Characteristics of strong ground motion generation areas inferred from fully dynamic multicycle earthquake simulations

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There is vast evidence that the fault regions that generate short-period and long-period wave radiation during a given earthquake can be spatially distinct. The most direct observations of this phenomenon have been obtained for large subduction earthquakes (e.g. 2011 Mw 9.0 Tohoku) for which the high frequency ground motion radiation has been detected in deep regions of seismogenic zones, while long-period ground motion are in shallow regions. In contrast, for moderate-size crustal events (Mw6-7) kinematic finite source models reveal that regions of large final slip (long-period generation areas) and regions of large peak slip velocity (short-period generation areas) spatially coincide. The phenomenon does not appear to be systematic for large Mw8 earthquakes. This feature has important implications on procedures adopted for the prediction of strong ground motion and need detailed study.

One plausible explanation for the discrepancy between short-period and long-period generation areas is based on the spatial heterogeneity of stress and strength (frictional parameters) along the fault. In fundamental models of earthquake dynamics, high-frequency radiation is generated by abrupt changes of rupture speed. High frequency radiation is also enhanced by short rise time which can be controlled by heterogeneous frictional velocity-weakening.

One fundamental goal of dynamic source modelling has been to design a class of spatial distributions of friction parameters that can be tuned to reproduce the statistical features of past earthquakes. An inherent difficulty in this effort was that stress and strength heterogeneities cannot be prescribed arbitrarily as was done in earlier work. Their inter-dependence must be consistent with a mechanical model of deformation and stress evolution over the longer time scale of the earthquake cycle. Failure to account for such mechanical correlations leaves the modeling framework so unconstrained that virtually any outcome is possible with sufficient tuning. For this reason we have developed the software infrastructure to simulate multiple earthquake cycles with rate-and-state friction, in which we solve consistently for long and short time scales of the earthquake cycle, combining periods of quasi-static and fully dynamic deformation.

With the benefit of the optimized software framework, we run simulations of a M8 vertical strike-slip fault. We associated the slip weakening Dc distribution with different degrees of fault maturity. Large variations of Dc represent immature faults and lower variations of Dc represent mature faults. We impose a lognormal distribution of Dc that correlates in space and defined two fault cases where fault case 1 has lower Dc variability (sigma = 0.25, mature fault) whereas fault case 2 has larger Dc variability (sigma = 1.0, immature fault). We examine the distinct locations of areas of large slip and large slip velocity. The analysis of the discrepancy of short-period and long-period generation areas has been supported by analysis of other dynamic quantities, including rupture speed, rise time and general attributes of band-passed filtered slip velocity time histories. With simulation results at hand (for peak slip and peak slip rate distributions slip see example below) we conclude that asperity area and high slip velocity area tend to be similar for Case 1 (mature faults), but occur in different places for Case 2 (immature faults). We found that high slip rate areas correspond to short rise time and high rupture velocity areas.

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