Definition and expected physical properties of fault damage zones

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1. Introduction

We can estimate the potential magnitude of an earthquake on a fault from its length. Further, the fault length is proportional to the process zone thickness (Vermilye and Scholz, 1998). It is thus possible to estimate the magnitude of the earthquake from the process zone thickness, provided that the thickness is clearly identified by observations. Yamamoto and Yabe (2008) have defined the damage zone that controls the earthquake magnitude and showed the relation of the damage zone thickness to the process zone thickness. Here, we talk about the definition and the physical properties expected to be observed for fault damage zones.

2. Definition of fault damage zones

A zone near the fault core axis is compressed in the fault normal direction (Chester et al., 1993). It has been observed near the fault core axis that one of the principal stresses lies in the fault normal direction and that the stress difference is very small. The small stress difference in the zone that is expected to be heavily strained implies that the zone is in the so-called post-failure state. Here we define the fault damage zone as the zone around the fault core axis that is in the post-failure state under the compressive stress normal to the fault plane.

3. Expected physical properties

When axial loading of compression (s_1.gt.s_2.eq.s_3) is performed for a rock specimen, tensile cracks with their surfaces parallel to the axial stress s_1 are known to be produced. The density c of the tensile cracks is expressed in relation to the shear crack density G = G(u) by

c = Cf(s_3)G(u)....(1)

for a constant C of about 10 and u = r/r_f, where r = (s_1 - s_3)/(s_1 + s_3) and r_f is the value of r corresponding to the shear strength of intact rocks (Yamamoto, 1995). f(s_3) is approximately proportional to ${s_3}^{-1/2}$ and G(u) is interpreted to be the volume fraction of fractured rocks or the fracture density at u (Yamamoto, 1998).

3.1 Fracture density

Assuming that a damage zone is produced by the compressive stress normal to the fault zone and s_1 is the normal stress, the value of G for the zone can be estimated from the measured stresses. G is estimated nearly at 0.8 (Yamamoto et al., 2002).

3.2 Elastic wave velocity

In the case of (s_1.gt.s_2.eq.s_3), tensile crack density c may be given by (1). c is estimated by taking s_3 = g(r_s - r_f)d, where g, r_s, r_f, and d, respectively, are the gravitational acceleration, density of rocks, that of pore fluid and depth. The average P-velocity has been showed to explain well the observed data (Yamamoto et al., 2002). The average velocity means here the velocity for rocks including randomly oriented cracks, which is calculated by NSC (or DS). The velocities for arbitrarily oriented cracks are calculated by 'Weak Interaction Approximation' method (Yamamoto et al., 2002).

In the case of (s_1.gt.s_2.eq.s_3), there are 3 modes of elastic waves, P, S_1 and S_2 waves. S_1 and S_2 waves respectively have the displacements in the vertical plane and the parallel plaane to the fault plane. These velocities vary depending on whether rocks are saturated with fluid or not. For saturated rocks, the P-velocity is equal to that of the host rocks at the propagation direction of 0 deg. from the fault surface normal, and decreases to the smallest at a direction near 50 deg. The S_1 wave velocity is largest at a direction near 50 deg. The velocity for the direction of 0 deg. is the smallest. For S_2 waves, the velocity is equal to the smallest velocity of S_1 for all propagation directions. At 10km depth, the smallest velocity is about 80% of that of the host rocks for P, about 50% for S_1 and S_2. These amounts are large enough to be observed.

The relationship between velocity and propagation direction for dry rocks is not the same as for saturated rocks described above. Further discussions will be made in this talk.