Inversion of spatiotemporal moment-tensor distribution: Application to the 2013, Balochistan, Pakistan earthquake

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Teleseismic waveforms contain a rich information of slip evolution during an earthquake together with the geometric feature of the fault geometry, which can be resolved with the seismic source analysis. A single fault plane or configuration of fault planes has been deployed as a model space where the slip history is resolved in the ordinary seismic source modeling, but if the model-space geometry is dissimilar to that of the real fault, uncertainty of Green's function for the representation of slip could become large and it makes it difficult to estimate a reliable seismic source process due to a large amount of modeling error.

We developed a seismic source modeling method that represents slip by five basis-moment-tensor components in order to mitigate the modeling error originated from the inaccurate assumption of fault geometry, which was an inherent limitation of the conventional source inversion scheme representing slip with two basis-moment-tensor components where the explicit assumption of fault geometry was required. Our inversion scheme, representing slip by five basis-moment-tensor components, simultaneously solves pseudo-slip together with the focal parameters that are independent of the model-space geometry.

We examined the validity of the developed method by applying it to the 33 teleseismic P-waveforms of the 2013 Balochistan, Pakistan, earthquake (Mw 7.7) that has been thought to involve a geometrically complex fault system in the pioneering source studies. The Balochistan earthquake occurred on the Makran accretionary prism where a curved pattern of the tectonic fabric can be seen in a topographic feature and the pre-known fault system around the epicenter of the Balochistan earthquake. Surface displacement of the Balochistan earthquake, revealed by the optical satellite images, indicated that the Balochistan earthquake occurred along the curved fault, which was consistent with the prior knowledge of the topographic feature and the active fault system. We set a single-flat plane dipping 0° to entirely cover the potential source area onto a reference depth of 10 km.

Spatiotemporal distribution of the seismic potency released during the Balochistan earthquake showed that the potency focused near the hypocenter and the rupture propagated almost unilaterally toward southwest of the epicenter. Spatiotemporal distribution of the moment tensor solution showed that the focal mechanism at each source knot generally sheared a left-lateral strike-slip faulting. The strike angle of the preferable nodal plane continuously changed between 205°–250° from northeast to southwest of the epicenter.

These results suggest that the Balochistan earthquake was the strike-slip earthquake evolved along the curved fault. The estimated variation of focal parameters was consistent with the topographic feature and the curved surface ruptures recognized in the optical satellite images. We alternatively tested a single-flat plane dipping 64°, and we could get a similar spatiotemporal distribution of moment tensor and the related variation of fault geometry, which supports that the proposed method is a robust method that is not affected by the assumed model-space geometry. The proposed method enables us to estimate both the spatiotemporal distribution of seismic potency and the fault geometry for the earthquake occurred within a geometrically complex fault system and/or spatiotemporal variation of focal mechanism by just arranging a single-flat plane without assuming fault geometry.

Keywords: teleseismic waveform, moment tensor, 2013 Balochistan earthquake, kinematic inversion, fault geometry, inland earthquake