Earthquake magnitude estimation under nonuniform stress and friction

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We investigated the earthquake magnitude (Mw) under the nonuniform initial shear stress and friction laws by comparing theoretical estimates based on static fracture mechanics with those by 3-D dynamic rupture simulations.

For rupture growth, the energy release rate must be equal to or larger than the fracture energy (Gc). Theoretical works on rupture initiation have assumed the uniform or axisymmetric shear stress distribution and the uniform friction properties (e.g., Andrews, 1976, JGR; Uenishi & Rice, 2003, JGR; Galis et al., 2015, GJI). Under the uniform stress and friction, once a rupture propagates dynamically, it does not stop. However, stress and friction distributions are considered to be heterogeneous (e.g., Olsen et al., 1997, Science; Aochi & Ide, 2014, EPS), and the heterogeneity would contribute to the stopping of ruptures.

In this study, we evaluated the Gc/Gst, where Gst is the static energy release rate at elliptical static crack rim under the nonuniform shear stress and friction. Because it is difficult to obtain Gst analytically, we calculated Gst numerically. In the calculation, we used triangular elements same as those used in the dynamic rupture simulations. First, we calculated the static slip distribution in the crack using the solution of the triangular dislocation by Nikkhoo & Walter (2015, GJI) so that the stress drop and slip amount satisfy the friction law at each element. From the static stress changes at the outside of the crack caused by the obtained static slip and the shortest distance between each adjacent element and the crack elements, we estimated the static stress intensity factor (Kst) and thus Gst, which is proportional to Kst^2, along the crack rim. The axial length of the elliptical crack was set every 10 km. The nonuniform stress and friction distributions were same as those used in the dynamic rupture simulations.

We computed the dynamic rupture propagation by the boundary integral equation method with triangular elements (Hok & Fukuyama, 2011, GJI). Nonuniform stress and friction distributions were obtained by the simulations of quasi-static stress accumulation along the Nankai trough (Hashimoto et al. 2017, JpGU-AGU Joint Meeting 2017) under the slip- and time-dependent constitutive law (Aochi & Matsu’ura 2002, Pageoph). A rupture started at a localized elliptic region stressed beyond the peak stress of the friction laws (initial crack). We examined 16 cases: eight hypocenter locations and two sizes of the initial crack for each hypocenter location. A rupture did not grow outside the initial crack in the cases with smaller size of the initial crack, but it propagated in the cases with larger size of the initial crack, for all hypocenter locations. In the latter cases, the region where slip grew and thus Mw varied with the hypocenter locations (Urata et al., 2017, IAG-IASPEI 2017).

We revealed that the Gc/Gst distributions can predict a rupture growth. The rupture did not grow outside the initial crack in the dynamic rupture simulations if the Gc/Gst values were larger than a certain value, α, at the almost whole rim of the static crack whose size is the same as the initial crack size of the dynamic rupture simulation. Otherwise, the rupture grew. For the nucleated cases, the Gc/Gst and local rupture velocity had negative correlation. The Gc/Gst distribution also predicted the rupture growth to

˜M8. If the Gc/Gst values are larger than α at the almost whole rim of the static crack with the axial length of 60-80 km, Mw was smaller than 7.5 in the dynamic computations. Otherwise, Mw was larger than 7.5. The α value was larger than 1 in this study. This might be related to the coexistence of the modes II and III, the friction law, and the element size. These results would be useful in the study on the earthquake rupture scenarios.