LANDFORM CHANGES IN AN ACTIVE FOLDING ZONE INDUCED BY THE OCTOBER 23, 2004, MID NIIGATA EARTHQUAKE, JAPAN

K. Konagai[1], T. Fujita[2], T. Ikeda[3] and S. Takatsu[4]

[1] *Professor, Institute of Industrial Science, University of Tokyo, Tokyo. Japan*
[2] *PhD candidate, Institute of Industrial Science, University of Tokyo, Tokyo. Japan*
[3] *Senior Researcher, Research Institute of Technology, Tobishima Corporation, Japan*
[4] *Researcher, Geotechnical Division, CTI Engineering Co. Ltd., Japan*
Email: konagai@iis.u-tokyo.ac.jp

ABSTRACT :

About 8 months after the October 23rd, 2004, Mid-Niigata Earthquake, the middle reach of the Uono River was flooded in a heavy rain. The flood-ravaged zone was immediately upstream of the most seriously devastated zone in the Mid-Niigata Earthquake, and tectonic deformation caused in this earthquake was considered to be one of the causes of this flooding. Precise digital elevation models (DEMs) before and after the earthquake were obtained with stereoscopy for aerial photographs and Laser Imaging Detection and Ranging technology (LIDAR), respectively, and then compared to detect elevation changes and translations. It was clarified in this study that an about one-kilometer wide brush along Kajigane syncline has shifted about 0.5m eastward causing the area where the Uono River meets the Shinano River to be raised upward by 0.5 to 1.5 meters.

KEYWORDS: Mid-Niigata Earthquake, tectonic deformation, post-quake disaster, rehabilitations

1. INTRODUCTION

A massive earthquake often causes long-lasting issues, and the October 23rd 2004 Mid-Niigata Earthquake was no exception. The prevalence of NNE-SSW-trending active folds characterizes the epicentral area of this earthquake. Stratified Pliocene rocks are found everywhere curved upward or downward. Since the up-folded rocks along anticlines were expanded and weakened, anticlines frequently have their crests eroded deeply. As the consequence, asymmetric ridges called cuesta, characterized by a steep cliff or escarpment on one side, and a gentle, dip slope on the other, have been formed. With this geological background, Higashiyama mountain zone had been regarded as one of the most landslide-prone zones in Japan, and in this earthquake, a large number of landslides in this mountain zone blocked major trunk railways, highways, and national routes. The landslides also forced the local authorities to suspend the operation of 233 segments of prefecture routes (Hokuriku Regional Bureau, 2004). Therefore, the local authorities as well as the Japanese Ministry of Land, Infrastructures and Transport have made all-out efforts to stabilize landslide masses first thing for rehabilitation. Although the landslides were primarily responsible for the property damage and the human suffering, the surface tectonic deformation is considered to have caused some long-lasting problems for rehabilitating the affected areas. About 8 months after the Mid-Niigata Earthquake, the middle reach of the Uono River was flooded in a heavy rain. The flood-ravaged zone was immediately upstream of the most seriously devastated zone in the Mid-Niigata Earthquake, and the ground upraised in this earthquake was considered to be one of the causes of this flooding. Thorough monitoring of landforms has highlighted the cause-and-effect relationship of this flooding as will be described hereafter.

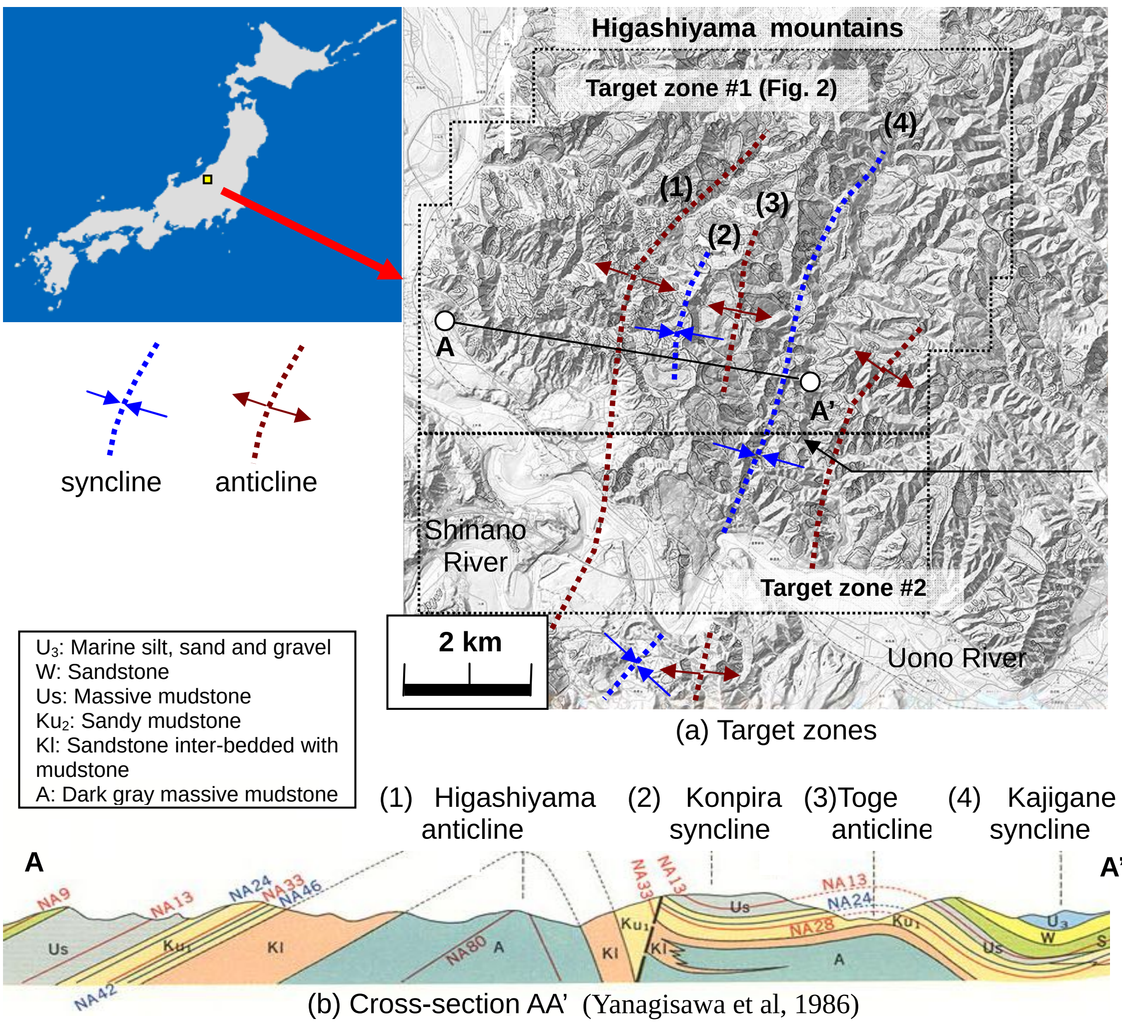
2. DETECTION OF LANDFORM CHANGES

2.1 Detection of tectonic displacements

The landform changes due to the earthquake are first assessed. Interferometric Synthetic Aperture Radar (InSAR) is one of the most advanced technologies that can measure elevation changes with high precision (United States Geological Survey, 2005). However, thick vegetation and thousands of landslides have made fringe patterns too complicated for extracting pure elevation changes (Ozawa et al, 2005). Therefore in this study, precise digital elevation models (DEMs, hereafter) before and after the earthquake were obtained using stereoscopy and Laser Imaging Detection and Ranging technology (LIDAR).

After the Mid Niigata Earthquake, affected areas have been laser-scanned at different times. A target study zone of 11×7 km^2 (Zone #1 in Fig. 1) was first selected in such a way that it would include major landslides. Three years later, Zone #2 was added to get the whole picture of the tectonic deformation because it turned out that the tectonic deformation was more serious in the immediate south of the Zone #1. No precise DEM was available for each target zone before the earthquake. Therefore a series of aerial photographs on a scale of 1/8000 to 1/10000 taken in 1975-1976 together with the triangulation data of 1985 were used to prepare a precise DEM of the topography before the earthquake.

The DEM for both Zones #1 and #2 from the 1975-1976 aerial photographs was first compared with the DEM developed from the LIDAR survey of Oct. 24th, 2004. Fig. 2 shows elevation changes that have been built up in the target zone during the interval of 29-30 years including the changes due to the Oct. 23rd, Mid Niigata earthquake. The changes of elevation are displayed with different colors for pixels arranged in a 2 meter by 2 meter square grid. Though the elevation changes show some scattered pattern especially in mountains, there is a general tendency that the western half of the Zones #1 and #2 has been raised while the eastern half has subsided. This tendency is clearly seen in flat lands, which include the area near the junction of the Uono River and the Shinano River (see lower left part of Fig. 2). To show this tendency in an easier way to understand, elevation change of the National Route #17 along the Uono River is shown in Figure 2(b).



(a) Target zones

(b) Cross-section AA' (Yanagisawa et al, 1986)

Figure 1. Target zones in the Mid Niigata Prefecture

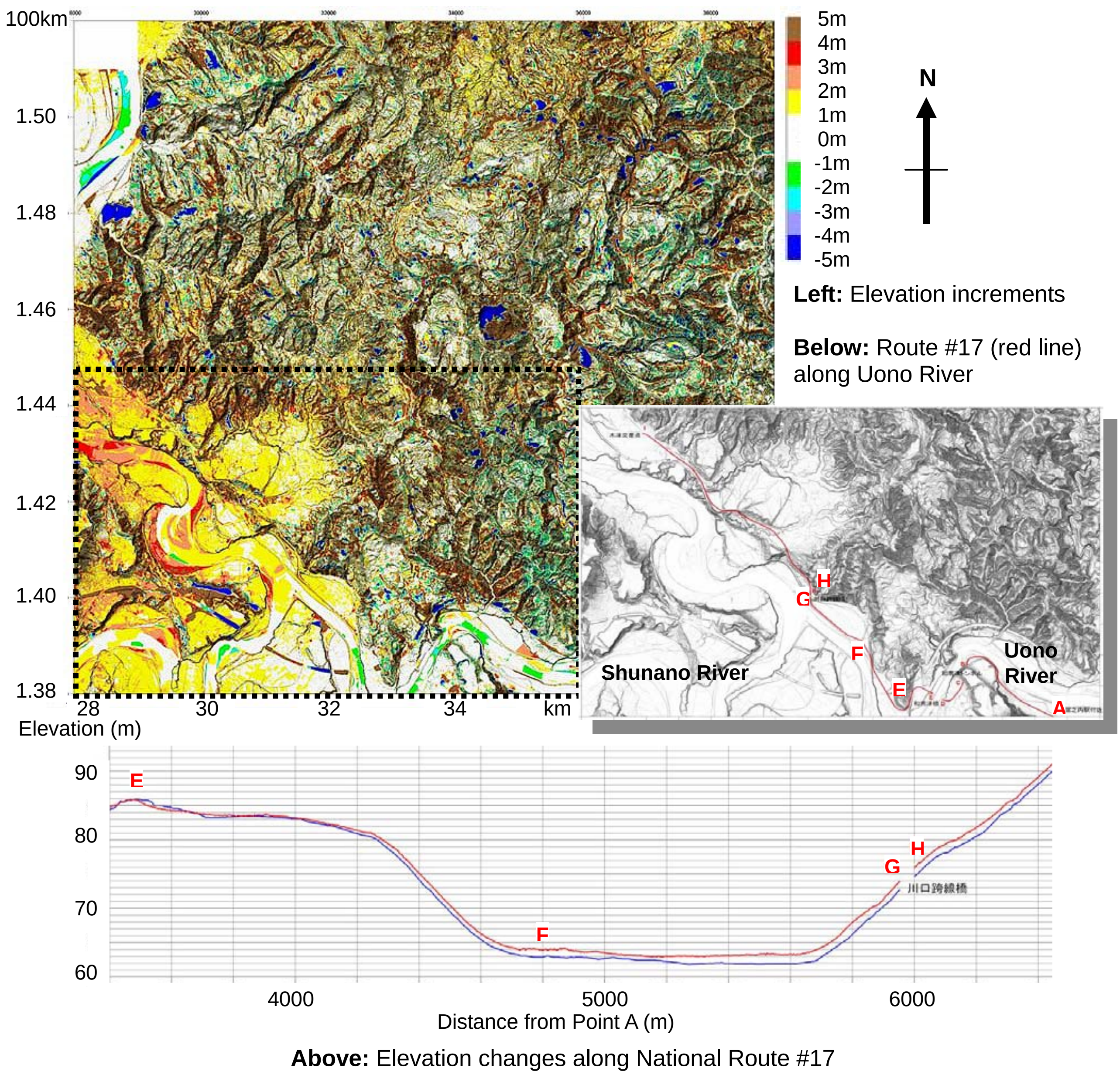
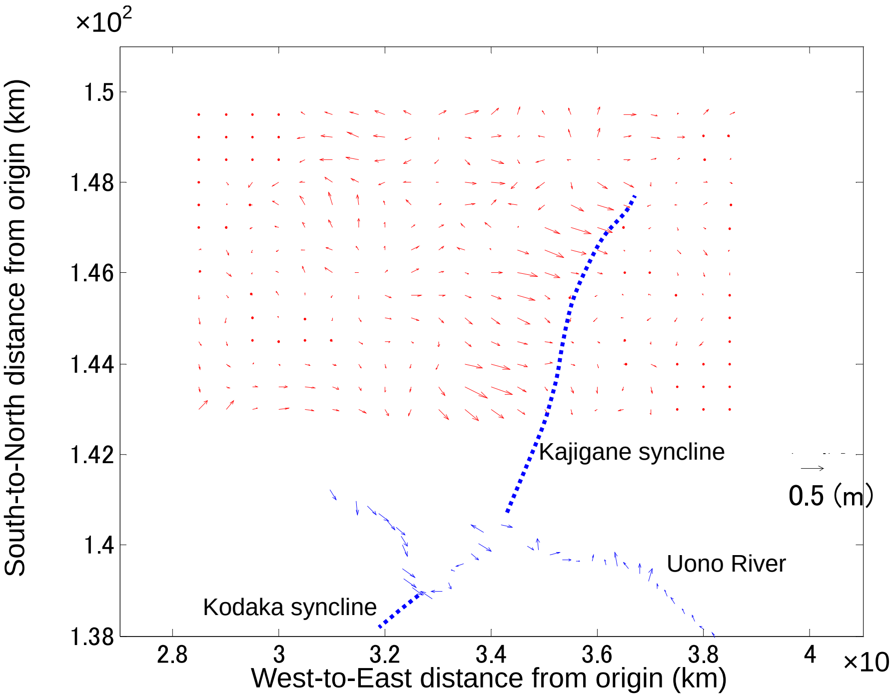


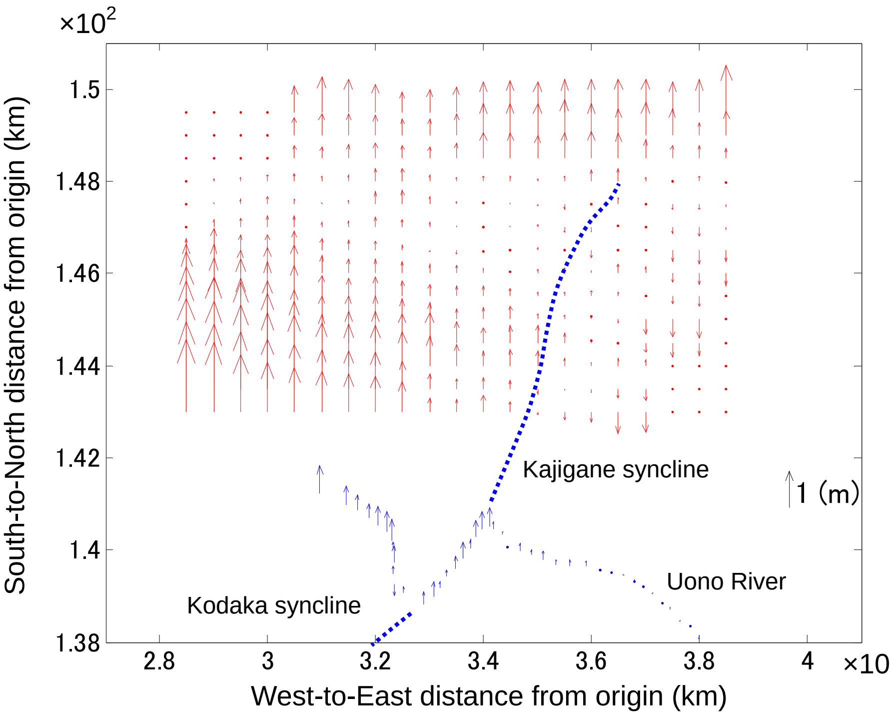
Figure 2. Elevation changes in the target zone on Eularian coordinate system (Zone VIII of the Japanese National Grid System): The Japanese Geological Survey uses the Japanese National Grid System. It divides Japan into a set of 19 zones assigned with Greek numerals from I to XIX in principle in a row-by-row pattern starting from the zone at the southwest corner. Exceptions (from XIV to XIX) are for isolated islands. The surveyed area is included in Zone VIII with its southwest corner located at 138º30’00”E, 36º00’00”N.

National Route #17 crosses the Uono River near Point E where the Uono River forces its way through its constricted part. After this point the road (red line) is becoming steadily higher than its original level (blue line), and the elevation change converges on about 1 to 1.5m after passing Point F.

The detected elevation changes are all observed in Eulerian coordinates, a coordinate system fixed in space, which does not follow the motion of soil particles. Moreover, the elevation changes that had been built up during this time interval of 29-30 years are (1) crustal movement in the Mid-Niigata Earthquake of 2004, (2) landslides in both the earthquake and snow-melting times, and (3) land improvement works and cultivations. Therefore, the first and essential step for identifying the cause of the damage preceding any rational and scientific reconstruction work should be to separate from each other the above-mentioned components of ground displacements.



(a) Lateral components



(b) Vertical components

Figure 3. Surface tectonic displacements of the target zone on the Japanese National Grid System (Zone VIII). (Konagai, et al, 2008a and 2008b)

Konagai et al. (2008a, 2008b) extracted three orthogonal components of the crustal movement by virtue of the fact that the spatial fluctuation of elevation changes due the crustal movement had much longer wave lengths than those due to the other causes. Note that the elevation increments have a margin of error (-0.033m biased and with 0.34m standard deviation), which has been verified by using six triangulation points in the target zone whose movements were not considered to have been affected by landslides, land improvement works and/or cultivations.

Figs. 3(a) and 3(b) show respectively horizontal and vertical components of surface tectonic displacements in Zone #1 extracted from the DEMs. Zone #1 turned out to be slightly small for discussing the entire tectonic deformation that spreads beyond the boundaries of this zone, and tectonic displacements in Zone #2 is being analyzed to get a whole picture of deformation. It was, however, fortunate that the Shinano River Office, Hokuriku Regional Bureau of the Ministry of Land, Infrastructure and Transport (MLIT), had been measuring exact locations of bench marks along both Shinano and Uono Rivers on a regular basis. This information can cover the south neighboring area of the zone. Lateral and vertical displacement components of the bench marks along the Uono River were also plotted on Figs. 3(a) and 3(b), respectively. In both Figs. 3(a) and 3(b), the Uono River, after flowing straight west through a flat wide spread valley of Horinouchi, hits the sedimentary silty sand rock ridge of Cenozoic Era. The river then abruptly changes its direction, from SE-NW to NE-SW, along this rock ridge making a sharp down-folded bend. Then it forces its way through the narrow and lowest points among the mountains making a sharp up-folded bend. On the geological map of this area (Yanagisawa et al, 1986), the approximately 2 km-long stretch of the Uono River between these two bends continues straight to both Kajigane and Kodaka synclines at its north and south ends, respectively, suggesting that this 2 km-long stretch of the river is a part of the large Kajigane syncline. For the horizontal components, there is a NNE-SSW trending wide brush of large eastward movement to the west of and along the Kajigane syncline. This about one-km-wide brush of the lateral movements suggests the presence of a thrust fault hidden beneath it.

For the vertical components, it is notable that there are two areas in the target zone, which have been pushed up by 0.5 to 1.5 meters (Fig. 3(b)). The most remarkable hump spreads wide across the southwestern part of the target zone where the Uono River joins the Shinano River. This part is near the southwestern end and on the hanging wall side of the hidden fault.

2.2 Flooding

Areas along the upper reach of this part of the Uono River were flooded due to heavy rainfall of June 27th-28th, 2005, about 8 months after the earthquake (Fig. 4). Inundated farm lands (mostly paddy fields) are shown in Fig. 5.

Figure 4. Flooded area near Benchmark No. 37.5km on June 28, 2005 (Photo by Kotajima, S.)

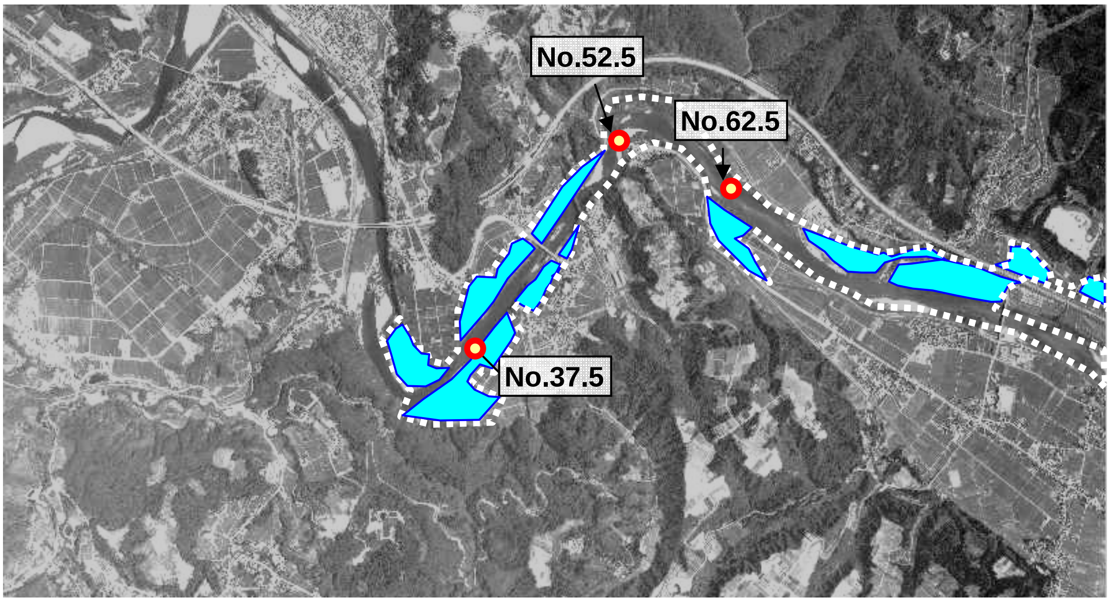


Figure 5. Flooded farm lands (data provided by the Hokuriku Regional Agricultural Administration Office, Ministry of Agriculture, Forestry and Fisheries, and Uonuma City)

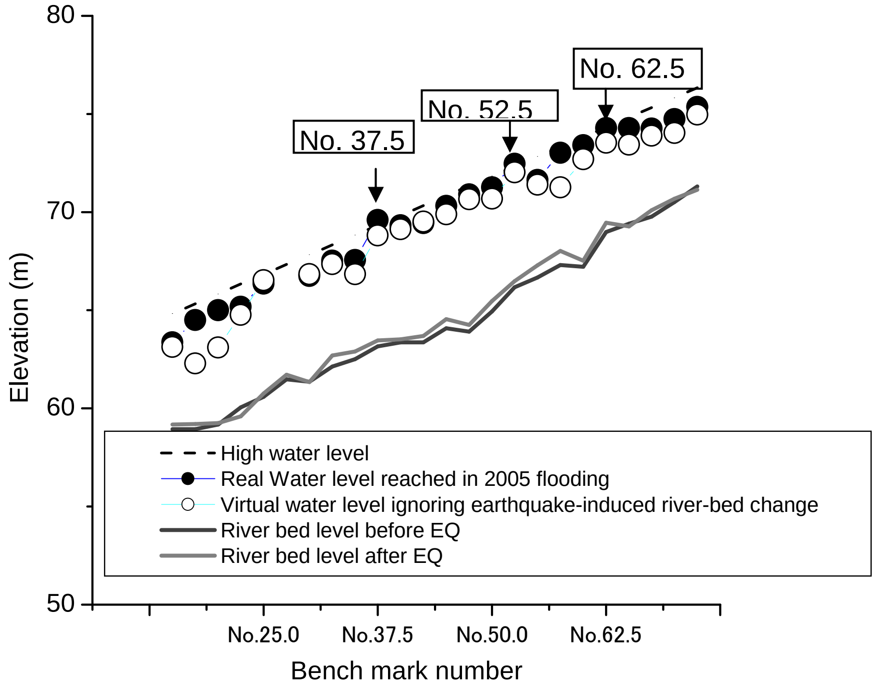


Figure 6. Actual water levels at all bench marks reached in the 2005 flood, and the virtual water levels for the Uono River as existed before the earthquake (Konagai et al., 2008a and 2008b).

Assuming that the same amount of water in the 2005 rain flowed down the Uono River as existed before the earthquake (ignoring the landform changes caused by the Chuetsu earthquake), possible water depths at all bench marks along the 57.5km-long flooded zone (from BM No. 15 at 37°15'59"N, 138°51'44"E, to BM No. 72.5 at 37°15'33"N, 138°54'00"E) were estimated by using the Manning empirical equation (Dooge, et al, 1992, Chow, 1988). For this estimation, precise dimensions for the river cross-sections and inclinations at all benchmarks before and after the earthquake were provided by the Shinano River Office, Hokuriku Regional Bureau of the Ministry of Land, Infrastructure and Transport (MLIT).

Solid circles in Fig. 4 show the actual water levels at all bench marks reached in the 2005 flood, while open circles show virtual water levels calculated for the Uono River as it existed before the earthquake. At almost all points, the virtual water levels are lower than those reached in the 2005 real flood. Actual water levels were higher than the high water levels (HWL) at bench marks # 37.5, # 52.5 and # 62.5, while virtual water levels at these points do not reach the high water levels. This figure thus suggests that there was a cause-and-effect relation between the earthquake-induced tectonic deformation and the flooding of June, 2005.

3. CONCLUSIONS

In the October 23, 2004 Mid-Niigata Earthquake that occurred in the central part of Honshu island, Japan, it is beyond doubt that landslides were primarily responsible for not only the property damage and the human suffering but also geotechnical difficulties in rehabilitation works. But surface tectonic deformation also made rehabilitation difficult in affected areas.

This paper estimated the surface tectonic deformation, which is indicative of the interior deformation of soils induced by the Mid-Niigata Earthquake. Digital elevation models of the surface terrain before and after the earthquake were first obtained as raster graphic images with pixels arranged in a 2m×2m square grid; each pixel has an information of its elevation. Excluding the effect of shallow surface landslides, large-scale ground surface deformation was detected.

The east-west components of landform changes are in general much larger than those in the north-south direction, and they showed a NNE-SSW trending belt of large eastward movements of soil to the west of and along Kajigane syncline.

There are two humps in the analyzed zone, which have been raised upward by 0.5 to 1.5 meters. The southern hump spreads widely across the area where the Uono River joins the Shinano River, and therefore could have been one of the causes of flooding that occurred about eight months after the earthquake.

ACKNOWLEDGEMENT

This paper summarizes one of the outcomes of the Research and Development program for Resolving Critical Issues, “Earthquake damage in active-folding areas: creation of a comprehensive data archive and suggestions for its application to remedial measures for civil-infrastructure systems,” Special Coordination Funds for Promoting Science and Technology, Ministry of Education, Culture, Sports, Science and Technology. The authors would like to express their sincere thanks to all members of the project steering committee organized under the Japan Society of Civil Engineers as the core of the project.

REFERENCES

Hokuriku Regional Development Bureau (2004), Quick report of the damage to infrastructures, Ministry of Land, Infrastructure and Transport, http://www.hrr.mlit.go.jp/saigai/H161023/1023_top.html.

Konagai K., Fujita T., Ikeda T. And Takatsu S. (2008a): Deformation buildup in tertiary rocks in the October 23, 2004, Mid-Niigata earthquake. *Geotechnical Earthquake Engineering and Soil Dynamics*, IV, ASCE, Sacramento CA.

Konagai K., Fujita T., Ikeda T. And Takatsu S. (2008b): Tectonic deformation buildup in folded mountain terrains in the October 23, 2004, Mid-Niigata earthquake. *Soil Dynamics and Earthquake Engineering*, doi: 10.1016/j.soildyn.2008.01.013, in press.

Yanagisawa, Y., Kobayashi, I., Takeuchi, K., Takeishi, M., Chihara K. and Kato H. (1986), Geology of the Ojiya District, Quadrangle Series Scale 1:50,000, Niigata (7), No. 50, Geological Survey of Japan.

United States Geological Survey (2005), “What is InSAR?” *Earthquake Hazard Program*, http://quake.usgs.gov/research/deformation/modeling/InSAR/.

Ozawa, T., Nishimura, S., Wada, Y., Okura, H. (2005), Coseismic deformation of the Mid Niigata Prefecture Earthquake in 2004 detected by RADARSAT/InSAR, *Earthquake Planets Space*, 57. 423-428.

Okada Y. Surface deformation due to shear and tensile faults in a half space, *Bulletin of the Seismological Society of America*, 75(4), 1135-1154, 1985.

Dooge, J. C. I. in Channel Wall Resistance (1992), Centennial of Manning’s Formula, edited by B. C. Yen, Water Resources Publications, Littleton, Colorado.

Chow, V.T. (1988), Open-Channel Hydraulics, McGraw-Hill, New York, 1988.