Responses of Stick-Slip Oscillator to Periodically External Forces (2)

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There have so far been a large number of studies on statistical significance of periodicity and seasonality of seismic activities. Recently, some studies have proposed physical mechanisms causing such periodicity and seasonality. For example, the following studies have been executed: stress perturbation on faults causing some correlation between seismic activity and Earth-Ocean tide (Tsuruoka & Ohtake, 2002); correlation between activity of low frequency earthquakes and oceanic tide (Nakata et al.,2008) and proposal of its nonlinear response (Ide & Tanaka,2014); correlation between large earthquake activity and long-term lunar tide (8.85 years) and amplification mechanism of lunar tide(Tanaka,2014); seasonality of Nankai trough earthquake occurrences (Mogi,1969; Ohtake & Nakahara,1999) and correlation between long-term lunar tide (18.61 years) and their occurrences (Ide & Tanaka,2014). Recently, Uchida et al.(2016) reported the existences of 1-6 year periodicities of repeating earthquake activities on the Pacific plate interface and their triggering large earthquakes.

As stated above, there exist some periodicities of slip behaviors ranging from slow slips to large earthquakes. And earthquakes occurring on plate interfaces and inland faults have some rhythms of recurrence intervals called earthquake cycles and co-rupturing of some earthquakes. We may consider the former periodicities as responses of stick-slip oscillator to periodic forces such as earth and ocean tides, and the latter earthquake cycles as interaction of coupled stick-slip oscillators in asperities and the co-rupturing as synchronization of asperity ruptures. Following these ideas, I started to explore the possibility of constructing a new model of earthquake activities and cycles, by both employing earthquake cycle simulations following rate-state friction law and synchronization theory developed in non-linear sciences (e.g., Kuramoto,1984).

Sugiura et al.(2014) investigated synchronization of coupled stick-slip oscillators following rate-state friction. There have been, however, no studies on responses to external forces. Therefore, Hirahara (2015, SSJ Fall meeting) investigated the responses of 1 degree of freedom stick-slip oscillator to external forces. This talk is a follow-up report.

Hirahara (2015) found m:n synchronization phenomena, which is usually called as Devil's Staircase, in cases of applying periodic external stresses with the amplitudes of 1/10 and 1/100 relative to the whole stress changes in stick-slip cycles. Here, fe:fc=m:n (m and n are coprime integers) where fe and fc are frequencies of external force and simulated system, respectively. Earth and ocean tidal loading has stress with the amplitude of kPa-10kPa, and such loading may cause synchronization of SSE with small stress changes of several 100 kPa.

In this talk, I try to explain m:n synchronization and its synchronization width by employing simulated phase response curves. Then, I show the responses to external forces with not single but multiple frequencies, and also the responses to forces based on actual earth and ocean tidal models. Further, I report another interesting phenomena of non-synchronization, where the intervals of slip increasingly varies, especially in rage of the larger external periods outside of m:n synchronization. These phenomena may be related to the observed fluctuations of periodicity of earthquake activities and cycles.

Keywords: Stick-Slip Oscillator, Synchronization, Rhythm, External Force, Earthquake Cycle Simulation

