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An interpretation of the Tohoku Earthquake in terms of a damage zone/asperity model of faults

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1. Introduction: We proposed a damage zone/asperity model of faults to interpret the source parameters of an earthquake in terms of the physical properties of a fault zone (Yamamoto & Yabe, 2003, 2006 in SSJ meeting). Here, we will apply this model to the Tohoku earthquake to estimate the fault zone thickness and the recurrence time of the earthquake.

2. Model of Faults: In this model, a fault zone consists of the damage zone and the asperity zone. The damage zone is defined to be the zone filled with rocks under the post-failure state. The zone is incompressible and non-rigid for quasi-static shear deformation, but elastic for dynamic deformation. In the asperity zone, intact rocks support shearing force applied to the fault zone boundaries between the fault zone and intact rocks outside of the fault zone. Thus, the shear stress imposed on the fault zone boundaries is supported only by the asperity, while the normal stress is supported by whole the fault zone.

The rupture breaking from the asperity propagates into the damage zone to form a slip-plane. No shear stress is assumed on the slip-plane after faulting as inferred from the stress measurements. The size of a fault plane is determined by equilibrating the released energy from the asperity and the rocks outside of the fault zone with the apparent fracture energy and the seismic energy. The apparent fracture energy is almost equal in magnitude to the work done by the vertical displacement due to the rotation of a damage zone against the normal stress. The energy is proportional to the fault zone thickness. Denoting the areas of the fault plane and the asperity by S and s, respectively, f = s/S is estimated at a few percent at most.

Consider a fault zone of a uniform thickness t_d, of which the length is l. The relationship between t_d and l is expressed by

$t_d = 0.0016*l$.

The shear strength tau_f of the asperity is approximated by

$tau_f = r*e_f$,

where r and e_f respectively are the rigidity and the strength in terms of shear strain. The asperity is assumed to fracture at the time that the strain reaches to its critical value of e_f. The relative displacement u_c for e_f between the fault zone boundaries is expressed by

$u_c = t_d*e_f$

u_c is called by the critical displacement. e_f is assumed at 0.01 hereafter.

Here we assume a circular crack in a uniform host rock to evaluate the strain energy released from the rocks outside of the fault zone and the displacement between the fault zone boundaries. The crack surface is identical in size to the slip plane. The seismic energy is expressed by

$E = h*(8/7)*r*(l/2)^3*(f*e_f)^2$,

where h denotes the seismic efficiency and f is the function of h. The average displacement is given by

$u_{bav} = 8*l*f*e_f/(7*pi)$

The displacement on the slip plane is written by

$u = u_c + u_b$

When the crack is buried, the magnitude of an earthquake is approximated by

$M_s = \log(S) + 4.0$

for h around 0.7.

3. Application to the Tohoku Earthquake: The aftershock area of the Tohoku earthquake is about 500 km in length and 200 km in width (JMA, 2011). If we take this length as the fault length, the followings are determined; t_d = 0.8 km, u_c = 8 m, u_{bav} = 20 m, and the largest of u_b is about 28 m for h = 0.7. The largest of the displacement on the slip plane, that is about 1.4 times of u_{bav}, is estimated to be about 36 m. This suggests the recurrence time of M9 earthquakes more than 450 years for the average slip rate of 8 cm/y. The area of the circular crack is about $2*10^5$ km^2. M is determined at 9.0 by taking into consideration that the energy has been released from the half area of the circular crack in the underground.

4. Conclusion: The above result suggests that the magnitude of an earthquake is determined by the thickness of the fault zone where the fractured asperity has existed or the G-R rule depends on the thickness distribution. In order to estimate the magnitudes of the potential earthquakes on the fault, it is important to clarify the distribution of fault zone thickness.

Keywords: fault model, damage zone, weak faults, critical distance, The Tohoku earthquake, recurrnce time