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Critical size and overstress of the initiation zone for spontaneous dynamic rupture propagation with a linear slip-weakening friction law

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Numerical simulations of dynamic earthquake ruptures require an artificial initiation procedure. Under linear slip-weakening friction, the concept of a stress asperity is often applied, in which the asperity is characterized by its size, shape, and overstress (difference between static strength and initial stress inside the asperity). However, the physical properties of this initiation zone may have significant impact on the resulting dynamic rupture propagation.

Criteria for estimating the critical size of the initiation zone (the minimum size of the initiation zone leading to spontaneous rupture propagation) have been proposed for 2D and 3D problems based on simplifying assumptions. However, these estimates do not provide general rules for designing 3D numerical simulations, and hence a trial and-error approach is often necessary. Therefore, it is desirable to define guidelines to estimate the size of the initiation zone and the overstress such that the effects of the artificial initiation are minimized when generating realistic dynamic rupture scenarios.

We perform an extensive parameter study in terms of numerical simulations of 3D dynamic rupture propagation to examine the critical size of square, circular and elliptical initiation zones as a function of asperity overstress and background (off-asperity) stress. For fixed overstress, we find that the area of the initiation zone controls the nucleation process. Comparing our numerical results with published theoretical estimates, we discover that the estimates by Uenishi & Rice (2004) are applicable to configurations with low background stress and small overstress. None of the published estimates are consistent with numerical results for configurations with high background stress. We therefore derive new equations to estimate the initiation zone size in environments with high background stress. Our results provide guidelines to appropriately define the size of the initiation zone and overstress to minimize effects of the forced initiation on the subsequent spontaneous rupture propagation.