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Long-term measurement and evaluation of tiltmeter applied to long-term borehole observation

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JAMSTEC project team has been advancing long-term borehole observation project for understanding the mechanism of earthquake generation. For this scientific purpose, some sensors including BBS(broad-band seismometer), strong-motion accelerometer, high-sensitivity geophone, strainmeter, tiltmeter, thermometer and pressure-gauge are planned to be installed to seafloor boreholes. These sensors should have high-sensitivity, and high-stability for high-precision long-term monitoring. We have been developing these sensors with iterative evaluations. In this report, we introduce about continuous recording using tiltmeter in Matsushiro seismological observatory of JMA to evaluate long-term stability and sensitivity. And we compare tiltmeter data with BBS data to confirm the response of the tiltmeter.
Continuous recording using tiltmeter started on April 22th in Matsushiro seismological observatory. This tiltmeter, LILY, is a digital self-leveling borehole tiltmeter provided by Appled Geomechanics Inc. LILY can be self-leveled through a range of +-10 degrees with 1 nrad. resolution over a dynamic range of +-330 mrad. LILY can sense angular movement in two orthogonal vertical planes using precision electrolytic tilt sensors with less than 1 Hz frequency response. The acquired analog signal is converted to digital data stream. In this experiment, we have been using three LILYs to evaluate long-term stability. One of them was installed to steel cased borehole (diameter 100 * depth 1000mm). Others are installed to a caisson (diameter 450 * height 600 mm) on ground directly. BBSs (CMG-1T,3T: Guralp systems ltd.) are also installed to this caisson. Both are filled by dry sand after sensor installation. Tiltmeter data was acquired by laptop PC with constant sampling interval, 5samples/sec (5Hz). The time stamp is provided by the internal clock of the laptop PC without synchronized with GPS. For time correction, PC clock time is compared to True time with accuracy of 1 sec when data collection. For correction short period data such as earthquake, we pick first bread of earthquake record of BBS with synchronized by GPS and tiltmeter. Finaly, time correction is carried out by shifting tiltmeter record with differential time between both first breaks.
As a result of plotting all of acquired data, we confirm the followings. The tiltmeter installed to the borehole have very low noise response with a range from +-2 to 3 mrad.. However, the tiltmeters installed to the caisson have obvious trend tilted to one direction with a range from 20 to 30 mrad. for 1week from start time of measurement. The acquired data have become stable gradually as the measurement continues. It seems that the trend is caused by the unstableness of the caisson on ground or a creep movement of sand in the caisson. It is not coupled tilt data with ground motion. Some earthquake data including local and teleseismic are acquired during the measurement term. We calculate the power spectrum density (PSD) from background noise data of tiltmeter in the borehole and BBS in the caisson. We confirm that both PSD plots have similarity between a range of earth tremor and both PSD plots calculated from a few earthquake data including teleseismic and local earthquake have similarity from a range of less than 1 Hz. For precision comparison, we calculate power and phase coherency. As the result, we confirm that tiltmeter and seismometer have good coherence in power. However, there are not obvious linear relationship between tiltmeter and seismometer in phase. It seems that it is caused by incompleteness of time correction,

and there are not enough records of earthquake for quantitative evaluation. For future work, we should process more earthquake data for more statistical evaluation. On the other hand, as a stability experiment, the long-term stability of tiltmeter is confirmed during the measurement term (8 months) because frequency response has time-independent value.

Keywords: Long-term borehole observation, tiltmeter, long-term stability, broad-band seismometer, earthquake