Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

STT59-01 Room:104 Time:May 20 14:15-14:30

Large- and multi-scale earthquake cycle simulation

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Since the pioneering work of Tse and Rice (1986), earthquake (EQ) cycle simulations, based on rate and state friction laws, have been executed to successfully reproduce historical EQ cycles. In most of these simulations, we set a fault or plate interface in a half-space homogeneous elastic medium, on which frictional parameters are distributed, and simulate EQ cycles driven by a relative plate motion. In these simulations, we use a boundary-integral equation method to divide the fault or the plate interface into a number of cells smaller that the critical size determined from frictional parameters. And, by integrating the equation of motion combined with a rate and state frictional law, we trace the spatiotemporal slip evolution there. Current problems of these simulations are the needs for including 1) not quasi but fully dynamic rupture processes in earthquake cycle simulations, 2) the effects of structural heterogeneity and viscoelasticity in the medium, 3) the effect of pore pressure change in the fault zone throughout EQ cycles, 4) the examination of friction laws, especially at high slip rates. In addition, we are facing the need for large- and multi-scale EQ cycle simulations.

In this talk, we confine ourselves to discussing mainly quasi-dynamic EQ cycle simulations in a homogeneous elastic medium, taking into account the next generation super computer. First, we show the need for large- and multi-scale EQ cycle simulations, especially for interplate earthquakes at subduction zones. Namely, we need to 1) simulate cycles of giant EQs such as the 2011 Tohoku and the soon-coming Nankai EQs, and further the Japanese Island-scale EQ cycles including the interfaces of plates subducting beneath the whole Japan Islands, 2) simulate multi-scale EQ cycles including several sizes following the GR law in regional scales. These multi-scale simulations target the understanding of the different earthquake size distribution between the off-Tohoku and the Nankai focal regions, and of the temporal change in b-value before large earthquakes, and further the Nankai EQ simulations including short- and long-term slow slip events.

These large- and multi-scale simulations demand huge computational memories and CPU times. On the other hand, some researches have started to estimate frictional parameters based on physical models including rate and state friction laws through a method of data assimilation, which involves a large number of iterative computation. Therefore, we need to reduce memory sizes and CPU times required in EQ cycle simulations, and physics-based data assimilations. Dividing the fault or the plate interface into N cells, the multiplication of the slip response function matrix (NxN) and the slip deficit vector (N), that appears repeatedly in the simulations, requires memory sizes and CPU times of O(NxN). For reducing O(NxN) to O(N)-O(NlogN) in memory sizes and CPU times, we have used FFT(Fast Fourier Transform), FMM(Fast Multipole expansion Method) and recently H-matrices method. We review these reduction methods employed in EQ cycle simulations, and discuss the further challenge.

Keywords: Earthquake cycle, Large-scale simulation, Multi-sacle simulation, Interplate earthquake, Subduction zone