Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS27-01 Room:103 Time:May 23 09:00-09:15

Fundamental study on estimation of change in local stress field using coda-Q

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In this study, we tested a hypothesis that "coda-Q, i.e., an attenuation parameter for the part of natural earthquake seismogram (called coda-wave) after the S-wave arrival, has a relationship with the state of local stress field in the crust". In the past, it has been discussed that the coda-Q changes before a large earthquake or shows anomalous values around a volcanic zone. However the mechanism causing the change in the coda-Q has yet not been revealed since the coda-Q is considered as a parameter to reflect strong heterogeneity of the medium of seismic wave propagation. In other word, the coda-Q has not been well analyzed to obtain any change of the physical state in the subsurface since the interpretation using the coda-Q is mainly used to interpret the heterogeneity of such medium. We focus on a hypothesis proposed by Aki (2004) pointing out that the prediction of earthquakes is a difficult task since the shallow part of the crust covering earthquake sources is too inhomogeneous, and that the coda-Q could be indicating some preseismic process. In his study, he reported that the seismicity around the San Andreas Fault in California shows high correlation with the variation of the coda-Q inverse around the fault in time. When the seismicity is correlated with the variation of coda-Q, the correlation coefficient becomes higher than 0.8. Therefore, we hypothesize that "the variation of coda-Q has a relationship with the change in the local stress field, which triggers an earthquake". In fact, the coda-Q is reported to show a change before the Southern Hyogo prefecture earthquake in 1995 by Hiramatsu et al. (2000). Their results also imply that the relationship between the stochastic parameter, coda-Q and the state of subsurface medium. This study also supports the hypothesis mentioned above.

To verify our hypothesis, the variation of the coda-Q against the stress was examined using numerical simulation of seismic wave propagation. In this study, we assumed that the coda part of earthquakes would be formed by superposed scattered waves originating from cracks distributed in the medium. We then simulated the coda-wave to estimate the coda-Q for various stress loads. As Okamoto et al. (2010) already reported, the coda-Q varied with respect to the change in the direction and the magnitude of the loaded stress under the condition that the elastic displacement of crack locations were took place due to the loaded stress. The order of the change in the coda-Q against the stress, however, is much smaller than the change in the real data observed by Aki (2004). The calculated change in the coda-Q is only the order of several permill for 10 MPa change in the loaded stress, while observed were tens of percent for earthquakes in California (Aki, 2004). So there should be another mechanism to augment the change in the coda-Q much effectively than the effects of the elastic displacement of cracks. We finally assumed two types of additional effects; (1) phase velocity anisotropy induced by the selective closure and opening of microcracks, and (2) the azimuthal alignment of mezzo-scale cracks. The simulation was done for case that a plane wave travels through the bottom boundary of the model. As a result, we confirmed that the change in coda-Q had a qualitative relationship with the magnitude of the change in the mean normal stress (confining pressure). In addition, the order of the change in the coda-Q agrees with the order of the change of the real data observed in Aki (2004). This result suggests that the magnitude of the stress can be estimated from observation of the coda-Q. Unlike the qualitative relationship between the coda-Q and the crustal stress, the quantitative relationship between them can leads to a new stress monitoring method.

Keywords: Coda-Q, attenuation, anisotropy, stress field, numerical simulation