Overview of geophysical studies in the Nojima Fault Zone Probe Project: Repeated water injection experiments and continuous borehole measurements

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Abstract

The Nojima fault is one part of the earthquake source fault of the 1995 M_w 6.9 Hyogo-ken Nanbu (Kobe) earthquake in southwest Japan. The Nojima Fault Zone Probe Project started immediately after the occurrence of the earthquake, as a joint research of several universities and institutes in Japan. We drilled three boreholes with depths of 1800, 800, and 500 m, respectively, through or close to the Nojima fault, near its southwestern end. Continuous downhole measurements with seismic, crustal movement, groundwater, and geoelectric instruments have been carried out, and also core samples have been analyzed, to investigate the fault-zone structure, earthquake generating process and material properties in the fault-zone. We carried out repeated water-injection experiments in 1997, 2000, 2003, 2004 and 2006 to measure the fault-zone permeability and its temporal change. The water was injected at a depth of 540 m in the 1800-m-deep borehole, with wellhead pressure of 2.8-4.6 MPa, flow rate of 8-26 x 10^{-3} m^3/min, and total flow of 23-529 m^3. The permeability was estimated to be 1-4 x 10^{-6} m/s at depths around 540-800 m from modeling the observations of groundwater level (or discharge) and crustal strain at the 800-m-deep borehole, and also the measurement of self-potential at ground surface. These permeability measurements showed temporal decrease (by ~70 % in groundwater level) from 1997 to 2004. Elastic constants of rocks around the 800-m-deep borehole were also estimated from continuous strain measurements, and they showed, for example, an increase in bulk modulus from 1996 to 2006. These suggest the healing process of the Nojima fault at depths shallower than ~800 m. Decrease in fault-zone permeability at deeper part, down to ~2-4 km, was also estimated from modeling the space-time distribution of injection-induced ultra-microearthquakes. The induced seismicity occurred at a depth of ~2-4 km, at ~4-5 days (in 1997), ~6-7 days (in 2000), ~7-12 days (in 2004) and ~15 days (in 2006) after the injection. We analyzed borehole seismograms from injection-induced and background microearthquakes to study their source process,

generating properties such as clustering, and detailed fault-zone structures. For example we detected fault-zone trapped waves in the seismograms recorded at 1800-m-deep borehole, for ~7 % of the microearthquakes (aftershocks) occurring in the Nojima fault area. Fault-zone structure averaged along the propagation path was estimated as follows; width of 150-290 m, S-wave velocity of 2.6-3.0 km/s, and Qs value of 40-60. We also observed fault-zone trapped waves at the GSJ 720-m-deep borehole, which is located at the central part of the Nojima fault. From modeling these seismograms, we estimated along-strike variation of the fault-zone structure, i.e., approximately 2-3 times wider fault-zone at the southwestern end of the Nojima fault. We will continue borehole seismic observations to detect fault healing process from the waveform changes in the fault-zone trapped waves. We are also planning to make a water injection at a depth of 1800 m of the Nojima fault, to measure the permeability of the earthquake source fault itself, and also to reveal the generating process of induced earthquakes in more detail by injecting water directly to their sources.