Dynamic rupture simulation on geologically constrained segments of the Uemachi fault, Osaka, Japan

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Abstract

We simulate a rupture on Osaka's Uemachi fault, and show how the geometry of a fault jog affects the earthquake size. This finding illustrates an approach in which the dynamic rupture simulation is constrained by fault segmentation, basement structure, and tectonic stress field. We also simulate the ground motions in Osaka basin. Our goal is to make a reliable ground motion prediction, using dynamic rupture scenarios and a 3-D underground structure model.

Theory

We computed spontaneous rupture processes on the basis of a fault model and assumptions about the stress field.

We model the Uemachi fault from its observed surface traces and the shape of the Osaka basin-floor (Figure 1). In the model, the fault shows pure reverse slip, strikes north-south, dips 60° east, extends about 45 km, and contains two segments separated by a jog. Unfortunately, surface traces are not always clear, and the subsurface fault structure deeper than a few kilometers is unknown. There is no information on a possible initial rupture point. For the reasons given above, we carried out many simulations, varying the fault-parallel and fault-normal distances (D_p and D_n) between the two segments and the location of the initial crack.

Principal stresses are proportional to depth. The minimum principal stress (σ_3) is equal to the overburden load. The maximum principal stress (σ_1), which is tectonic, trends east to west. We assumed the dynamic coefficient of friction and the ratio of strength excess to stress drop (S; Andrews, 1976 [1]). We varied the depth-dependence of σ_1 and the static coefficient of friction. We then calculated rupture processes, to search for values of σ_1 and S most consistent with an observed vertical dislocation of about 2.8 m near the surface. Table 1 shows the parameters used in our numerical simulations.

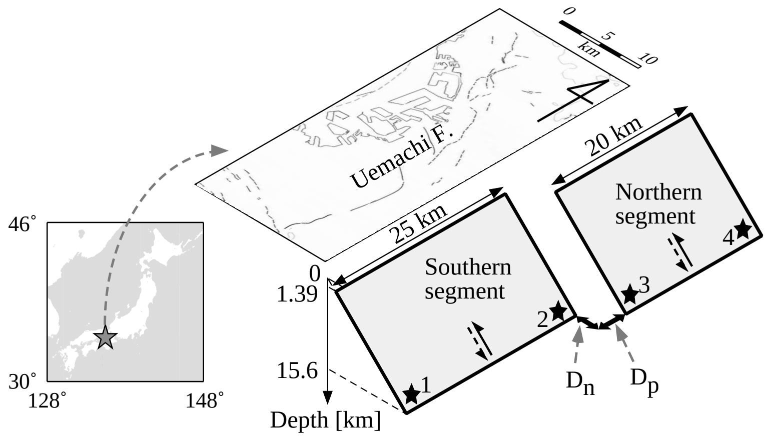

Figure 1: Fault model used in this study. In a map after Okada and Togo (2000) [6], solid and dotted lines indicate active faults of certainty I and II, respectively.

Table 1: Simulation parameters

P wave velocity [km/s]	5.3
S wave velocity [km/s]	3.0
Density: ρ [g/cm^3]	2.6
Maximum compressional stress: σ_1 [MPa]	$51z$
Minimum compressional stress: σ_3 [MPa]	$\rho g z$
S	1.6
Critical displacement: D_c [m]	0.25
Static coefficient of friction	0.30
Dynamic coefficient of friction	0.20

At time $t = 0$, the shear stress on the initial crack drops to the level of dynamic frictional stress. The rupture then begins to propagate spontaneously. Slip occurs at points where shear stress exceeds static frictional stress, which is equal to the static coefficient of friction times the normal stress. After the slip starts, the shear stress obeys the slip-weakening friction law (Andrews, 1976 [1]; Day, 1982 [2]), and drops to the dynamic frictional stress, which is equal to the dynamic coefficient of friction times the normal stress. We solved the 3D wave equations using a finite-difference method.

Results

We made many simulations, varying the location of an initial crack and the fault-parallel and fault-normal distances (D_p and D_n) between the two segments. Whether rupture propagates across the fault jog depends on these parameters.

Figure 2 shows whether rupture propagates across the jog. When an initial crack is located at the fault jog (Hypocenter 2 or 3), it is unlikely that two-segment rupture occurs. A shorter distance between segments allows two-segment rupture. This result agrees with results under the uniform stress condition (Harris and Day, 1999 [3]; Kase and Kuge, 2001 [4]). In a simulation using observed values of D_p and D_n, a rupture terminates at the jog in the model. These results indicate that either the jog persists at depth and a rupture seldom crosses it, or that two-segment rupture occurs only if the segments approach or meet at depth.

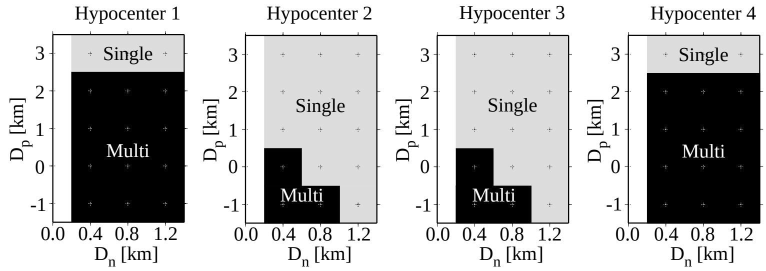

Figure 2: Results of parameter studied. Black regions indicate that a rupture jumps a jog. Grey regions indicate that a rupture terminates at a jog.

Focusing on rupture propagation on the faults in detail, Figure 3 shows rupture time and slip distribution on the faults. Ruptures start on the northern segment. When an initial crack is located at the northern end, the rupture jumps to a deep portion of the southern segment. When an initial crack is located at the southern end, on the other hand, the rupture of the southern segment is triggered near the Earth's surface.

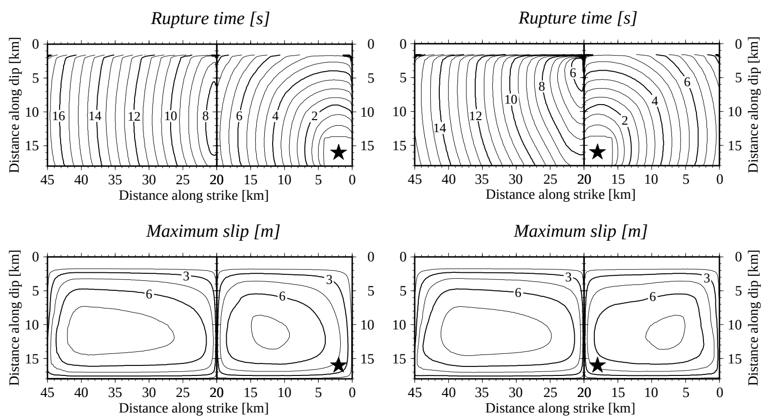

Figure 3: Rupture time and slip distributions in cases with the initial crack located at (left) the northern end of the northern segment and (right) the southern end. In both cases, D_p and D_n are 0 km and 0.4 km, respectively.

For segments located close together, a rupture jumps to the deep portion and propagates smoothly. For segments with greater distance, however, a rupture jumps near the Earth's surface. This result agrees with rupture processes under the depth-dependent stress condition (Kase, 2002 [5]). Even though fault model and slip distributions are very similar, different rupture propagations cause different ground motion distribution.

Conclusion

We proposed an approach of dynamic rupture simulation constrained by geologic information. A fault model is constructed from fault segmentation and basement structure. A stress field is assumed by considering the tectonic stress field. We simulated spontaneous rupture processes of a two-segment reverse-slip fault, representing the Uemachi fault. We showed that the location of an initial crack and the geometry of the fault jog affects rupture process. When an initial crack is located at the fault jog, the rupture tends to terminate at the jog. Shorter distance between segments leads to multi-segment rupture and smooth rupture propagation.

References

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