Arrival time and energy fluctuations of P-ave and their relationship with heterogeneity size of medium

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We made experimental studies to find a relationship between travel time (or energy) fluctuation and scale length of heterogeneity. Elastic waves are generated by a piezo-electric transducer and observed by a Laser Doppler Vibrometer, which accomplishes very accurate measurements. About 100 waveforms were measured over a square grid with a spacing of 1mm, by changing the size of heterogeneity and wave frequency covering the various ratios of heterogeneity scale lengths and seismic wavelength. We found a positive correlation between variance of statistical distribution of arrival time (and energy) and the scale of heterogeneity.

When seismic wave propagates through random heterogeneous media, waveform is distorted by scattering due to the underground heterogeneity, causing fluctuations in arrival time and amplitude. The study of spatial fluctuations of arrival time and wave energy and their relationship with size of heterogeneity is important in mapping complex subsurface structures. However, the nature of relationship between arrival time/energy fluctuations and size of heterogeneity is not clearly understood. In order to elucidate such relationship, we performed laboratory model experiments using homogeneous (steel) and heterogeneous rock samples, Westerly and Oshima, characterized by small and large grain size respectively. We also considered homogeneous and artificially made heterogeneous Gypsum samples for this study. Elastic waves are generated by a piezo-electric transducer and observed by a Laser Doppler Vibrometer, which accomplishes very accurate measurements. About 100 waveforms were measured over a square grid with a spacing of 1mm, by changing the size of heterogeneity and wave frequency covering the various ratios of heterogeneity scale lengths and seismic wavelength.

We studied the micro-structural images of Westerly and Oshima granites to decipher the actual size of the heterogeneities. From the autocorrelation function of velocity fluctuations in these rock samples, the heterogeneity scale lengths, 0.22 mm for westerly granite and 0.46 mm for Oshima granite, were estimated.

For the estimation of arrival times, we employed a method based on autoregressive model and Akaike Information Criterion that yielded reliable P-wave arrival times. The estimated arrival times are then corrected for extra path lengths due to square grid array configuration. We also studied spatial fluctuations of wave energy by using the amplitude data of first cycle of the P-wave. The statistical distributions of arrival time and energy fluctuation were analyzed to find out a relationship between these fluctuations and the scale length of random heterogeneity.

We first obtained the observed probability density function (PDF) by computing derivative of cumulative distribution function of arrival times and log energy. A Gaussian PDF, computed with sample mean and variance as parameters, was then fitted to the observed distribution. Actually, the observed distributions of the travel time fluctuation and log energy fluctuation indicate that the distributions are skewed, and deviate slightly from the Gaussian PDFs. The parameters of the PDFs indicate that the variance is larger for the heterogeneous sample compared to that for the homogeneous Gypsum sample. The distributions for steel, westerly and Oshima exhibit that the variance increases gradually from steel, westerly and to Oshima granites. This relationship holds for both arrival time and log energy. The increase of variance from homogeneous to heterogeneous (Gypsum); and from Steel, Westerly to Oshima granites depicts that there is a positive correlation between variance of statistical distribution of arrival time (and energy) and the scale of heterogeneity. Our results suggest that the distribution of travel time fluctuation is skewed and may be explained by best-fit distribution other than Gaussian. We are contemplating to derive an empirical relationship between fluctuations of arrival times\energy and causative heterogeneities by conducting more detailed experiments on various rock samples.