Development of an inversion method to construct fault geometry from teleseismic data

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Seismic source inversion has been used to estimate the earthquake rupture process (e.g. Olson & Apsel, 1982, BSSA; Hartzell & Heaton, 1983, BSSA). Fixing a fault geometry a priori and representing slip vectors spanning the fixed fault plane have been common practice in finite fault inversion. However, inappropriate assumptions of fault geometry increase modeling errors and hence distort the solution (e.g. Ragon et al., 2018, GJI). There have been a few attempts to directly obtain the attributes of fault geometry in the framework of finite-fault inversion, but it has been still challenging because of the strong nonlinearity of the inversion technique. In this study, we propose a new inversion method to estimate both the fault geometry and the rupture process of an earthquake from teleseismic P waveform data, based on a recent development of the finite-fault inversion analysis (Potency-density tensor inversion; Shimizu et al., 2020, GJI). That method improves upon the conventional ones by representing slip on a fault plane with five basis double-couple components, expressed by potency density tensors (e.g. Ampuero & Dahlen, 2005, BSSA), instead of two double-couple components forcibly aligned with the fault-direction assumption. Because the slip direction obtained from the potency density tensors should be compatible with the fault direction that is independent from the model-geometry assumption, we can flexibly obtain the fault geometry consistent with the rupture process. Here in this study, we develop an iterative process to construct fault geometry: (1) setting an initial model fault plane comprising a finite number of flat subfaults, (2) estimating potency density tensor distribution on the input model-fault surface by performing the potency density tensor inversion, (3) choosing more realistic strike and dip angles from the estimated potency density tensor at each subfault, and (4) updating the input model-fault geometry to be consistent with the strike and dip angles of the potency density tensor distribution, and then going back to the step (2) unless the average of the absolute value of the inner products between the normal vector of each subfault and that of the fault surface consistent with the estimated potency density tensor at all subfaults becomes acceptably close to 1. Through this iterative process of constructing a non-planar model-fault surface, we assume, for simplicity, that the fault direction changes only in either the strike or the dip direction in order to reduce the number of iterations. After evaluating a general performance of the proposed method through synthetic tests, we apply it to the teleseismic P waveforms from the M_W 7.7 2013 Balochistan, Pakistan, and the M_W 7.9 2015 Gorkha, Nepal, earthquakes, which occurred along geometrically complex fault systems. We find the modeled fault for the Balochistan earthquake is a curved strike-slip fault convex to the south-east, which is consistent with the observed surface ruptures. We also find the modelled fault for the Gorkha earthquake is a reverse fault with a ramp-flat-ramp structure that shows lower dip angles around the depth of the hypocenter than those in the up- and down-dip regions, which is also consistent with the fault geometry derived from geodetic and geological data. These results suggest that the proposed method works well for constraining fault geometry of an earthquake. The proposed methodology was published as Shimizu et al. (2021) by Geophysical Journal International.

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