# A Constitutive Law for the Shear Failure of Rock under Lithospheric Conditions

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## Abstract:

This paper first reviews recent studies on constitutive formulations for shear failure, which leads to the conclusion that revealing the constitutive property for not only frictional slip failure, but also shear failure of intact rock in the brittle to brittle-plastic transition regimes is critical to establish the constitutive law which governs earthquake shear failure that proceeds in the lithosphere. To this end, a unique, high stiffness testing apparatus capable of applying polyaxial stress fields to rectangular rock specimens, has been constructed, for which a brief description is given. The paper then presents new results of laboratory experiments on constitutive properties of shear fracture of intact granite at lithospheric conditions. In view of the physical principles and constraints to be imposed on the constitutive law for shear failure, the slip-dependency is a more fundamental property than the time- or rate-dependency, and hence the constitutive law for shear failure should primarily be slip-dependent. This slip-dependent constitutive law, which itself is self-consistent, can unifyingly and quantitatively treat the entire phases from stable, quasistatic ruture growth to unstable, dynamic fast-speed rupture propagation for shear failure of any type, whether it is frictional slip failure along a preexisting fault or shear fracture of intact materials. The slip-dependent constitutive law includes a scaling parameter $D_c$ (critical slip displacement) explicitly, which in turn is scaled by a characteristic length $\lambda_c$ representing geometrical irregularities of the fault surfaces. Incorporation of $D_c$ (or $\lambda_c$) enables this constitutive law to provide a common interpretation for shear failure of any size scale as an earthquake source, from small scale in the laboratory to large scale in the Earth. The present experiments corroborate the slip-dependent constitutive relation and other constitutive properties over the entire process from slip-strengthening to slip-weakening of intact granite, under the conditions that confining pressure is in the range 440 to 500 MPa, pore pressure is in the range 30 to 300 MPa, temperature is in the range from room temperature to 456°C, and strain rate is in the range $10^{-4}$ to $10^{-7}$/s. It is found that some constitutive law parameters are not independent, but mutually related. The constitutive relation for shear failure and the parameters such as $\Delta\tau_b$ (breakdown stress drop) and $D_c$ prescribing its relation, are affected by ambient conditions such as temperature and strain rate.

*Keywords: constitutive formulation; earthquake shear failure; brittle to brittle-plastic transition regimes; slip-dependent constitutive property; scaling of size-dependent properties*