Dynamic rupture process of the Chi-Chi earthquake

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The Chi-Chi, Taiwan earthquake of September 21, 1999 is a large thrust earthquake. We use a bending fault model to simulate the observed large strong motion and GPS data. The joint inversion result reveals that in the south part ruptures mainly occurred in the shallow portion, reached the largest slip on the north section, where rupture propagated to the deep part of the fault. On the basis of the kinematic inversion result, the dynamic rupture is recovered using a 3-D skew grid model. Our final dynamic model shows that displacements on the hanging wall are much larger than that in the footwall. This is consistent with the GPS observation, which shows much larger movement on the hanging wall than the footwall.

The Mw 7.6 Chi-Chi earthquake, rupturing with a large thrust component, occurred in the western Foothills of the central Taiwan at 1:47 (local time) on September 21, 1999. Its epicenter is 23.85N, 120.81E and the focal depth of 7km, determined by the Central Weather Bureau (CWB) using its routine earthquake monitoring network.

We express the slip rate on the fault plane as a 3-D basis function expansion, 2-D spatial and 1-D temporal expansion (Ide & Takeo, 1997). After convolution with Green functions, we have the observation equation for the strong motion data. Using an analytical express of surface deformation due to a finite rectangular fault deduced by Okada (1992), we have the other observation equation.

A total of 47 strong motion stations and 60 GPS stations are included in this study. We then introduce a bending fault in the north end. While most of fault strikes N5dE (72 km long,44km wide) , we let the fault turn to northeast (strike N22E, 12km long; NEN fault) in the north part since the surface rupture trace does turn to the northeast in this area.

We hence obtained a kinematic rupture process of the Chi-Chi earthquake. In this study, using the finite diffence method in a 3-D skew grid model, we apply the 3-D spontaneous, dynamic shear crack propagating over a dipping fault. Due to computer limitation, we restore the rupture process with a rough grid spacing of 4km.

We assume that rupture will not occur until the rupture front arrives. The rupture front used here is obtained from the kinematic waveform inversion. The shear stress on the fault drops to the assigned stress state immediately when the rupture starts, and no prior friction law is applied. We start from a uniform stress drop model to simulate the dynamic rupture. Then we compare the dynamic slip distrution with the kinematic result and adjust the asigned stress drop by the ratio of the kinematic slip to the dynamic slip. So we move to the next iteration started from the adjusted stress drop model. We can finally reach a reasonable difference of the kinematic slip and the dynamic slip, i.e., the final dynamic rupture model.

The final dynamic rupture model shows that displacements on the hanging wall are larger than on the footwall. Somewhere in the vicinity of the free surface, displacements in the hanging wall are as large as 2-5 times of the displacements of the footwall. For example, the dip component and strike component of a displacement in the hanging wall reach 7.2m and 5m, respectively, whereas they are merely 2.7m and 1.4m in the foot wall, respectively. Dynamic stress drop in the north is generally larger than in the south. In the north, the stress drop in the dip direction exceeds 12 MPa in the shallow section, and 20MPa at depths, while the strike-direction exceeds 9 MPa in the shallow section, and 28MPa at depths. Using the rupture front determined by the kinematic model, we calculate the stress strength. The strike-direction strength excess is comparatively small and somewhat homogeneous in the south faulting area, whereas we have obtained larger strike-direction strength excess at depth in the north. Distribution of the dip-direction strength excess is much more heterogeneous than the strike-direction one. It reaches the maximum, about 28MPa, in the north faulting area. In general, the strength excess in shallow sections is smaller than at depths.

We propose that in the north section the direction of the maximum compressive stress of the regional stress there rotates to the north. It means that the NS-striking fault has been unfavorably oriented and rupture in the north section will eventually die off and come to a stop. Besides the Chi-Chi earthquake, the San Andreas fault system has been well known for its complex geometry. Bouchon et al. (1997,1998) related the rupture termination of the 1992 Landers earthquake to the unfavorably oriented fault segments.