Sensitivity of the Final Slip Amount to the Initial Slip Velocity Derived from the Universal Law

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We consider the system including the interaction among the thermal pressurization and dilatancy effects associated with dynamic earthquake slip process. The governing equation system is described in terms of two variables, the normalized slip velocity v and porosity \phi. We consider the solution orbit on the \phi-v space. First, note that the \phi axis is the common nullcline for both \dot{v} and \dot{\phi} in this system, where the overdot describes the temporal differentiation. The point where the \phi axis and the curve v=1-\beta f (\equiv g(\phi)), where \beta is a constant and f is the normalized porosity evolution law, cross is defined as (\phi_c,0). It should be emphasized that the line attractor emerges in the present system on the \phi axis from (0,0) to (\phi_c, 0). In addition, the initial points of the solution orbits are always on the v axis. Therefore, the solution orbit crossing the point (\phi_c, 0) is assumed to cross the point (0, v_c). We consider the solution orbit crossing the points (0, v_c-\delta v) and (\phi_c-\delta \phi, 0), where \delta v and \delta \phi are positive amounts satisfying \delta v \ll 1 and \delta \phi \ll 1. Let us assume that \forall j, \ g^{(j)} (\phi_c)=0, g^{(n)}(\phi_c) \neq 0, and n \ge 1, where j and n are positive integers and j \le n. Furthermore, if n is odd (even), we assume g(\phi_c) >0 (<0). With these assumptions, we can analytically show the relation: \delta \phi \propto \delta v^{1/(n+1)} (Suzuki, 2017, PRE). Moreover, we can also show that \delta u \propto \delta v^{1/(n+1)}, where \delta u =u_c-u_\infty, u_c is the slip at \phi=\phi_c and u_\infty is the final slip amount. We should emphasize that the universal critical power value is 1/(n+1), which does not depend on either \beta or the details of g(\phi_c) and decreases with increasing n. This result predicts that the region on the \phi axis near the point (\phi_c, 0) is harder for the solution to approach with larger n, because the disturbance in \delta v is enlarged beyond that in \delta \phi (note that \delta v<1 and \delta \phi<1) and the enlargement is stronger, even though the region is on an attractor. These treatments are important from the viewpoint of nonlinear dynamics. In addition, this result indicates that the final slip amount is susceptible to the initial slip velocity, implying that predicting the final earthquake size is hard.

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