能動震源ACROSSの開発と地震波モニタリング

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Active seismic source monitoring through the development of ACROSS

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ACROSS, which stands for Accurately Controlled Routinely Operated Signal System, was conceptually designed by Kumazawa and Takei (1994), and a system for practical use was started to be developed in Nagoya University in 1995. The development efforts spread into some institutions and now about 10 vibrators are in operation in and outside of Japan. All of them have a common design of operation that have established in the first few years of development in the discussion among researchers and students headed by Kumazawa. Among them are a GPS synchronization and a repeating frequency modulation (FM) operation, which are principal subjects of ACROSS operation. A source synchronization technique to GPS clock was developed to make a remote synchronization to receivers because the GPS signal were already used as a reference clock for seismic observations. The repeating FM operation is designed so that a same FM operation repeats with a constant time interval. FM operation is a combination of up-sweep and down-sweep of rotational frequency of ACROSS source to cover a certain frequency range as a source signal. This operation produces multiple narrow spectral peaks with constant frequency interval, improving stacking efficiency for quite a long time period to have a good signal-to-noise ratio. Another but notable advantage of the repeating FM operation is separation ability among signals of ACROSS sources that cover common range in frequency. Spectral peaks of repeating FM operation can be shifted so that none of the peaks are shared by multiple ACROSS sources in operation. This enables simultaneous operation of multiple sources in a common frequency range.

An important result in the earlier period of the development of ACROSS is the detection of temporal variation of seismic velocity observed in Awaji test site, near the Nojima fault of 1995 Kobe earthquake (Ikuta et al. 2002, Ikuta and Yamaoka, 2004). They found coseismic delays of seismic velocity caused by strong ground motions. They also proved that the change is induced by the pressure increase of ground water based on the observation of anisotropic change in both seismic velocity and strain measurements. The observation of coseismic delays are now very commonly observed in seismic interferometry observation.

Tsuji et al. (2017) found a secular increase of seismic velocity as well as coseismic decrease, probably for the first time in such monitoring experiments. They analyzed the 10-year-long monitoring results of ACROSS source in the central part of Shizuoka prefecture, Japan, and found a secular increase for 13 Hi-net stations around the source. This can be interpreted as a gradual closure of cracks probably by a precipitation of minerals from the ground water.

Temporal change is also detected in a volcano area, with use of ACROSS being deployed in Sakurajima volcano, Japan. Maeda (2015) revealed the difference of amplitude of transfer function between the active and inactive periods of the volcanic eruptions. Yamaoka et al. (2017) detected a temporal change of transfer function at the time of magma intrusive event of Sakurajima in 2015, suggesting the stress change of volcanic body.

In spite of achievements above the limitation of single ACROSS source became obvious. A use of multiple ACROSS sources, for example, of the order of 10 source operation should be put into practical use. To achieve the purpose low-price ACROSS source should be developed.

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