論　文　の　内　容　の　要　旨

論文題目　Tectonic deformations and shallow soil deformations induced in the active folding zone in the Oct. 23rd 2004 Mid-Niigata Earthquake (2004 年 10 月 23 日新潟県中越地震における活褶曲地帯の地殻変動と浅層地形変動)

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The main shock of the Chūetsu Earthquake jolted Mid Niigata Prefecture, central Japan at 17:56 JST on Saturday, October 23, 2004. The Japan Meteorological Agency (JMA) has named it “The Mid Niigata Prefecture Earthquake of 2004”. Three M6 class aftershocks followed the main shock within one hour.

This event reportedly triggered and/or reactivated thousands of landslides, and the economic loss due to these landslides was initially estimated at 8 billion US dollars, making this one of the costliest landslide events in history (Kieffer et al., 2006). National Research Institute for Earth Science and Disaster Prevention of Japan (NIED here after) prepared a landslide map mainly from aerial photos and laser-scanned images taken on the second day after the main shock (Oyagi et al., 2008). A remarkable number of landslides make up an about 1 km wide brush west of Kajigane syncline, on the other hand there is a “gap” in the vicinity of Kizawa hamlet at the southern end of this brush where landslides are remarkably sparse. Konagai et al (2009) surveyed this gap area, and reported that the concrete lining of Kizawa tunnel in this area suffered a serious cracking. Konagai et al

(2009) indicated that a hidden shear plane in the soil was the possible cause of this cracking and the entire rock mass above the shear plane is considered to have slipped east to southeast gripping the southern part of the tunnel.

Since the tunnel is 7-8 km away from the nearest recognized trace of the seismic fault, it is not very likely that the shear plane was a part of the fault rupture plane but a part of a hidden landslide’s slip surface. This possibility caused a worry to villagers that the hidden landslide beneath them would be reactivated in snow melting times. To investigate the presence of the hidden slip surface, the author surveyed the area and found some traces including two wells dislocated in the deep interior of the soil. These clear traces of dislocation were found distributed roughly on a large plane with a strike in east-west direction and about 6 degrees dip to the south.

The discussion was also made by analyzing Digital Elevation Models from different times. In these days of highly developed remote-sensing technologies, changes in landforms can be detected by using Interferometric Synthetic Aperture Radar technique. However, with the presence of thick vegetation and many landslides, the fringe pattern appeared in the C-band InSAR imagery of the target area was largely perturbed. Therefore Digital Elevation Models at different times were obtained and compared among each other. In either InSAR or DEM imagery analyses, they just provide us with changes in elevation or along the narrow effective waves transmitting and returning to the satellite. To discuss the above-mentioned issues, real soil particle movements in the Lagrangian coordinate system are to be obtained first. Secondly, they are to be separated into two major components caused by tectonic deformation and shallow surface deformations. Konagai et al., (2009) obtained Lagrangian components of tectonic displacement by assuming that tectonic displacements varies gently in space, and therefore three adjacent nodes of DEM would have the same Lagrangian displacements. If these three points undergo a rigid-body-translation movement, their Lagrangian components can be obtained by solving simultaneous equations for these three adjacent points. Though this method was successfully used to discuss tectonic deformations, which was considered to have been responsible for the flood in 2005 along Uono River, the method needed some improvements for both shallow and deep soil deformations. Firstly, the method was to be used on condition that soil mass covered by three adjacent points moved keeping their integrity. Therefore, points suffering large rotational movements and/or with ill-conditions for solving simultaneous equations were to be excluded. The excluded points were found to exhibit similar distribution patterns of “visible” landslides. Secondly, since differences in DEMs at different times are to be discussed, they need to be the same in their accuracies. However, the DEM before the earthquake was obtained from aerial photos, while those after the earthquake were from Laser Imaging Detection and Ranging (LIDAR), whose imageries often contain high spatial frequency components.

Moreover, there were clear man-made changes So the smoothing for LIDAR-described terrains has been done assuming an optimum plane that best fits 25 (5 times 5) nodes of DEM arranged in square in the least-square sense, and the center of the plane and the plane tangents at this point were assumed to represent the elevation and tangents for this Eulerian point, respectively. Even after this smoothing procedure, obtained Lagrangian displacement components often showed remarkable scatters. Therefore, the moving average method was used for overall features of both tectonic and shallow displacements. The window size is desirable to be larger than the largest hidden landslide in the target area for the discussion of tectonic deformations to minimize the effect of the hidden landslides, and was set at 1km considering that the largest landslide in this terrain cannot be larger than the half wave length of the active folding. The emerged image showed that there were two major clusters of large lateral components of tectonic deformation, the first one appeared as an about 1km-wide brush along Kajigane syncline and the other appeared several km northwest of it. Interestingly, major visible landslides were mostly found within these two clusters of lateral displacements. As the window size decreases, we will see more local deformations which may be largely affected by shallow soil movements. To exclude man-made changes such as road constructions and farmland consolidations, the window size was set at 200m, and the tectonic displacements were subtracted from the emerged image for discussing if there were some hidden landslides in the target area. As for Kizawa hamlet is concerned, obtained vectors showed down-slope movements, and they are consistent with observed traces of dislocations that were found in Kizawa tunnel and irrigation wells.

The method proposed in this paper has a great potential to be applied to the other areas for discussing post-earthquake geotechnical and land conservations. However more case studies will be necessary to determine appropriate window sizes for moving average smoothing.