S040-005 Room: C417 Time: May 31 10:00-10:15

A model for the stress-velocity relationship: Elastic anisotropy of damaged zone

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The stresses at sites close to the Nojima fault were measured by deformation rate analysis (DRA) and the hydraulic fracturing technique (HF) after the earthquake. These measurements revealed as follows: 1) The direction of the largest horizontal stress is almost perpendicular to the strike of this nearly vertical fault at all the sites with an exception. 2) In the zone within a distance of about 100 m from the fault core axis, the shear stress is small compared with those at a distance from the zone. The results (1) and (2) have been interpreted as the reflections of the small fracture strength of the damaged zone that is in the post-failure state. The zone of small shear stress near the fault core axis is referred to as the damaged zone hereafter.

There is a model proposed in order to correlate the fracture density and the crack density of damaged rocks with the applied stresses to the rocks. The seismic wave velocities of damaged zone were estimated from the shear stress obtained near the Nojima fault by using this model together with the theory of effective elastic constants. For the comparison of the estimated velocities with the observed ones, the followings are assumed:The fracture density is constant throughout the damaged zone and invariable for any fault. The observed seismic wave velocity can be regarded as the velocity averaged over the propagation and motion directions, that is the velocity of the zone that is elastically isotropic. It has been seen from this comparison that the estimated velocities of P- and S-waves are close to the observed ones for some fault zones. It is noticeable that sealed or pressurized fluid is not required to explain the velocities of the damaged zone.

The damaged zone in the post-failure state under compression is expected to be elastically anisotropic. However, there are no evidences explicitly to show the anisotropy of the damaged zone. One of the purposes of this paper is to show the theoretically expected anisotropy in seismic wave velocities for the observations in future. Li et al. (1998) and Li and Vidale (2001) observed the recovery of travel times of P- and S-waves after the 1992 M7.5 Landers earthquake. The other purpose is to interpret the observed recovery of the travel times in terms of anisotropy of damaged zone.

Anisotropy of seismic wave velocities is calculated on the assumption that the crack surfaces lie parallel to the direction of the largest principal stress and orient symmetrically around the direction. At the depth of 10 km, the velocity of the S1-waves, that are the S-waves coupled with P-waves, varies in the range from about 43 to 85 % of the host rock velocity with the change in the propagation direction, while the velocity of P-waves does in the range from about 99 to 75 % of the host rock velocity. The largest and the smallest velocity respectively are attained at the propagation directions of about 50 and 0 or 90 (deg) from the principal direction for the S-waves and at the propagation directions of 0 and about 60 (deg) for P-waves.

The decrease in the crack density of the damaged zone advances the arrival times of the direct P- and S-waves. The ratio of the advance of P-waves to that of S-waves was observed to be around 0.7 after the Landers earthquake. If it is assumed that S1-waves are reflecting while propagating in the damaged zone, the ratio can be almost explained for the similar values of G as obtained from the in-situ stresses. This suggests that the direction of the largest principal stress of compression is perpendicular to the fault plane for the Landers fault as well.