compressibility that is often assumed for wet cracks) leads to large errors in the prediction of complementary variations in the shear- and bulk elastic moduli. Among dry sandstones, the majority have $q > 2$ and many sandstones exhibit unusually high q»1 suggesting quite rough and tortoise nature of real cracks in those rocks. We demonstrate that in such cases, the use of the conventional assumption $q \sim 2$ typical of penny-shape cracks leads to striking inconsistency between the predicted and experimentally observed crack-induced complementary variations in different elastic moduli. Furthermore, among samples with q»1, we revealed numerous examples that demonstrate negative Poisson's ratio at low pressures.

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