



DEVELOPMENT OF REPEATING EARTHQUAKE ANALYSIS TO EXTEND LARGE AFTERSLIP PERTURBATION

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Analysis of repeating earthquake (repeater) has been a useful tool to monitor the slip velocity field on worldwide plate boundaries driven by preseismic and postseismic slip (Uchida and Matsuzawa 2013). In analyses of repeaters, a scaling relation between the seismic moment and slip amount proposed by Nadeau and Johnson (1998) is commonly used.

For transform faults, it is possible to compare slip amount between repeating earthquake analysis and inland crustal deformation such as creep meter. To determine the scaling relation, however, they assumed a long-term slip rate of 23 mm/yr for the San Andreas Fault based on the then-current geodetic observations, which is significantly less than the present results of 30 mm/yr (e.g., Murray and Langbein, 2006). This difference, which would be partly derived from M6 event in 2004, may affect the validity of the scaling relation. Moreover, it is still unclear as to whether the scaling relation is applicable in cases involving large postseismic slip or slow slip events at subduction zones.

Therefore, it is important to develop the repeating earthquake analysis to monitor fault movement on the major faults such as North Anatolian Fault System where great earthquakes may occur around the Marmara Sea in the near future (Figure 1).

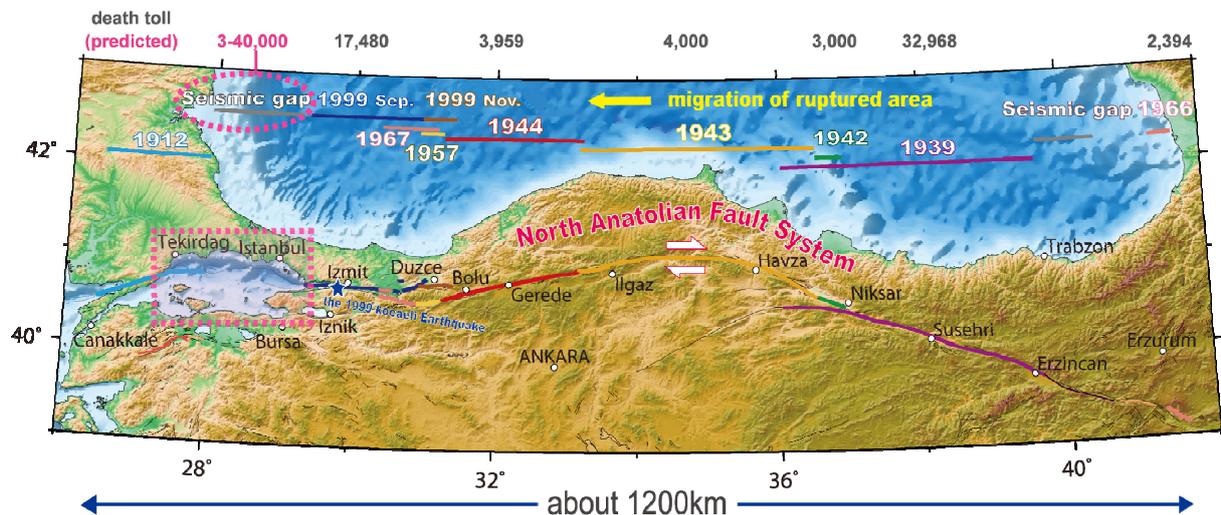


Figure 1. Overview of North Anatolian Fault System revised from Kondo et al. (2010). The region enclosed by pink rectangle indicates seismic gap around the Marmara Sea.

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For another example, it is well known that repeater sequence off Kamaishi had occurred with similarity of recurrence interval of about 5 years (Matsuzawa et al., 2002), seismic magnitude (about M4.8) and spatial slip distribution (Shimamura et al., 2011) to each repeater, which has been explained by isolated asperity model (Igarashi et al., 2001).

Just after the 2011 Tohoku earthquake, however, Ye et al. (2012) reported that temporal earthquake activation had occurred off Kamaishi, where their recurrence intervals were temporarily much shorter than usual (about 9 days at shortest) and some of their magnitudes were not only greater (M5.9) but also smaller (M4.3) than the characteristic one. For the greater earthquakes, it is thought to be related to fast loading of repeaters due to a rapid postseismic slip (Uchida et al., in submission). For the smaller earthquakes, however, that seems to be inconsistent. Ye et al. (2012) thought that the greater and the smaller earthquakes are composed of different asperities. If so, it has not been clear that why the smaller asperities ruptured just once (M4.3 on 29 March) or twice (M4.8 on 29 April which was smaller at that time), not constantly.

In addition, it has not been clear how to describe friction behavior on actual plate boundaries. For a major example, it is well-known that rate/state dependent friction (RSF described in Eq. (1)) law (Dieterich, 1979; Ruina, 1983) can reproduce earthquake cycle. However, several versions of RSF law has been proposed:

$$\mu = [\mu_0 + \{a \ln(V/V_0) + \Theta\}], \quad (1)$$

$$\frac{d\Theta}{dt} = \frac{bV_0}{d_c} \left\{ \exp\left(-\frac{\Theta - \mu_0}{b}\right) - \frac{V}{V_0} \right\} - c \frac{d\mu}{dt}, \quad (2)$$

$$\frac{d\Theta}{dt} = -\frac{V}{d_c} \left\{ \Theta - \mu_0 + b \ln\left(\frac{V}{V_0}\right) \right\}, \quad (3)$$

where a and b are frictional parameters of stability, d_c is the critical slip distance, μ_0 is the nominal friction at steady state when slip velocity $V=V_0$, Θ is state variable. Eq. (1) is general expression of friction coefficient for RSF law and we call aging-law and Nagata-law in case of coefficient of the stress weakening $c=0$ and 2 in Eq. (2), respectively (Nagata et al., 2012), and slip-law in case of Eq. (3) (Ampuero and Rubin, 2008).

In this study, we formulate a simplified model of long-term cycle for repeaters perturbed by the passage of large postseismic slip generated from a nearby large earthquake in subduction zone, in order to explain the temporal activation and extract frictional properties based on RSF laws and characteristics of the complicated earthquake cycle. Other than applied friction law, simulation method is similar to previous studies (Ariyoshi et al., 2007; 2009; 2012; 2013).

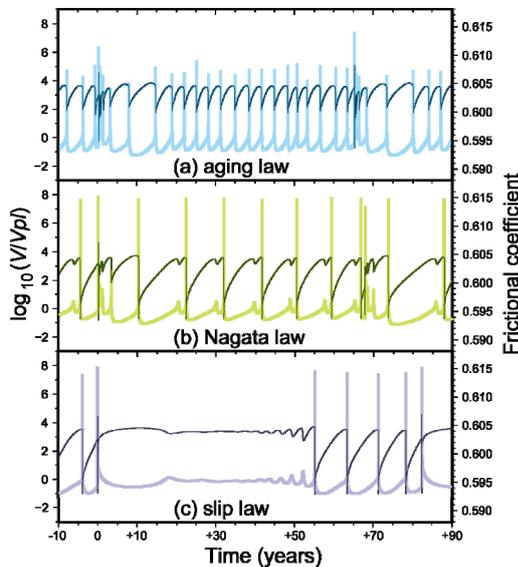


Figure 2. Time histories of friction coefficient (or shear stress normalized by effective normal stress) (thin line) and slip velocity normalized with respect to plate convergence rate (V_{pl}) on a common-logarithmic scale (bold line) averaged in small asperity. The origin time is set to the occurrence of large earthquake (M7.7-7.9) in large asperity. Adopted friction laws are (a) aging- (cyan), (b) Nagata (lime green), (c) slip- laws (purple), respectively. The distance between large and small asperities is about 30 km.

Our results show that (i) the temporal activation can be well reproduced in case of aging-law rather than slip- and Nagata-laws (Figure 2), (ii) the reason why the greater and smaller earthquakes off Kamaishi temporarily occurred may be explained by the difference between overall and partial rupturing of asperity, (iii) the observed perturbation of the activated earthquake hypocenters almost in the east-west direction may reflect that the large postseismic slip of the 2011 Tohoku earthquake propagated from east to west off Kamaishi, (iv) the observed region of repeating earthquake quiescence may reflect strong plate coupling of megathrust earthquakes.

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