

FAULT RUPTURE AND ASSOCIATED GEO-HAZARDS OF FUKUSHIMA-PREFECTURE HAMADOORI EARTHQUAKE

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ABSTRACT: On April 11th, 2011, Iwaki region of Fukushima prefecture was jolted by Fukushima-Prefecture Hamadoori Earthquake. Surface ruptures were observed along causative Idosawa and Yunotake faults. In addition to numerous small slope failures, a coherent landslide and damage to Tabito Junior High School, bisected by Idosawa Fault, were observed. A precise digital elevation model of the coherent landslide was obtained through the LiDAR surveys. Repeated measurements of perimeters of Tabito Junior High School have shown that ground undergoes a slow and steady/continual deformation.

Key Words: Hamadoori Earthquake, Idosawa and Yunotake Faults, landslide, gymnasium building, swimming pool, ground deformation

INTRODUCTION

On March 11, 2011, the 2011 Off the Pacific Coast of Tōhoku Earthquake, also known as the Great East-Japan Earthquake, of magnitude 9.0 jolted the east coast of Japan. The earthquake triggered extremely destructive tsunami waves of up to 38.9 meters (128 ft), in some cases traveling up to 10 km (6 miles) inland. According to the United States Geological Survey (USGS), Japan had experienced over 900 aftershocks since the March 11th earthquake with about 60 being over 6.0 M and three over 7.0 M.

One month after the Great East Japan Earthquake, the Iwaki region of Fukushima Prefecture was jolted by a series of intense earthquakes. The largest one of them was the Fukushima-Prefecture Hamadoori Earthquake (Hamadoori Earthquake hereafter), a strongest inland event after the 2011 Off the Pacific Coast of Tōhoku Earthquake, of Mj7.0 (Mw6.6), that occurred at 17:16 JST (08:16 UTC)

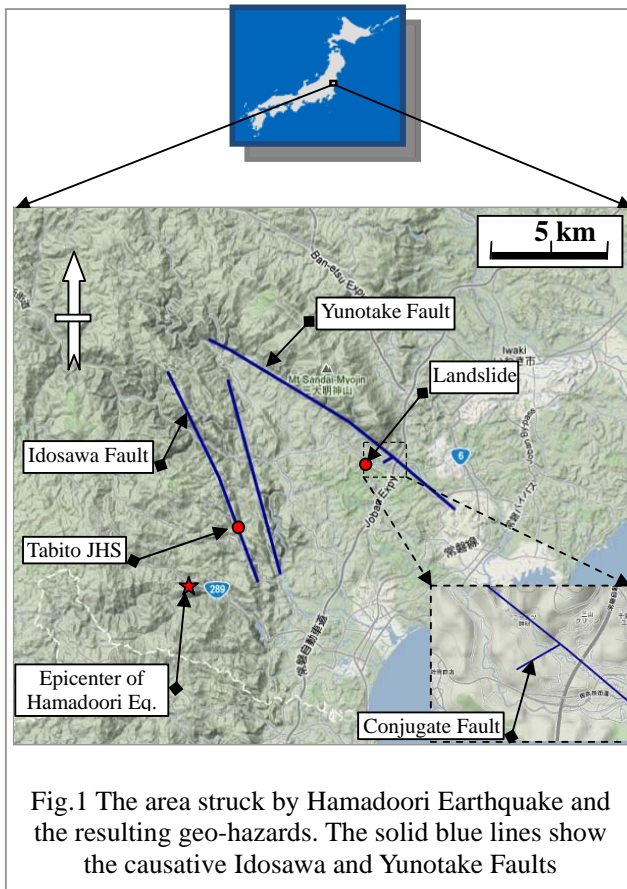
on Monday, April 11th, 2011 (JMA, 2011). In the first 24 hours, the Hamadoori Earthquake was followed by eight aftershocks of magnitude greater than 4.5, including three with magnitude greater than 5.5 and hypocenters shallower than or equal to 20 km (Table 1).

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

Date	Time (JST)	Magnitude	Depth (km)
April 11 th	17:56	7.0	6.4
	20:42	5.9	10.5
	22:05	4.7	11.2
April 12 th	00:43	4.5	10.8
	00:57	5.0	10.5
	02:21	4.5	20.0
	05:03	4.5	10.0
	07:03	4.5	20.0
	14:07	6.4	15.0

The focal mechanism of this earthquake was a normal-fault type with the tensional axis oriented in west-southwest to east-northeast direction and was a shallow crustal earthquake. This area had been seismically inactive until the Great East Japan Earthquake, but frequent seismic events of the normal fault type have been reported since then. In the Hamadoori Earthquake, surface fault ruptures appeared along the recognized traces of Idosawa and Yunotake Faults (Figure 1) over a distance of at least 11 km in southeastern Fukushima Prefecture (Ishiyama et al., 2011). Though major hazards were found mostly along Yunotake Fault, Idosawa Fault was considered to be the most responsible for the April 11th Hamadoori Earthquake. Actually fault dislocations were in general larger along Idosawa Fault (most of the observation ranging from 0.8 to 1.5 meters) than those along Yunotake Fault (Figure 2). Where present in shallow bedrock, the fault rupture was relatively distinct and linear; however, where present in unconsolidated alluvium the rupture is characterized by a fold scarp and hanging-wall cracking.

A big earthquake can cause large strains as well as intense shakes to be localized near the activated seismic fault, where large scale mass movements such as landslides, rock falls and debris flows would occur. Justifying the conclusions derived from the past studies, Hamadoori Earthquake was responsible for some landslides, rock falls and other geo-hazards, damaging roads, buildings and drainage structures. One of the major concerns was that the disturbed soil masses would move again in the upcoming rainy seasons and/or in possible aftershocks that might occur in rapid succession. Understanding this threat, the authors have been frequently surveying the areas along Idosawa and Yunotake Faults since the occurrence of Hamadoori Earthquake (May 18th, June 7th, June 23rd and August 20th). Other than slope failures and failures in the areas difficult to access, a coherent landslide and building structures of Tabito Junior High School, bisected by Idosawa Fault, were found along the causative faults (Figure 1). Much of the time of authors' survey was devoted to gather every small sign of continual mass movement and to attain the current configuration of the landform that might be used as reference in future to evaluate soil mass movements that might occur in frequent aftershocks and/or heavy rains. The above mentioned two geo-hazards along with other observations along both the faults are discussed in detail in the following sections. It is also noted that there was a conjugate fault of Yunotake Fault appeared near the coherent landslide (Figure 1). Although no clear trace was found close to coherent landslide, the conjugate fault might have skimmed this area and could have been one possible cause for this landslide.



LANDSLIDE

The landslide, mentioned above, was one of the most catastrophic failures caused by this earthquake. The soil mass moved coherently down the slope and blocked local Highway No. 14, which connects the area with a major freeway, the Joban Expressway. The landslide was triggered at the contact between highly weathered tuff and mudstone. Additionally, tall and steep road cuts were present adjacent to the landslide in (Figure 3, 4 and 5), which suggest that the road construction resulted in significant removal of lateral support. 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 was planned to be constructed over the landslide mass. It was, therefore, important to monitor the gradual movement of the landslide mass, given the current landform configuration as reference. Large scale tension cracks, indicating the presence of deep seated slip surfaces, were observed along the top of the landslide mass which indicated a possibility that the landslide mass would move, especially during the rainy season. For this, the authors conducted a LiDAR survey on May 18th to obtain a precise digital elevation model (DEM hereafter). The obtained DEM (Figure 6) covered only an upper middle to toe parts of the landslide mass because we had a narrow view of the landslide mass through thick vegetation covering it. Later on it turned out that one more image from an air-born LiDAR was obtained by Aero Asahi Co. for the upper half of the landslide mass, and the image was combined with what obtained from our field survey (Figure 7).

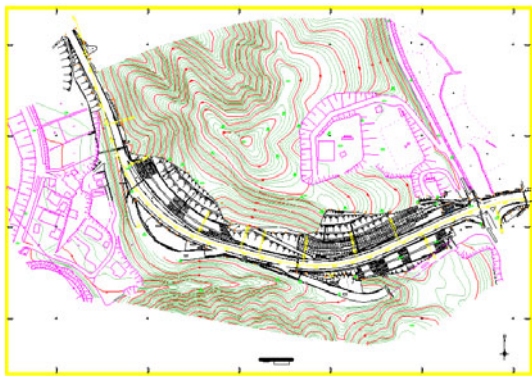


Fig. 3 Contour map of the area before the landslide was triggered. (Figure provided by Fukushima Prefecture).



Fig. 4 An aerial view of the landslide mass (Photo by Kyodo News). The coherent landslide mass flushed the road passing by its toe.



Fig.5 A closed view of the landslide mass (37°00'00.3", 140°47'14.5")

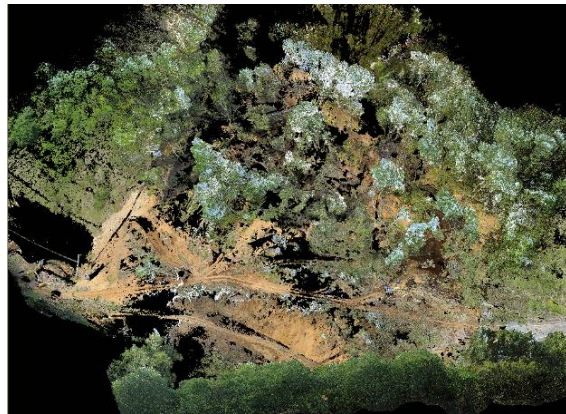


Fig.6 Landform of the lower half of the landslide mass obtained by ground LiDAR survey

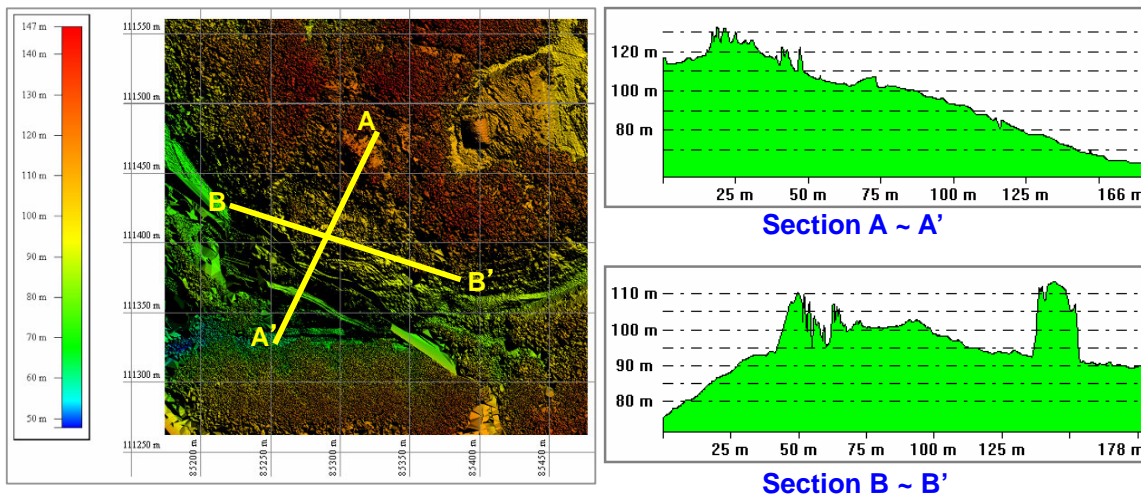


Fig. 7 Precise Digital Elevation Model (DEM) of the whole landslide area obtained by combining the ground and air-born LiDAR survey data

After the authors' LiDAR survey, the landscape was dramatically changed for the construction of temporary road (Figure 8). Earth cut and fill operations were done in such a way that the road would be constructed directly on the landslide mass without deeply cutting it, thus the greater toe part of the landslide mass would remain as it is for better stabilization of the soil mass. However, a careful and continuous eye is to be kept on it because of the disturbed landslide mass as well as the fill for the temporary road is not completely consolidated (Figure 9) and there surely exists a deep-seated slip surface, as can be seen from the presence of large tensional cracks along the top of landslide mass (Figure 10).



Fig. 8 Panoramic view of the landslide mass, re-profiled to an apparent stable configuration for the purpose of road construction.



Fig. 9 Embankment of the road constructed on the landslide mass (left photo). Small scale cracks were observed near the base of embankment even during construction (right photo).



Fig. 10 Huge tension cracks present along the top of the landslide, showing the presence of deep seated slip planes.

A natural slope immediately right to the current landslide reportedly started to move slowly immediately after the road was constructed across this area. Therefore the slope was intensively tied back with pre-stressed anchors. During the above mentioned earthquake, this slope was also disturbed significantly, being dragged by the adjacent major landslide mass. During the last survey on June 23, the positions of ground anchors were also measured to monitor gradual slippage of this slope (Figure 11).



Fig. 11 A disturbed natural slope adjacent to the coherent landslide mass. The numbers for the ground anchors were marked for the reference to be used in future.

TABITO JUNIOR HIGH SCHOOL

On the southern extension of Idosawa Fault, there is Tabito Junior High School whose gymnasium building and swimming pool, immediately next to each other, were located exactly above Idosawa Fault. As shown in Figure 12, the structures were deformed and tilted, about 3° westward, to unserviceable condition and large scale open cracks were observed along their peripheries. Though the damage to these structures had nothing to do with major landslides along Idosawa Fault, temporal monitoring of their deformed shape can give an idea of a possible continuous deformation buildup in soils near the fault.



Fig. 12 Idosawa Fault passing under the gymnasium building (left photo) and swimming pool (right photo) of Tabito Junior High School, tilting and deforming the structures ($36^{\circ}57'52.2''$, $140^{\circ}42'10.0''$)

Perimeters of both the structures were laser scanned on June 7th, 24th and August 20th to observe the continual ground deformation. Swimming pool was small and visible enough to be scanned from a single scanner position while for the gymnasium building, four scanner positions were required to scan the complete periphery. Although a single reference point (top of an antenna) was also measured from all the positions, the resolution of the tilt-meter was not so accurate in shooting the reference point at

large dip angles to figure out the deformations all along the periphery of the gymnasium building. Therefore, the front and rear faces (AB and CD in figure 13, respectively) of the gymnasium building, perpendicular to the fault line, are considered only.

Assuming that the hanging wall has not moved, elevations of all other points are determined setting the hanging wall elevation as a reference. On June 7th, only front face of the gymnasium building was measured. While comparing it with that measured on June 24th, it is found that the footwall side has sunk down by about 3~4cm (Figure 13a).

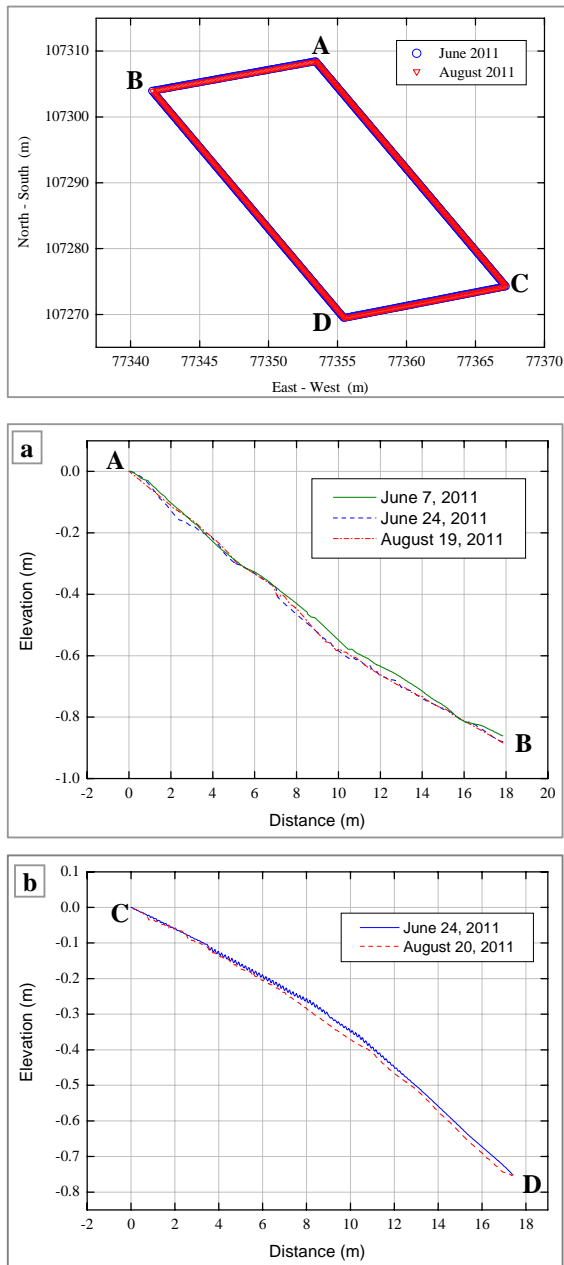


Fig. 13 Continual deformation of the ground supporting gymnasium building of Tabito Junior High School from June 2011 to August 2011 a) face AB b) face CD

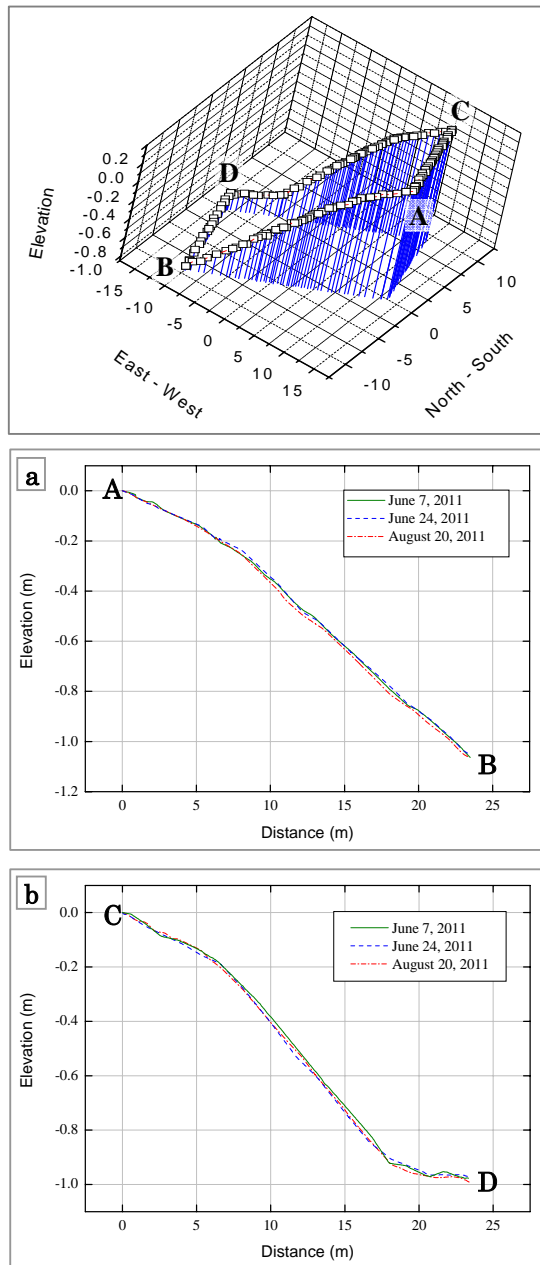


Fig. 14 Continual deformation of the ground supporting swimming pool of Tabito Junior High School from June 2011 to August 2011 a) face AB b) face CD

Similarly, comparing the measurements of June 24th and August 20th, the front face does not show any change but the rear face shows that foot wall area has deformed by 2~3cm (Figure 13a and b). This suggests that ground had been undergoing a continuous/continual deformation; as one of teachers at this junior high school noticed that some cracks were getting wider slowly but steadily.

The swimming pool was deformed considerably by the fault dislocation (Figure 14). Following the same way as for the gymnasium building, change in elevation of the faces perpendicular to the fault line (face AB and CD, marked in Figure 14) was determined. It is quite clear from Figure 14 that the football side has sunk down by almost the same amount as it was observed for gymnasium building.

CONCLUSIONS

A big earthquake can cause large strains as well as intense shakes to be localized near the activated seismic fault, where large scale mass movements such as landslides, rock falls and debris flows would occur. Justifying the conclusions derived from the past studies, Hamadoori Earthquake was responsible for some landslides, rock falls and other geo-hazards, damaging roads, buildings and drainage structures.

Once a soil mass gets disturbed, it is very likely that it moves again with a slight increase of driving force, which may come from frequent aftershocks, changes in pore water pressure and water infiltration during the rainy seasons.

Though there is an immense need to rehabilitate/reconstruct structures and other facilities damaged by the slope failures, it's quite important to ensure that the soil masses are stable enough to support these facilities. Otherwise we shall have to suffer from repeated failures and economical loss. A precise DEM of the landslide mass discussed in this article can be of great importance to monitor its slow and steady deformation. By measuring perimeters of the gymnasium building and swimming pool of Tabito Junior High School, it was found that the ground still undergoes a slow and steady deformation.

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