Dynamic modeling of the 1999 Chi-Chi (Mw7.6) earthquake: New insights on energy partition in large earthquakes by incorporating in-situ stress measurements into the constitutive relationship from kinematic modeling

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The September 20, 1999 (UTC) Mw7.6 Chi-Chi earthquake in Taiwan was a devastating event of historic proportions. Although this event caused severe damage, it also provided a large data set of high-quality near-field strong motion acceleration records from the Taiwan Strong Motion Instrumentation Program. Despite ongoing advances in kinematic modeling in the last two decades, some questions remain unresolved. One of those questions is the seismic energy partition in radiated energy and fracture energy. We address this question by investigating the dynamic rupture behavior of this event. We constructed a 3D dynamic rupture model which is constrained by the well resolved spatiotemporal slip distribution and in-situ stress measurements from fault-zone drilling. In our model, we consider the fault ruptures with both spatially uniform and non-uniform frictional behavior and perform a series of numerical experiments with different sets of input variables (e.g., slip-weakening distance, \(d_c\), and initial stress on fault plane) based on a slip-weakening friction law. We examined the parameters controlling the slip patterns as the result from kinematic modeling. For the constraints of the input variables, we first derived the constitutive relationship between slip and stress change on the subfaults from the temporal and spatial slip distribution of the kinematic models by Ji et al. (2003), and then determined the dynamic parameters (e.g., apparent slip-weakening distance, \(d'_c\), and the ratio of strength excess and stress drop, \(S\)). Our initial normal stress on the fault plane is based on the geophysical logging analysis of the Taiwan Chelungpu-fault Drilling Project. Our optimal model can simulate a rupture similar to the kinematic model by Ji et al. (2003) and suggests that the final slip distribution is mainly controlled by the spatial distribution of the normal stress. We require a downscaling (\(\alpha\)) of the apparent slip-weakening distance, \(d'_c\), from the derived constitutive law of the kinematic model to allow a dynamic rupture propagation with large slip velocity comparable to the observations. With the downscaled slip-weakening distance, \(d'_c\), and a heterogeneous stress distribution, the slip-weakening curves from our optimal model suggests the downscaling in radiated seismic energy and fracture energy accordingly.