Physics Based (Dynamic) Modelling of the Velocity Pulses in Kobe City

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We target our study to the Kobe-city segment of the 1995 Hyogo-ken Nanbu earthquake and the destructive velocity pulses observed at KBU and MOT sites. Matsushima and Kawase[1)] successfully modeled these pulses by two large SMGAs having sub-parallel rupture propagation with different rupture initiation timings (**Fig. 1**). As considered by Recipe [2)], the study [1)] focused on characterized source model.

Our approach is fully dynamic source modelling using linear slip-weakening friction model described by stress drop $\Delta\sigma$, strength excess *Se*, critical distance *Dc*, and others. This method uses 3D finite-difference method (3D-FDM) that allows incorporation of the 3D velocity structure model[3)]. To reproduce observed waveforms, we use realistic velocity structure model JIVSM[4)] that includes the Osaka basin model[5)].

To reproduce two velocity pulses in succession, occurring due to two upward sub-ruptures, we guide rupture through the chain of asperities, identified by SMGAs in [1)]. To produce sub-parallel upward ruptures in SMGAs, we add barriers between asperities. Timing of generated pulses is adjusted by the rupture velocity (V_R) tuned by the *Se* settings, other than SMGAs of the model[1)]. We performed a parametric study with gradually increased complexity of the model.

We get insight from dynamic rupture generated by the earthquake cycle simulations[6)]. One of the ruptures had a subvertical barrier with a large *Dc* and a hole-like bridge beneath the barrier with a small *Dc*. Initial rupture was arrested by this barrier, but then the subsequent scattered rupture was able to penetrate through the hole and made upward propagation, similarly to **Fig. 1**.

A conceptual model employs this effect of the rupture penetration. It consists of four asperities and three barriers between them. Chain of the holes in barriers, build a bridge beneath them, which allow rupture to penetrate from one asperity (SMGA) to another and then propagate upward, similarly to the kinematic rupture model [2)].

By try-and-error method we get a dynamic friction model that reproduces observed pulses well (**Fig. 2**). SMGA1 and SMGA2 are combined into a single SMGA.

Snapshots of rupture propagation are shown in **Fig. 3**. Rupture nucleates and propagates through SMGA1 and SMGA2, and then propagates upward through SMGA3. After that, rupture enters the barrier and vanishes. At the same time rupture penetrates through the bridge between SMGA3 and SMGA4 under the barrier and re-nucleates within SMGA4. In final stage the rupture propagates upward through SMGA4.

With the adjustment of the barrier and *Vr* parameters, the waveforms at MOT and KBU stations well reproduce the two pulses (see **Fig. 4**). Results for *Vr* show that within SMGAs the resulting *Vr* is large: 2.8~3.0 km/s. This large value was necessary to reproduce short ~1 s velocity pulses.

We conclude that: 1) multi-hypo rupture propagation, strongly deviating from the concentric propagation, is physically possible; 2) high rupture velocity within asperities is necessary to generate short-period (~ 1 sec) pulses (a.k.a. killer pulses); 3) to drive multi-hypo rupture from one asperity to another with a strong barrier in between, an additional element (a bridge) is necessary under asperities and a barrier.

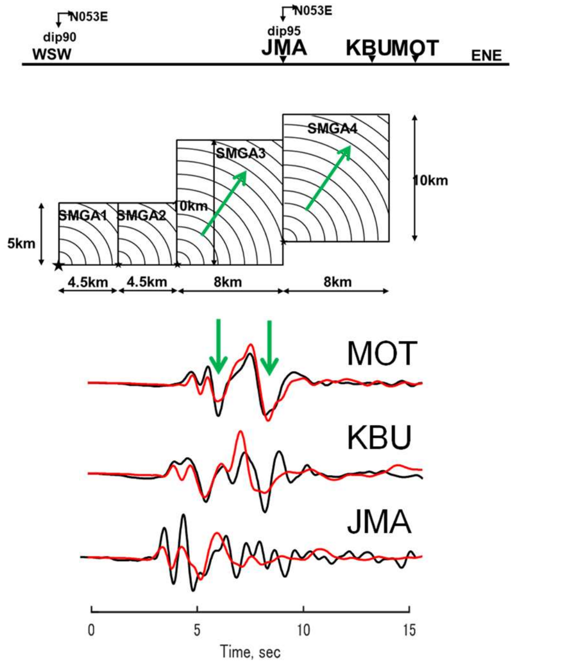

Fig. 1 Waveforms for the SMGA model [2]. Green arrows show rupture propagation through SMGA3 & 4 and corresponding waveform peaks.

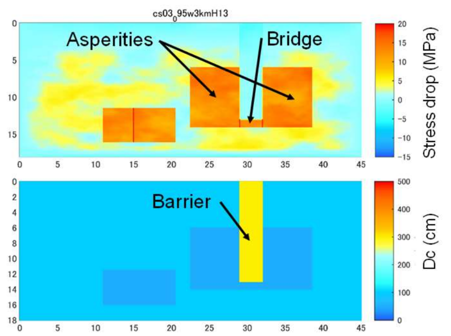

Fig. 2 Dynamic model concept and input parameters.

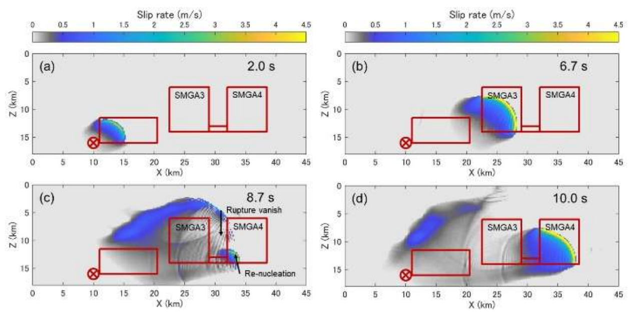

Fig. 3 Slip-rate snapshots of rupture propagation. (a) Rupture nucleation. (b) Upward propagation through SMGA3. (c) Rupture vanishes within barrier and re-nucleate in SMGA4. (d) Upward propagation through SMGA4.

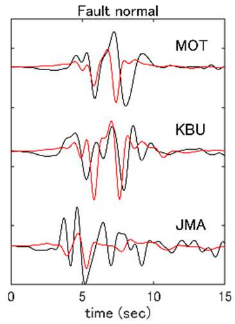

Fig. 4 Comparison of dynamic simulation waveforms (red) with observed waveforms (black). Dynamic model reproduces fault-normal velocity peaks at KBU and MOT.

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