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Source Dynamics of Shallow Dip-Slip Earthquakes: The Corner Effect

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Since Professor Keiiti Aki published his classical study of the Parkfield earthquake where he analytically reproduced the observed near field displacement of strike-slip fault successfully (Aki, JGR, 1968), the techniques to compute the near field from strike-slip faulting have become remarkably sophisticated. It is currently widespread to invert accelerograms for obtaining fault slip distribution and rupture history for large, shallow strike-slip earthquakes. For shallow dip-slip earthquakes, however, the situation is different because only few events of this type have been well recorded in the near field and the physical properties still remain unexplored due to analytical difficulties (see e.g., Madariaga, PAGEOPH, 2003). Here, we study source dynamics associated with a dip-slip fault located in a two-dimensional, monolithic linear elastic half space. The fault dips either vertically or 45 degrees and is subjected to a loading static stress that is zero on the free surface and increases linearly with depth. Using a finite difference technique, we investigate the seismic wave field radiated by crack-like rupture of this straight fault. The rupture propagates at a constant, subsonic (and sub-Rayleigh) speed. We simulate four different cases: (1) fault rupturing only at depth; (2) fault rupture initiated at depth and arresting well below the free surface; (3) fault rupture initiated at depth and arresting just below the free surface; and (4) fault rupture initiated at depth and reaching the free surface. We show the dynamic stress field can be totally different for the first three cases but the last two cases are similar: For the cases (3) and (4), in both vertical and nonvertical (inclined) cases, when the rupture front approaches the free surface, four Rayleigh-type pulses are generated: two propagating along the free surface into the opposite directions to the far field, the other two moving back along the ruptured fault surfaces (interface) downwards into depth. If the fault is vertical, the problem is still symmetrical and the induced particle motions are symmetrical with respect to the rupturing fault, although the downward interface pulses largely control the stopping phase of the dynamic rupture. If the fault is inclined, the geometrical symmetry is broken: On the hanging wall, the downward interface pulse interacts with the outward-moving surface pulse and induces a kind of shear wave (corner wave). This corner wave carries concentrated wave energy and generates strong particle motions on the hanging wall. On the contrary, on the footwall, the weaker surface pulse dominates the ground motion and the interaction between this surface pulse and the oppositely-moving interface pulse is also small. Thus, asymmetric ground motion is caused. The generation of the interface pulse and the corner wave has not been well recognized so far, partly because those waves are not expected for a fault rupturing only at depth. However, the comparison of these fundamental numerical results with the seismological recordings of the 1999 Chi-Chi, Taiwan, and the 2004 Niigata-ken Chuetsu, Japan, earthquakes also suggests the need for more careful analytical treatment associated with the effects of the geometrical asymmetry on the strong motion induced by shallow dip-slip faulting.