IMPLICATION OF RECENT CASE HISTORIES OF EARTHQUAKE-INFLICTED MASS MOVEMENT; A CASE STUDIES AT OJIYA CITY AFTERMATHS THE 2004 MID NIIGATA PREFECTURE EARTHQUAKE AND AT IWAKI CITY AFTERMATHS THE 2011 FUKUSHIMA PREFECTURE HAMADORI EARTHQUAKE

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ABSTRACT

Large strains built up in soils and rocks along a dislocated seismic fault can trigger post-earthquake disasters such as landslides and debris flows, which can cause long-lasting serious problems for rehabilitations and land conservations. Therefore one of what required of us is to deduce as much hidden signs as possible from observable change of landforms for rational rehabilitation strategies. Recent development of remote sensing technologies has enabled us to detect precise landform changes in the Eulerian space. However the description in the Eulerian coordinate system is to be converted to Lagrangian description of displacements to cope with post-earthquake geo-hazards. In this individual study, two examples are highlighted. One is in Uragara Hamlet, Ojiya City, Niigata prefecture in an active folding zone of low-rise mountain terrain, which was affected by the 2004 Mid-Niigata Prefecture Earthquake. An attempt was made to extract Lagrangian components of displacements from available set of elevation data for Uragara Hamlet. The second case study is from the 2011 Fukushima Prefecture Hamadori Earthquake. This normal-fault type earthquake triggered some landslides and rock falls in Iwaki City, Fukushima Prefecture, and there is a concern that they will grow into a serious problem given frequent aftershocks and heavy rains in summer. Much of effort is thus devoted to compile the current exact landforms as the reference for possible future soil/rock mass movements.

Keywords: Hidden Landslides, Lagrangian Displacements, Hamadori Earthquake.

1. INTRODUCTION

Generally, landslides triggered by an earthquake are one of the most damaging natural disasters. We have to recognize that not only shaking but also ground deformations can be equally or often more responsible for big devastation. A big earthquake can cause large strains to be localized near the activated seismic fault, where large scale mass movements such as landslides, rock falls and debris flows would occur. By taking a look at historical cases, it is found that these mass movements can last long and cause serious problems for rehabilitations and land conservations. Such cases include the May 8th, 1847 Zenkoji Earthquake (M7.4), October 23rd, 2004 Mid Niigata Prefecture Earthquake (M6.8) and May 12th, 2008 Wengchuan Earthquake (M7.9).

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2. CASE HISTORIES OF EARTHQUAKE-INFLICTED MASS MOVEMENTS

Earthquake-inflicted landslides and breaching failures of landslide dams frequently occurred worldwide. A large scale landslide is a rare event, to be sure, but once it takes place, it can cause long lasting serious problems. Two case histories of Japan, the 1707 Hōei Earthquake and the 1858 Hietsu Earthquake which triggered big mass movements, will follow hereafter.

2.1 Oya-Kuzure and Tateyama Mass Movement

Oya-Kuzure debris flow was caused by the 1707 Hōei Earthquake (M8.6), which occurred at 14:00 local time on October 28, 1707. At least one major slope failure was triggered by the earthquake, the Ohya slide in Shizuoka. This slope failure, one of the three largest in Japan, involved an area of 1.8 km^2, with an estimated volume of 120 million m^3. Another historical case is Tateyama (Tobiyama-kuzure) debris flow. The Hietsu Earthquake (M7.1) on April 9, 1858 caused numerous sediment disasters along the Atotsugawa Fault system. These debris flows completely transformed the Joganji River into one of the most devastated rivers in Japan and had generated serious sediment runoff causing ongoing problems despite numerous sabo facilities in the past century (Inoue et. al. 2010). A total of 400 million m^3 debris mass reportedly flowed down the mountain side. There is 200 million m^3 unstable debris mass still remaining there.

Earthquakes in active folding zones often trigger long lasting landform changes. Examining old documents, some past earthquakes have shown that earthquakes in such active folding zones can trigger long-lasting geological rehabilitation issues; they include the 1847 Zenkoji Earthquake, the 1914 Akita-Senboku Earthquake and the 2004 Mid-Niigata Prefecture Earthquake (Konagai and Kazmi 2011).

3. DETECTION OF HIDDEN LANDSLIDES

3.1 Method

The development of technologies such as Laser Imaging Detection and Ranging Technology (LIDAR), Interferometric Synthetic Aperture Radar (InSAR) and Differential-InSAR enabled us to acquire the images of landforms and the changes in elevation with high precision. On the other hand, the methods allow us to detect displacements only in the Eulerian description, in which the description of motion is made in terms of the spatial coordinates which does not follow the motion of soil particles. Discussions of earthquake-inflicted geotechnical issues require more direct description of soil particle movements because soils are typically history-dependent materials. Rather than the Eulerian displacements, we need to extract Lagrangian displacements of soils, whose behaviors are typically history dependent. 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 Digital Elevation Model (DEM) would have Lagrangian displacements. The method was later improved by Zhao (2010) and Konagai and Kazmi (2011) for more rational and robust scheme which allowed coherent and rotational mass movement to be extracted.

3.2 Target Area

A sequence of powerful earthquakes jolted Mid Niigata Prefecture, central Japan. The main shock occurred at 5:56 PM JST on October 23, 2004 with its hypocenter at 37.3 N; 138.8E, its focal depth of 13km and magnitude of 6.8 determined by the Japan Meteorological Agency (JMA). The 2004 Mid Niigata Prefecture Earthquake triggered and/or reactivated thousands of landslides, and the economic loss due to these landslides was initially estimated to be about 8 billion US dollars, making this one of the costliest landslide events in history (Kieffer et al., 2006).

Lagrangian displacements were extracted from DEMs for the area before and after the earthquake using the method proposed by Konagai and Kazmi (2011). The extracted displacements include both tectonic deformations caused by deep seated tectonic forces and shallow soil displacements. Moving average method was utilized to extract deeper soil deformations, which was expected to show more gentle variation in space than that of shallow soils. 1.4km x 1.4km square window was used for extracting lateral and vertical components of surface tectonic displacement. Figure 1, showing lateral components of the extracted Lagrangian displacements, highlights two major clusters of large lateral movements. One is the NNE-SSW trending 1 to 2 km wide belt of eastward movement to the west of and along the Kajigane syncline and the other is north-westward movement near Uragara Hamlet. Uragara Hamlet is near the projection on the ground surface of the hidden fault rupture plane for the first largest aftershock of M6.3, which took place at 18:03 JST, about 7 minutes after the main shock. Zoom in right on the Uragara area, Figures 2 and 3 show respectively lateral and vertical components of the extracted tectonic displacements. To obtain shallower soil displacements, a smaller square window of 200m x 200m was used, and the tectonic displacements were subtracted from the extracted displacements through the 200m x 200m window. Then a coherent downslope mass movement of about 1m was seen on the valley slope immediately north of Uragara. This information is really suggestive that there are still many shear planes hidden in the interior of soils (Figure 4). Careful and continuous eyes are to be kept on any suspicious movements of these hidden landslides.

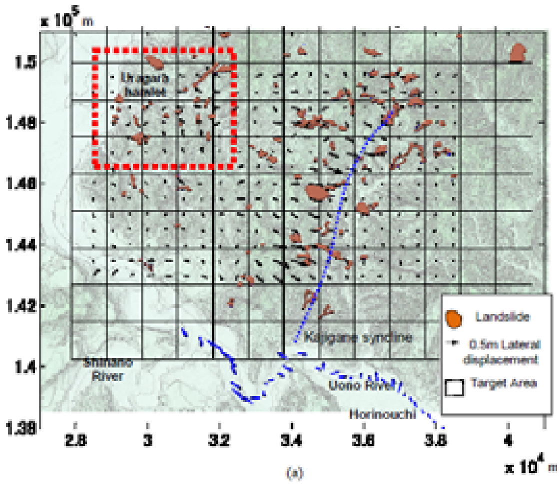

Figure 1. Horizontal component of tectonic displacement superimposed with landslides.

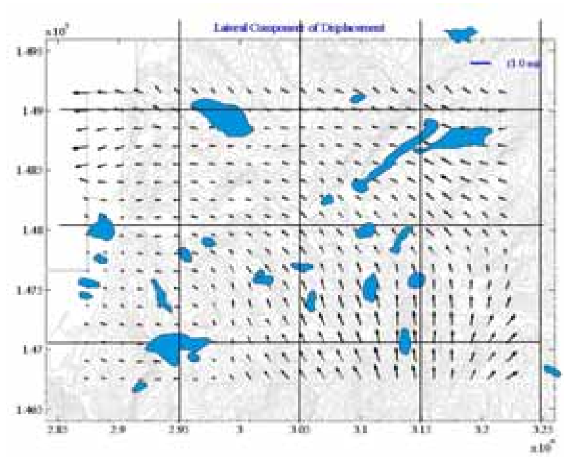

Figure 2. Lateral components of surface tectonic displacement of the target zone on superimposed with landslide distribution.

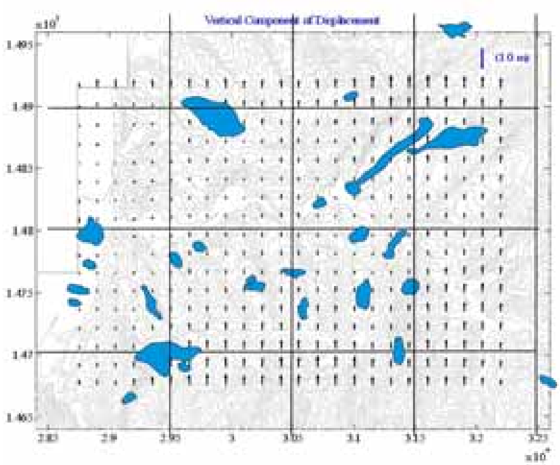

Figure 3. Horizontal components of surface tectonic displacement of the target zone on superimposed with landslide distribution..

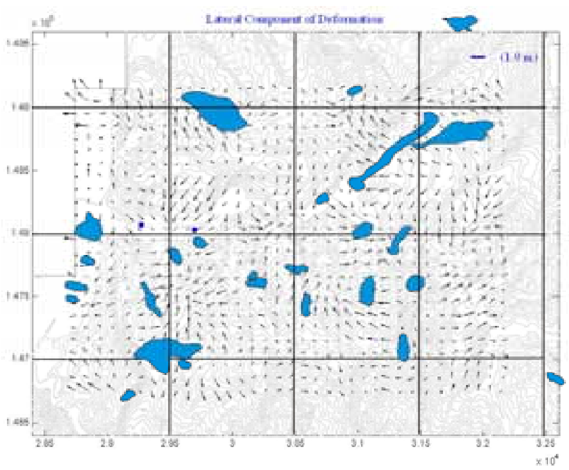

Figure 4. Shallow soil displacements of the target zone, Japanese National Grid System on Zone, VIII which are superimposed with landslides.

Our findings about the Uragara Hamlet study are summarized as follows;

I. A strong earthquake can cause soils and rocks in its epicentral areas to be largely deformed, and triggers long lasting geotechnical problems.

II. If there exists a hidden landslide, a hasty rehabilitation would cause too much to lose. The source area of the 2004 Mid Niigata Prefecture Earthquake, we need to remember that many hidden landslides can be reactivated especially in snow-melting times. An attempt is made herein to detect hidden coherent mass movements by reducing the smoothing window size to 200m x 200m.

III. Figure 4 shows the lateral components of the detected coherent mass movements in Uragara area. It is noted that there is a cluster of 0.5 to 1.5 meters soil displacements.

4. LANDSLIDES ALONG NORMAL FAULT TRACE

The earthquake and tsunami of March 11th, 2011 revealed vulnerabilities of disaster prevention schemes/systems along the several hundred kilometers stretch of the Pacific Coast of east Japan, given the tsunami heights exceeding the determined design heights. However, shaking damage to slopes was significantly less than what would be expected based on measured accelerations, indicating that it was a huge but far earthquake. More seriously some inland earthquakes that followed the March 11th Earthquake caused damage to slopes. They included the March 12th earthquake of M6.7 that took place near the border between Nagano and Niigata prefectures and the 2011 Fukushima Prefecture Hamadori Earthquake of M7.0 that took place in the mountainous outskirts of Iwaki City, southern part of Fukushima Prefecture. Though they are considered to have some physical cause-and-effect links with the March 11th earthquake, each earthquake is quite large enough to cause serious slope failures. All the more there is a concern that more intense aftershocks will follow these events, we need to keep a careful eye on these landslide masses which may exhibit some more continual movements.

4.1 The 2011 Fukushima Prefecture Hamadori Earthquake

One month after the great M9.0 the 2011 off the Pacific coast of Tohoku Earthquake of March 11th 2011 the Iwaki region of Fukushima Prefecture, was jolted by a series of moderate to large aftershocks (JMA, 2011). The largest one of them was the 2011 Fukushima Prefecture Hamadori Earthquake of JMA Magnitude Mj7.0 or USGS magnitude Mw6.6 that occurred at 17:16 JST (08:16 UTC) on Monday, 11 April 2011. The 2011 Fukushima Prefecture Hamadori Earthquake was followed by eight aftershocks above magnitude 4.5 in the first 24 hours, including three with magnitude greater than 5.5 and hypocenters shallower than or equal to 20 km deep (Table 1).

Table 1. According to NIED records; main shock of the 2011 Fukushima Prefecture Hamadori Earthquake and following aftershocks above M4.5 in the first 24 hours (from 11 to 12 April 2011)

Date	Time	Magnitude	Depth (km)
April 11th	17:56	7.0	6.4
	20:42	5.9	10.5
	22:05	4.7	11.2
April 12th	00:43	4.5	10.8
	00:57	5.0	10.5
	02:21	4.5	20
	05:03	4.5	10
	07:03	4.5	20
	14:07	6.4	15.0

The focal mechanism of this earthquake was normal-fault type with tensional axis toward WSW-ENE, and that was a shallow crustal earthquake. This area had been seismically inactive until the March 11th massive earthquake occurred but frequent seismic events of the normal fault type have been reported since then. In the 2011 Fukushima Prefecture Hamadori Earthquake, surface fault ruptures appeared along the recognized traces of Idosawa and Yunotake Faults. Idosawa Fault is the NNW-SSE trending right lateral strike slip fault while Yunotake fault is a NW-SE trending southwest dipping normal fault. Figure 5 shows epicenters of the 2011 Fukushima Prefecture Hamadori Earthquake and its aftershocks and location of both Idosawa and Yunotake Faults.

On 23rd and 24th July 2011, we made a site investigation trip around Idosawa and Yunotake Fault areas. In this survey, five geotechnical hazards were found near the southeastern end of Yunotake Fault as shown in Figure 15. One of major concerns was that they would move again in upcoming June, the rainy season in Japan, and in possible aftershocks that might occur in rapid succession. Therefore, much of time of our survey was devoted to gather every small sign of continual mass movements. As was explained above, there are two coherent mass movements (No. 1 and 2), two rock falls (No. 3 and 4) and one lateral spread (No. 5) in Figure 6 near the southeastern end of Yunotake Fault. It is also noted there was a conjugate fault of Yunotake appeared near No. 1 and 2.

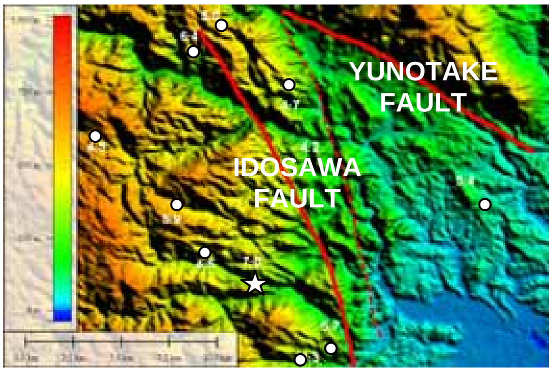

Figure 5. The 2011 Fukushima Prefecture Hamadori Earthquake location and aftershocks distribution between 07.04.2011-14.04.2011. White star refers the 2011 Fukushima Prefecture Hamadori Earthquake and white circles aftershocks.

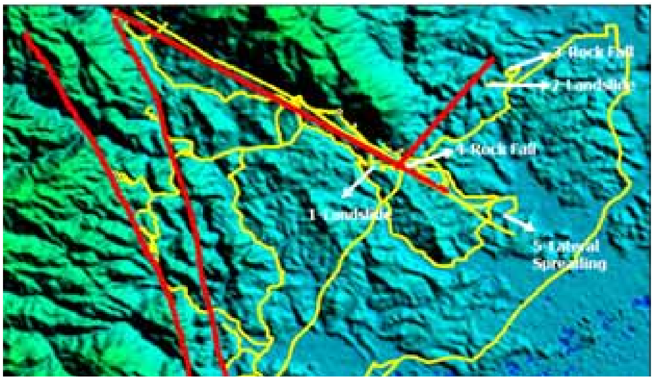

Figure 6. Iwaki city mass movement locations. 1-Gosaisho Highway Landslide Area, 2- Landslide Area Near The High School, 3- Rock Fall Area Near The House,, 4- Rock Fall Area Outside Of The Settlement Area, 5- Iwasaki Lateral Spreading Area.

Among the above mentioned five locations of geo-hazards, Landslide No. 1 is seemingly the most serious. The coherent soil mass moved down the slope, burying the road which was constructed by cutting the toe of the slope (Figure 16). One person, whose vehicle happened to pass by, was found dead in the landslide mass. Knowing the importance of that road, a new temporary road is planned to be constructed over the landslide mass to restate the route. It was, therefore, important to monitor the gradual movement of the landslide mass given the current landform as reference. Seismic activity is still high at Iwaki city and its vicinity. Moreover rains are expected in June, July and August. Therefore one of the most serious concerns in the affected areas is if these landslides will move again they frustrate all attempts for rehabilitation Our findings through the site investigation are summarized as follows:

I. The 2011 Fukushima Prefecture Hamadori Earthquake, in which Idosawa and Yunotake faults appeared as vertical offsets, triggered landslides and rock falls in Iwaki.
II. Mountains along Idosawa Fault were generally higher than those along Yunotake Fault.
III. Major geo-hazards including two cohesive mass movements, two rock falls and one lateral spread were found near the southeastern end of Yunotake Fault, though.
IV. The hypocenters of the 2011 Fukushima Prefecture Hamadori Earthquake and its aftershocks lined up not Yunotake Fault but Idosawa Fault.
V. Vertical offsets observed along Idosawa Fault were in general larger than those along Yunotake

Fault.

VI. There appeared a conjugate fault near the southeastern end of Yunotake Fault. The largest mass movement was found at around where the conjugate fault dies out. Although no clear evidence was observed, it is possible that the conjugate fault might have skimmed the landslide area and is responsible for triggering the landslide.

VII. Along Idosawa Fault, Abukuma metamorphic rocks are found while along Yunotake Fault, soft sedimentary deposits are clearly observed. This geological difference may have been the cause of geo-hazards distribution.

5. CONCLUSIONS

Earthquake induced landslides often cause serious destruction, which is often more serious than the immediate aftermath of the earthquakes. Historical data shows that both visible and hidden landslides can cause long lasting geotechnical problems for rehabilitations. In this individual study two examples were highlighted. One is in Uragara Hamlet in an active folding zone of low-rise mountain terrain, which was affected by the 2004 Mid Niigata Prefecture Earthquake. Though no distinct sign of a cohesive mass movement was reported on the valley slope of the Asahi River immediately north behind Uragara Hamlet, pavement of the National Route #291 was buckled up in this hamlet indicating the presence of a hidden landslide. A coherent downslope mass movement of about 1m was seen on the valley slope immediately north of Uragara. This information is really suggestive that there are still many shear planes hidden in the interior of soils. Careful and continuous eyes are to be kept on any suspicious movements of these hidden landslides.

The 2011 Fukushima Prefecture Hamadori Earthquake was considered to have some physical cause-and-effect link with the March 11th earthquake, and this earthquake was quite large enough to cause serious slope failures. Seismic activity is still high at Iwaki city and its vicinity. Moreover rains were expected in June, July and August. Therefore one of the most serious concerns in the affected areas was if these landslides would move again frustrating all attempts for rehabilitation, and it was necessary to keep a careful eye on these landslide masses.

On the basis that the method for extracting Lagrangian components of mass movements would be used in future, it was proven to be useful for coherent mass movements in mountain terrains. However, the obtained images are a mere indicator of hidden mass movements without clear-cut information of depths. Therefore it is necessary for this method to be combined with the other investigations so that causes of landform changes will be rationally discussed in a comprehensive manner. More case-histories are to be analyzed for more advanced use of the method for disaster preventions and land conservations.

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