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Groundwater level changes associated with aftershocks following the 2011 M7 earthquake occurred in Iwaki City, Japan

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The great Tohoku-oki earthquake induced a normal fault-type M7 earthquake beneath the western part of Iwaki City on April 11, 2011. A NNW-SSE trending surface rupture longer than ten kilometers emerged with west side throw as large as 2 m. It is an opportunity to observe ground water level (GWL) changes associated with many aftershocks within a short observation period. The observation at a short epicentral distance also is advantageous to detecting precursory changes. Borrowing two deep boreholes in the aftershock area, I conducted GWL observation during 50 days since April 21. Borehole SMK is located 4.3 km southeast from the southern tip of the surface rupture, and borehole HLN is 6.2 km east from SMK. The precision of water-level gauges used is 1 mm, and the data were acquired minutely. The GWL changes related to 23 inland shallow aftershocks and 4 deeper earthquakes off Iwaki City were recorded.

1) GWL rose about 4 m at SMK, while about 5 m dropped at HLN. These changes are approximated well by exponential functions of time whose origins are set at April 11. They indicate that the GWL at SMK (HLN) dropped (rose) about 8 m (10 m) just after the earthquake and rose (dropped) thereafter at a relaxation time of 47.6 days (29.4 days).

2) The effects of the earth tide and barometric pressure to GWL were corrected by using BAYTAP-G. Comparing the output components attributed to the earth tide with the corresponding volumetric strain calculated by GOTIC-2, 1 mm GWL change at SMK and HLN are estimated to be equivalent to the volumetric strain of 0.30 and 0.24 nano-strain, respectively.

3) After defining the normalized earthquake magnitude M∗ as M∗ = M - Mc and the lower limit magnitude Mc below which earthquakes are not detected as GWL changes as Mc = 2.4logr ? 1.0, 156 earthquakes which fulfill the condition M∗>1 were selected from JMA database. The parameter r denotes the epicentral distance (in km). The occurrence of the earthquakes with larger M∗ are synchronous with step-like GWL changes which are found in the trend-component output from BYTAP-G. Obviously the lager M∗, the higher step. Through such procedure 27 and 10 earthquakes-related GWL changes were identified in the data from SMK and HLN, respectively. The maximum change attains 52 mm.

4) Mc is expressed conclusively as Mc = 2.48logr ? 1.00 for the data from SMK. The relation between the observed GWL changes w (mm) and M∗ are approximated as M∗ = 0.704logw ? 0.198, being consistent with a theoretical consideration.

5) Focal mechanism solutions of the 24 earthquakes among the 27 earthquakes are opened on the websites of JMA or NIED. Using the source parameters and MICAP-G, static volumetric strain changes at SMK and HLN were calculated. They were converted to GWL changes and compared with the observed values. As a result, they are consistent each other for 15 earthquakes (63 %). When the epicentral positions are allowed to move slightly within their determination errors, the theoretical GWL changes can be consistent with the observed values for the additional 7 earthquakes (29 %). With regard to the data for 92 % of the earthquakes, the ratios of volumetric strain to GWL change are averaged to 0.38 nano-strain/mm for the data from SMK, being consistent with the volumetric strain equivalent to water level change (0.30 nano-strain/mm). These results strongly suggest that the main cause of the GWL changes is the static volumetric strain changes. The GWL changes related to other two earthquakes may be due to ground shaking.

6) It is not rare that small (<several mm) GWL changes preceded a few hours before earthquakes (11 among 37 observations). These preseismic changes may be attributed to the incomplete correction of the effects of the earth tide, but the preliminary examination rejected this possibility. Evidences which indicate the preseismic changes as precursors have not been obtained so far.

Keywords: groundwater level, Iwaki earthquake, aftershocks, volumetric strain, precursor