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Characterizing rock anisotropy and nonlinearity using a single uniaxial compression test

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The elastic deformation of many rock types is anisotropic and nonlinear due to their complex micro-structure. Taking rock anisotropy and nonlinearity into account allows accurate predictions of rock deformation under different loading types. Determination of the elasticity constants (both secant and tangent definitions) is therefore of crucial importance in a wide range of fields related to geomechanics and geophysics. An important application is related to so-called enhanced geothermal systems (EGS) or reservoirs. Previous methods to determine the elastic constants of anisotropic rocks require either multiple samples or multiple loading types. In this paper, we present a methodology to determine both secant and tangent values of elastic constants of anisotropic rocks using only a uniaxial compression test.

We developed a methodology to determine the static and dynamic values of the five elastic constants of transversely isotropic rocks from one cylindrical sample. We performed uniaxial compression tests on cylindrical specimens of granite, extracted from the underground rock laboratory in the Grimsel Test Site (GTS), Switzerland. These rock samples exhibit a clear foliation that induces anisotropy. Strains were measured at different polar angles around the circumference. Ultrasonic measurements were also conducted in order to obtain the orientation of the isotropy plane and the dynamic elastic constants.

The main conclusions of this research are as follows: 1) Not all five elastic constant can be determined exactly from one uniaxial compression test. Only the shear moduli can be determined exactly, while the rest of the elastic constant can be determined only when extra Information is provided with regard to one of the Young's moduli or Poisson's ratios, or a relationship among them. 2) Using the Saint-Venant relation as an extra equation provides a simple method to efficiently determine the five elastic constants of transversely isotropic rocks. 3) The presented methodology can efficiently determine both secant and tangent values of the elastic constants in transversely isotropic rocks from a minimum four strain gauge measurements. 4) Experimental results on Grimsel granitic samples yield average anisotropy ratios of two for the Young's moduli and the Poisson's ratios and 1.4 for the shear moduli. 5) The tangent values of the elastic constants show a significant stress dependency, where the tangent moduli increase by a factor of three to four when the rock is loaded up to about 20 MPa. 6) The comparison of the static and dynamic values of the elastic constants show that the dynamic values are significantly greater than the static ones and that the anisotropy ratio of static Young's moduli is larger than that of the dynamically determined ones.