Analysis of seismic source process during the 2016 Kumamoto earthquake by jointly using surface ruptures and teleseismic waveforms

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Waveform iversion of teleseismic body waves has been applied to earthquakes to analyze an earthquake source process. However, it is difficult to resolve fault slip near the surface because the relative travel time between the direct P-wave and the reflected waves becomes short and the waveform signal generated by a near-surface slip becomes small with increasing of the slip duration. On the other hand, we can measure relative displacement along surface ruptures with high accuracy after an occurance of the earthquake. By jointly using the teleseismic waveforms and the surface rupture observations, it is possible to estimate a source process of an earthquake, even for the past earthquakes which we do not have enough data with recent developed techniques such as InSAR or GPS. In this study, we demonstrated the utility of the joint inversion of teleseismic data and field survey data through analysis of the 2016 Kumamoto, Japan earthquake (M_{JMA} 7.3).

We used vertical components of teleseismic P body waves observed at 27 stations of the Global Seismographic Network (GSN) and relative displacements of surface ruptures at 408 measurement points (Kumahara et al. 2016, JpGU). It is difficult to uniquely determine variance of the field survey data since measurement errors of the data depend on the appearance-clarity of each measurement object (e.g., water channels, furrows on rice fields). We determined the relative weights among the teleseismic body waves data, the field survey data, and prior information using the Akaike's Bayesian information criterion (ABIC). We assumed a planar single fault model (strike: 234°, dip: 64.0°) along the Hinagu-Futagawa fault zone based on the focal mechanism, aftershocks distribution, and the surface ruptures. To describe in detail a slip behavior around a junction of the two fault zones, we discretized the fault model into 2 km ×2 km sub-faults and deployed 49 B-spline functions expressing source time functions of each sub-fault at intervals of 0.3 s. We projected the field survey data to the uppermost sub-faults on the fault model.

Main rupture can be seen in the Hinagu fault area from rupture initiation to 8 s where a right-lateral slip is dominant. The rupture then shifts to the Futagawa fault area, and gradually propagates to the surface with a right lateral slip involving normal faulting. The rupture terminates southeast side of Mt. Aso caldera at about 15 s after rupture initiation. From the total slip distribution, we can see a maximum slip of around 3 m along the Futagawa fault area, and a right lateral motion is dominant along the entire Hinagu fault area, while a right lateral slip with a normal faulting prevails along the entire Futagawa fault area.

Comparing the result with one estimated by using only the teleseismic body waves, we can see clear differences in spatiotemporal distributions of slip-rate near the surface. In the result from only the teleseismic records, the slip at the shallower than 1 km depth occurs at 7 s after rupture initiation and continually occurs along both the Hinagu and Futagawa fault areas until 15 s. In the result of the joint inversion, however, the time of occurrence of the slip is about 10 s after initiation, which is later than that by solely using teleseismic body waves. Synthetic waveforms of both the joint analysis and the teleseismic analysis well capture the characteristics of the observed waveforms, while the total slip and the slip directions near the surface estimated by the joint analysis are more consistent with the surface ruptures, compared with those from the teleseismic analysis. The path of the rupture propagation, the rupture transition from the Hinagu fault to the Futagawa fault, and the spatial pattern and the depth of maximum slip are consistent with the results from the strong motion records based on the detail fault geometry and

the InSAR data. The result in this study suggests that we can acquire the detailed slip distribution even if we use a simple planar fault model by using the field survey data together with the teleseismic body waves.

Keywords: Joint inversion using ABIC, Field survey data, 2016 Kumamoto earthquake

