

# LIDAR MEASUREMENT OF THE BREACHED EARTH-FILL DAM IN THE MARCH 11<sup>th</sup> GREAT EAST JAPAN EARTHQUAKE

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**ABSTRACT:** Fujinuma dam, an earth-fill dam for irrigation located in Sukagawa City, Fukushima prefecture, was breached in the March 11<sup>th</sup> Great East Japan Earthquake. The debris mass from the breached dam flushed a village lying its downstream leaving 8 dead and 1 missing. The authors made a survey along the stream channel of the debris flow. During their survey, the breached dam body was LiDAR surveyed for its entire 3D image. With the findings from the survey, this paper discusses a possible mechanism of dam breaching.

**Key Words:** Great East Japan earthquake, LiDAR, dam breaching, debris flow

## INTRODUCTION

The Great East Japan Earthquake measuring Mw 9.0 (USGS, 2010) hit the east Japan at 2:46PM, March 11<sup>th</sup>, 2011. The intense shake was followed by tsunami, which engulfed the entire stretch of the Pacific coast of east Japan leaving about 20,000 dead or missing. The earthquake-induced liquefaction had caused severe damage to dwellings, underground facilities in Kanto region, especially, in the Tokyo bay area. One of the most serious problems was the disaster at the Fukushima Daiichi nuclear power plant. This event yielded a long lasting problem of radioactive contamination. With the wide spreads devastation mentioned above, less attention was paid on landslides including seven slope failures in Shirakawa region, upstream reaches of the Abukuma River, which slides were responsible

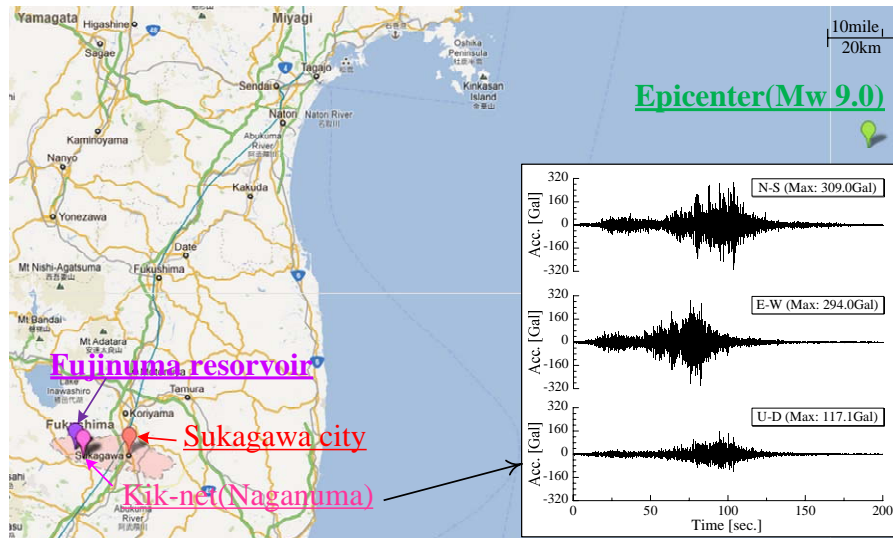


Fig. 1 Location of Fujinuma reservoir and epicenter of the March 11<sup>th</sup> Great East Japan Earthquake  
The recorded strong ground motion at Kik-net Naganuma station (37.2792, 140.2178)



Fig. 2 Survey map (modified from Geospatial Information Authority of Japan, 2011)

for at least 13 deaths (Kiyota, T., 2011). Early Pleistocene no-alkaline pyroclastic flow volcanic rocks spread in this region (Geological Survey of Japan), and more than 1000 slope failures occurred here due to a torrential rain back in Aug. 27, 1998. Fujinuma reservoir, located in Sukagawa city, Fukushima prefecture (37.301944, 140.195278: See Fig. 1) was constructed for irrigation in similar geological condition back in 1949. The northeast earth-fill dam of this reservoir was breached in the Great East Japan Earthquake with the surface maximum ground acceleration of 309gal recorded by the strong-motion seismograph at the nearest KiK-net Naganuma station (National Research Institute for Earth Science and Disaster Prevention), which is located about 2 km away from the Fujinuma lake (37.2792, 140.2178: See Fig. 1). The dam is 18.5m high, 133m long and 99,000m<sup>3</sup> in volume, and the full capacity of its reservoir of 1,504,000m<sup>3</sup> (Dam Association of Japan) was reached at that time. The water from the breached dam eroded its downstream valley and uprooted trees. The debris flow rushed down the valley and flushed at least 5 houses leaving 8 dead and 1 missing.

Authors surveyed along the stream channel of the debris flow. The breached dam body was LiDAR surveyed for its entire 3D image. With the findings from the survey, this paper discusses the mechanism of dam breaching.

## OUTLINE OF THE SURVEYED AREA

Authors surveyed both breached Fujinuma dam and its downstream reach on April 15<sup>th</sup>. Fig 2 shows the survey root along the stream channel of the debris flow and photo-shooting locations. There were large and small earth-fill dams stopping the water of the Fujinuma reservoir as shown in Fig. 2.



Photo 1 Sliding failure of small dam (April 15<sup>th</sup> at 37.299778, 140.195348)

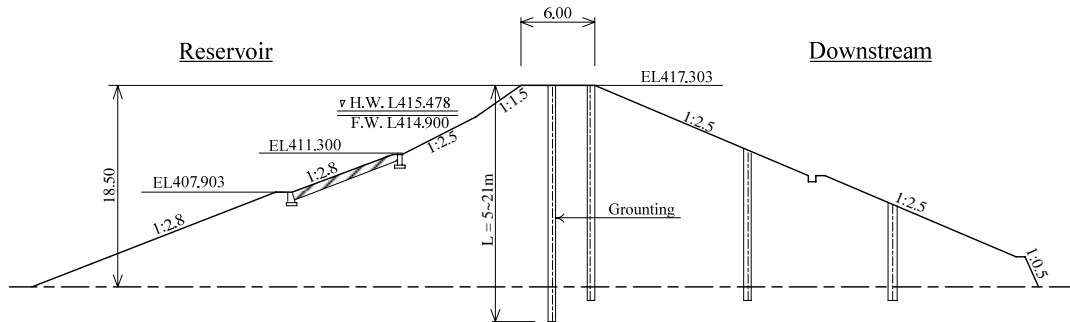


Fig. 3 Cross section of original large dam body



Photo 2 Breached dam body of large dam from right abutment (April 15<sup>th</sup> at 37.301265, 140.195401)



Photo 3 Breached dam body of large dam from left side (April 15<sup>th</sup> at 37.302465, 140.195223)



Photo 4 Breached dam body from downstream  
(April 15<sup>th</sup> at 37.302661, 140.196055)



Photo 5 Mark of debris flows on valley walls  
(April 15<sup>th</sup> at 37.306236, 140.199503)



Photo 6 Breached road embankment  
(April 15<sup>th</sup> at 37.305036, 140.198236)



Photo 7 Washed out box culvert  
(April 15<sup>th</sup> at 37.304499, 140.197989)

Photo 1 shows the failure of the upstream slope of the small dam (13m high, 55m wide and 108m long). Almost the entire upstream slope slid down into the reservoir leaving its thin and fragile crest soil behind the dam body narrowly escaped from breaching probably because the larger dam breached first emptying the water of the reservoir. During the emptying process, the soil mass of the upstream slope of the small dam may have been carried further down toward the bottom of the reservoir.

Fig. 3 shows the original cross section of the large dam. The large dam is 6 meters wide at its crest, 133 meters long with upstream surface concrete-block-faced. Photo 2 and 3 show the breached large dam body (Height 18.5m, Length 133m, Volume 99,000m<sup>3</sup>) from right and left abutments, respectively. The middle to right part of the dam body was scoured deep by the overtopped water. A clear laminar structure was seen on the exposed interior of the dam body. Dark-colored mudstone was exposed on the scoured abutment. 20 to 30 cm-thick Ignimbrite sand layers were also found bedding horizontally in the exposed dam body (See Photo 2) indicating that the dam body was constructed by compacting ignimbrite sand. The slide may have been followed by the subsidence of the entire dam body and thus water-overtopping.

The debris flow from the breached dam eroded its downstream valley and uprooted trees as shown in Photo 4. From mad marks remaining on valley walls, super-elevations were measured at several locations where the stream channel takes sharp turns, and the debris flow velocity was estimated to be around 10m/sec. Photo 6 and 7 show the road embankment being across a valley which was approximately 300m from the large dam and washed away by the debris flow together with a box culvert (1.5m-square, 0.14m-thickness).



Photo 8 Path way of debris flow and downstream stricken area (April 15<sup>th</sup> at 37.308131, 140.202481)

The box culvert was carried over 48m distance from its original location. Even though the road embankment was flashed, rocks and trees are found clogging the stream indicating that the debris mass was temporarily stopped there owing to the presence of the embankment. The debris flow, when it reached the village, took a sharp 90 degrees clockwise turn along the existing river channel and flushed downstream village (See Photo 8).

## LIDAR SURVEY OF THE BREACHED EARTH-FILL DAM

### Outline of LIDAR survey

The breached dam body was LiDAR surveyed for its entire 3D image using the laser profile measuring system LPM-321 (See Photo 9). LPM-321 is based on the time-of-flight measurement of short laser pulse. It covers 6000m distance without reflector (@ Laser class 1M), with a wide view filed of 150° x 360°, an expected maximum error of 25mm and measurement rate of maximum 1000 points / sec. Using a high resolution digital camera along with it, a RGB color image can be obtained for all laser-shot points. The authors conducted a LiDAR survey on August 21<sup>th</sup>. The dam body was laser-scanned from three different locations: two are on the right abutment; then one on the left abutment. And then, 3D digital surface models were combined for the 3D LiDAR image of the entire dam body. Fig.4 shows the obtained 3D image of dam body from the right abutment.



Photo 9 LPM-321 (left: LPM-321, right: laser-scanning scene)

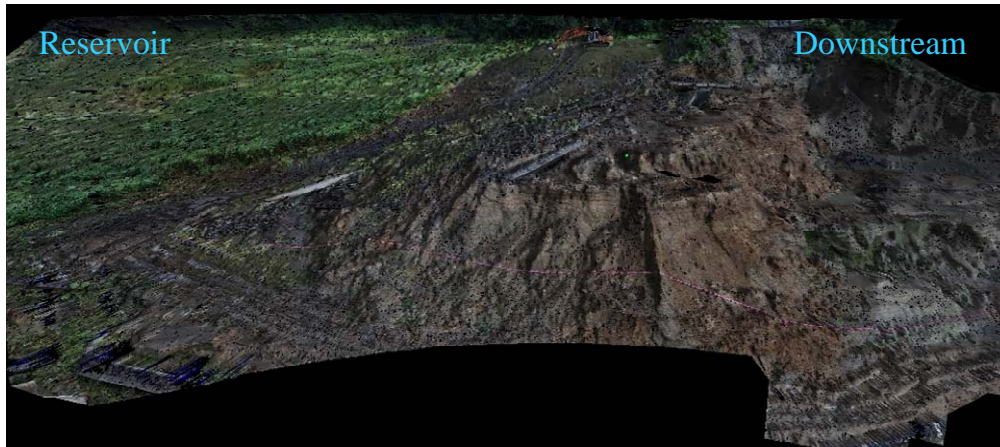


Fig. 4 3D image of the breached dam body using LPM-321

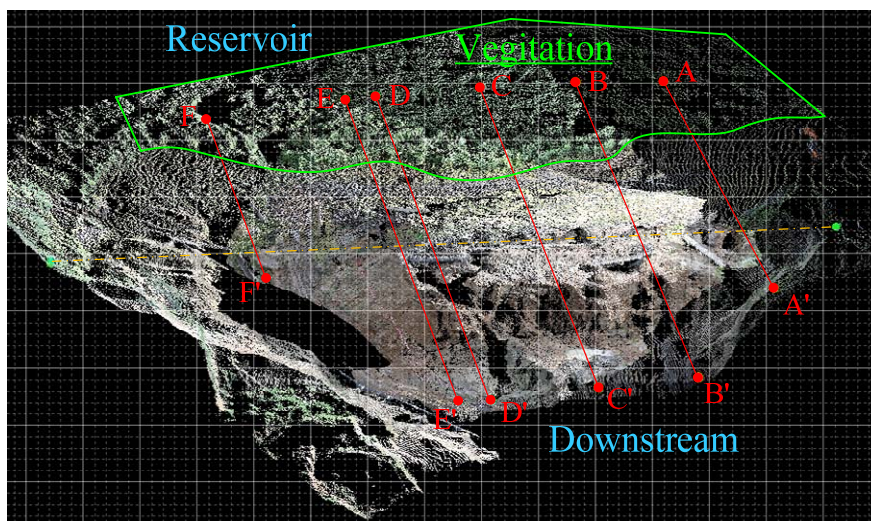


Fig. 5 Bird-eye view of the breached dam

### Result of LIDAR survey

Fig. 5 shows a bird-eye view of the breached dam body. There yet remained some areas hidden from laser light, which appeared black in this figure. 5 months after the earthquake, the bottom of the emptied reservoir was covered thick with vegetation. Fig. 6 is the contour map of the dam, with the coordinate origin set at 1.5m above the original dam body crest. This figure also show a longitudinal cross-section of the damaged dam body, where two lines indicate the top and bottom levels of original dam body, respectively. The top surface of the remaining left dam body is about 50m long, and about 8.5m below the original dam crest. Fig. 7 compares several cross-sections of the damaged dam body with their original ones. These cross sections in Fig. 7 respectively correspond to lines A-A', B-B', C-C', D-D', E-E' and F-F' in Fig. 5 and 6. With the presence of vegetation, every cross section after the earthquake shows an increase of the reservoir bottom by about 0 to 0.25m. It can be found from these figures that scouring of the soil mass was more serious near the middle to right part of the dam body than that near the left abutment. Therefore, it can be deduced that the right dam body, which is the highest part of the dam body constructed by compaction, slid first, causing either subsidence of the dam crest or razor-sharp earth wall to remain such that the water forced its way through this point. And then the overflowing water eroded both the upstream and downstream dam body.

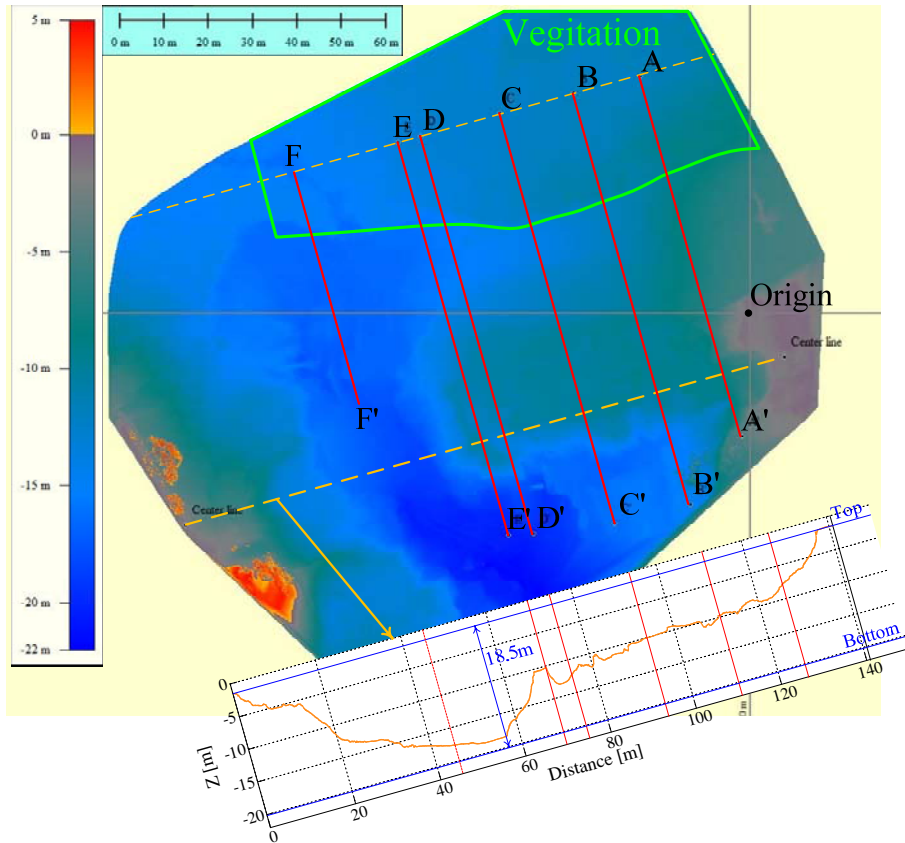


Fig. 6 Contour map of Z-value and the longitudinal section of breached dam

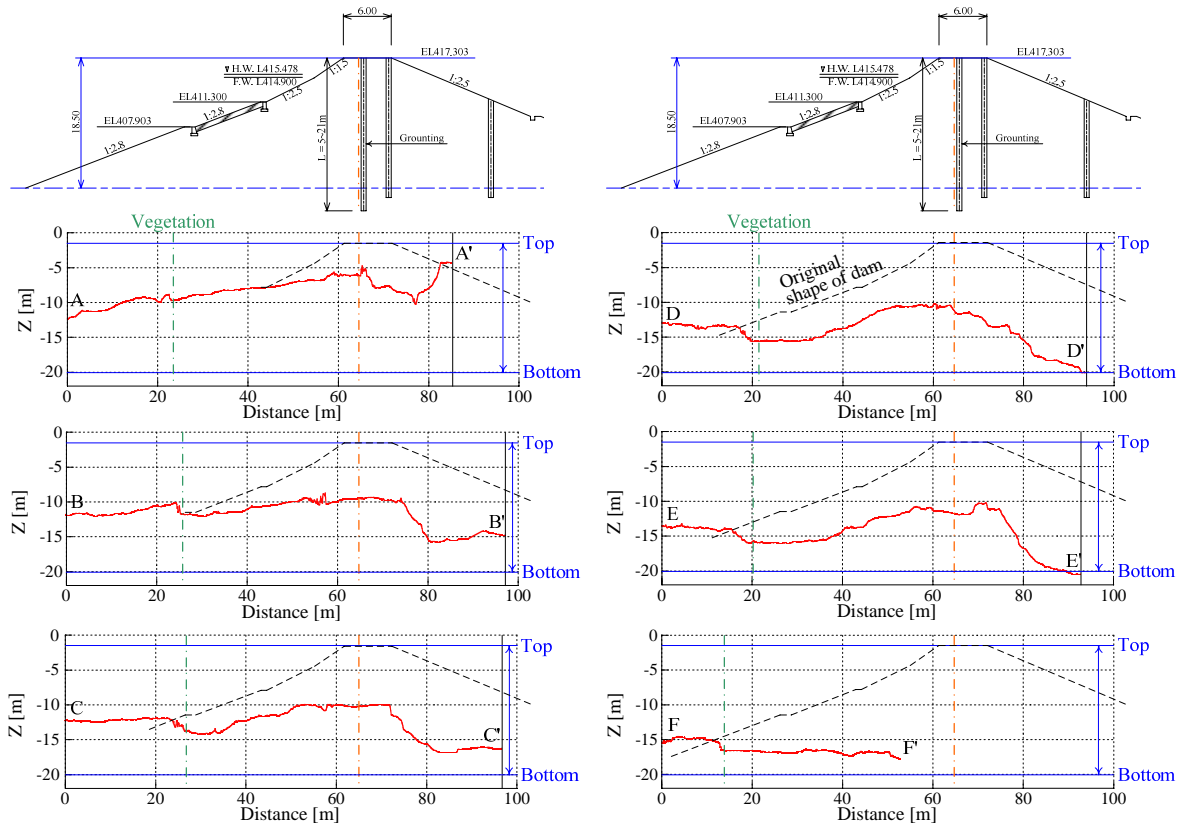


Fig. 7 Comparison of the obtained 3D image of the damaged dam with its original shape

## CONCLUSIONS

The northeast large earth-fill dam of Fujinuma reservoir, located in Sukagawa city, Fukushima prefecture, was breached in the March 11<sup>th</sup> Great East Japan Earthquake. Its entire dam body was eroded deep by overflowing water. Particularly soil mass of its right side was completely washed away. The debris flow, whose speed is estimated to be around 10m/sec from mud marks remaining on valley walls, rushed down the valley and flushed at least 5 houses leaving 8 dead and 1 missing. Comparing a 3D image of entire dam obtained from LiDAR survey with its original shape, the right dam body whose height is 18.5m was completely washed out from its bottom. From the reconnaissance and the LiDAR survey, it was deduced that the upstream slope of right dam body which was the highest point of the dam body slid first, causing either subsidence of the dam crest or razor-sharp earth wall to remain such that the water forced its way through this point. The numerical simulation will be carried out for a further discussion about the mechanism of the dam failure in later publications.

## REFERENCES

- USGS (2011). <http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/usc0001xgp.php>
- Kiyota, T., Kyokawa, H. and Konagai, K. (2011). "GEO-DISASTER REPORT ON THE 2011 TOHOKU-PACIFIC COAST EARTHQUAKE." Bulletin of ERS, No. 44, 17-28.
- Geological Survey of Japan. "Seamless Digital Geological Map of Japan."  
[http://riodb02.ibase.aist.go.jp/db084/zoomify\\_en.html](http://riodb02.ibase.aist.go.jp/db084/zoomify_en.html)
- National Research Institute for Earth Science and Disaster Prevention. "Digital Strong-Motion Seismograph Network KiK-net" [http://www.kik.bosai.go.jp/kik/index\\_en.shtml](http://www.kik.bosai.go.jp/kik/index_en.shtml)
- Dam Association of Japan, "Fujinuma Dam – Dam Handbook"  
<http://damnet.or.jp/cgi-bin/binranA/All.cgi?db4=0483>
- Geospatial Information Authority of Japan, "Portal Cyber-japan"  
<http://portal.cyberjapan.jp/index.html>
- RIEGL JAPAN, "LPM-321"  
<http://riegl.com/products/terrestrial-scanning/produktdetail/product/scanner/2/>