Slip-front-propagation velocity with non-vanishing friction stress at infinitely large slip velocity

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Ordinary and slow earthquakes are different in many perspectives such as slip velocity. Among those differences, rupture velocity is important; the rupture velocities for ordinary earthquakes are usually larger than those for slow earthquakes. We aim to explain the difference observed in the rupture velocities by assuming a simple 1D end-loading model.

We consider a visco-elastic block on a rigid and fixed substrate, and apply the loading stress acting on the left end in the direction tangential to the substrate. We assume that the friction stress tau is given by *tau* = *a* \dot{*u*}(2*b*-\dot{*u*})[*H*(\dot{*u*})-*H*(\dot{*u*}-2*b*)]= *a* \dot{*u*}(v_{van}-\dot{*u*})[*H*(\dot{*u*})-*H*(\dot{*u*}-v_{van})], where *u* is the slip, \dot{*u*} is the slip velocity, *H* is the unit Heaviside function, *a* and *b* are positive constants, and v_{van}=2*b*. We refer to this friction law as the quadratic-form (q-form) friction law. It should be noted that this friction law gives vanishing friction with \dot{*u*} > v_{van}. Based on this model setup, we already obtained the analytical value of the smallest steady slip-front-propagation velocity. This value has been interpreted as the smallest propagation velocity for ordinary earthquakes. However, we should investigate the case where the friction stress does not vanish with infinitely large slip velocity regime. We therefore assume the friction law with the form *tau* = *a b* \dot{*u*} exp(-\dot{*u*}^{2}/2b^2+1/2) here. This friction law will be referred to as the non-vanishing (NV) friction law below.

To compare the slip behavior with NV friction law to that with q-form friction law, we calculated the slip persistent time. We define the slip persistent time as the time at which the normalized slip velocity at all points on the slip plane becomes smaller than 0.1 $|p_{left}|$ as measured from the onset of end-loading, where $|p_{left}|$ is the normalized stress applied at the left-end point. Actually, the slip persistent time diverges with negligible $||p_{left}|-|p_c||$, where p_c is a constant, with the q-form friction law because the steady propagation emerges for $|p_{left}|>|p_c|$. On the other hand, the slip persistent time never diverges with the NV friction law, since the steady state does not emerge as shown in our previous treatments. However, the numerical result shows the power law between the persistent time and $||p_{left}|-|p_c||$ within the time range investigated, and distinction between the q-form and NV friction laws is impossible within the computational limit. This result clearly shows that apparent critical behavior emerges with the NV friction law. We can conclude that implications based on the q-form friction law is qualitatively applicable to the law where the friction stress decreases with increasing slip velocity in the large slip velocity regime, but never vanishes. In particular, the smallest propagation velocity for ordinary earthquakes can be robustly applicable. Moreover, we can imply that the slip-front-propagation velocity for slow earthquakes does not exceed such a velocity.

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