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The role of stressing rate in state evolution under rate-state friction

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Abstract:
Traditional descriptions of state evolution in the rate-state friction framework do not explain the whole range of laboratory friction experiments. Nagata et al. (2012) have recently suggested that adding a stressing rate dependence to Dieterich (Aging) law state evolution, derived using ultrasonic P-wave transmissivity across frictional interfaces in granite as a proxy for the state variable, could remedy these deficiencies. For 1-3 orders of magnitude velocity step datasets on both rock and gouge, each dataset better fit by the Ruina (Slip) than the Aging law, the stressing-rate dependent Nagata state evolution produces fits identical to the Slip law as long as the stressing-rate parameter c is larger than a lower bound. This lower bound on c increases with the size of the excursion from steady state, ranging from $\sim 10 - 70$ over 2- to 3-orders steps as opposed to the $c = 2.0$ reported by Nagata et al. (2012) for their smaller departures from steady state. On the other hand, the Nagata law with $c \sim 2.0$ fits the stress minima at the end of a sequence of holds better than both the Aging and Slip laws but fails to match the evolution of peak stresses upon reslide after long holds. These disagreements with laboratory data and the variations in c under different mechanical conditions lead us to question both the mathematical form of the Nagata stressing-rate dependence and their assumed linear mapping between acoustic transmissivity and state. We investigate these issues using a set of large velocity steps and long slide-hold-slides (SHS) on bare rock complemented by ultrasonic monitoring of the frictional interface. Unlike the experiments of Nagata et al. (2012), we study the micro-mechanical details of frictional sliding far from steady state by using S-wave transmitted phases. Preliminary analyses show that the values of c for the best Nagata law fits to the stress data, which also lead to the best agreement between the Nagata law state variable and shear wave transmissivity, differ by almost an order of magnitude between large velocity steps and SHS tests during the same experimental run. The Nagata law, however, fails to match both the stress peaks and the evolution of transmissivity across reslides after long holds suggesting that the stressing rate dependence of state, as formulated by Nagata et al. (2012), might need revision.

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