Geotechnical Extreme Events Reconnaissance (GEER)

Preliminary Observations of the Fujinuma Dam Failure Following the March 11, 2011 Tohoku Offshore Earthquake, Japan

by

Leslie F. Harder, Jr.[1], Keith I. Kelson[2], Tadahiro Kishida[3], and Robert Kayen[4]

June 6, 2011

Acknowledgments

The authors had the opportunity to visit the site of the Fujinuma Dam failure which breached following the March 11, 2011 Tohoku Offshore Earthquake. Our visits occurred a few weeks after the event. The principal purpose of the visits was to observe and document the failure of the main dam and the upstream slide in the auxiliary dam. The authors were greatly aided by the reports available on the internet at the time of the visits, most notably those by Matsumoto (2011). Since that time, other observations have been made by Chigira et al. (2011), Towhata et al. (2011), and Wartman et al. (2011) that assisted in the preparation of this report. The assistance of our Japanese colleagues was invaluable in providing support and in developing and clarifying the observations and information included in this report. The GEER Team greatly appreciates the assistance and information shared by these colleagues.

Introduction

Japanese authorities inspected over 400 dams following the March 11, 2011 M9.0 Tohoku Offshore Earthquake. According to reports by Matsumoto (2011), almost all of these dams withstood minor to severe ground shaking and retained their reservoirs with generally minor to moderate damage. The exception to this was Fujinuma Dam, an embankment dam located in southern Fukushima Prefecture that failed shortly after the earthquake. The failure of the dam resulted in the uncontrolled release of the entire reservoir, which flowed downstream into a small village and killed 8 people (Matsumoto, 2011; Towhata et al., 2011).

Fujinuma Dam had a maximum height of about 18.5 meters and had a maximum reservoir volume of approximately 1.5 million cubic meters (~1,200 acre-feet). It has sometimes been referred to as Fujinuma-ike, which means it was considered to be a pond-retaining structure because the dam was not on a regulated river (Matsumoto, 2011). According to Wikipedia

[1] Senior Water Resources Technical Advisor, HDR Engineering, Inc., Folsom, CA
[2] Senior Principal Engineering Geologist, Fugro Consultants, Inc., Walnut Creek, CA
[3] Assistant Professor, Chiba University, Chiba, Japan
[4] Research Civil Engineer, United States Geological Survey, Menlo Park, CA

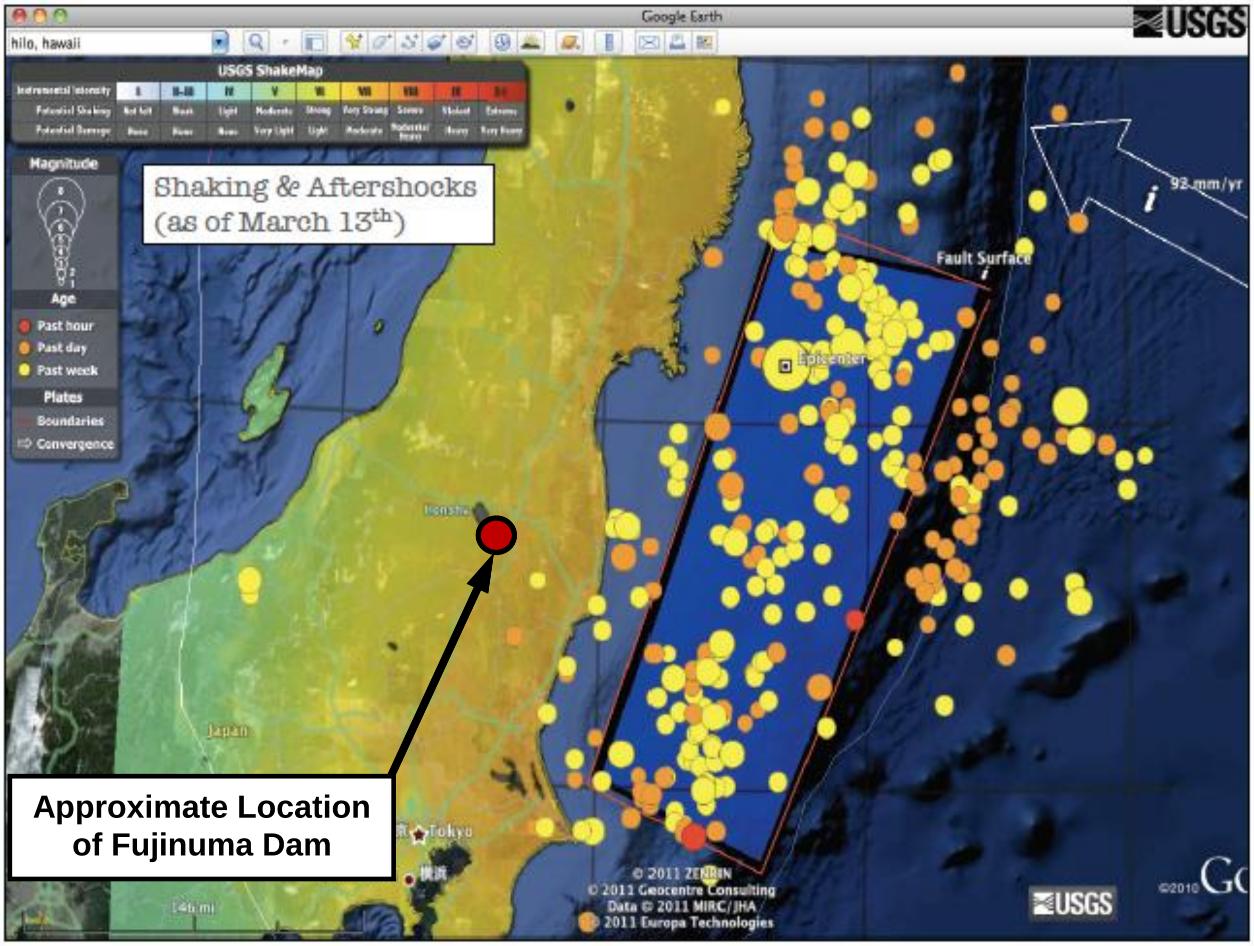

Figure 1: Approximate Location of Fujinuma Dam in Southern Fukushima Prefecture Shown on USGS Shake Map for March 11, 2011 Tohoku Offshore Earthquake, (adapted from USGS, March 13, 2011)

(referencing the Dam handbook produced by the Dam Association of Japan), the dam and reservoir was owned by the Ebana River Coastal Reclamation District.

History and Characteristics of Fujinuma Dam

Construction of Fujinuma Dam began in 1937 and was halted during World War II. Following the war, the dam was completed in 1949 (Matsumoto, 2011; Towhata et al., 2011; and Wikipedia/DAJ, 2011). There were actually two embankment dams retaining the reservoir: an 18.5-meter-high main dam and a ~6-meter-high auxiliary dam (see Figure 2). Figure 3 presents a general cross section of the main dam obtained from Matsumoto (2011). The main dam had a crest width of 6 meters and an upstream slope which ranged principally between 2.5:1 to 2.8:1, together with small benches and a relatively steep 1.5:1 upper slope. The downstream slope had a general slope of 2.5:1 with a small bench at mid-height. It also had a steepened downstream toe, perhaps indicative of a possible rock or gravel toe. It is believed that the auxiliary dam had a similar geometry. The main dam had a crest length of 133 meters.

There are currently no drawings available at the time of this writing to detail the design and construction history of the dam. It is not known what the zoning of the dam was designed to be, although some reports indicate that it was a homogeneous embankment design (Matsumoto, 2011). Nor is there any information currently available regarding what type of and amount of foundation treatment was provided at either the main dam or auxiliary dam. At the time of the March 11, 2011 earthquake, the main outlet appeared to be through the main dam's right abutment. However, there appears to be at least one additional outlet near the left abutment of the auxiliary dam. It is not clear whether any of these outlets were used to dewater the foundation and provide diversion capacity while the dam was under construction and/or during the construction shut-down during the war, or whether other temporary measures were employed. Figure 4 illustrates the hilly topography that the dams and reservoir were situated in.

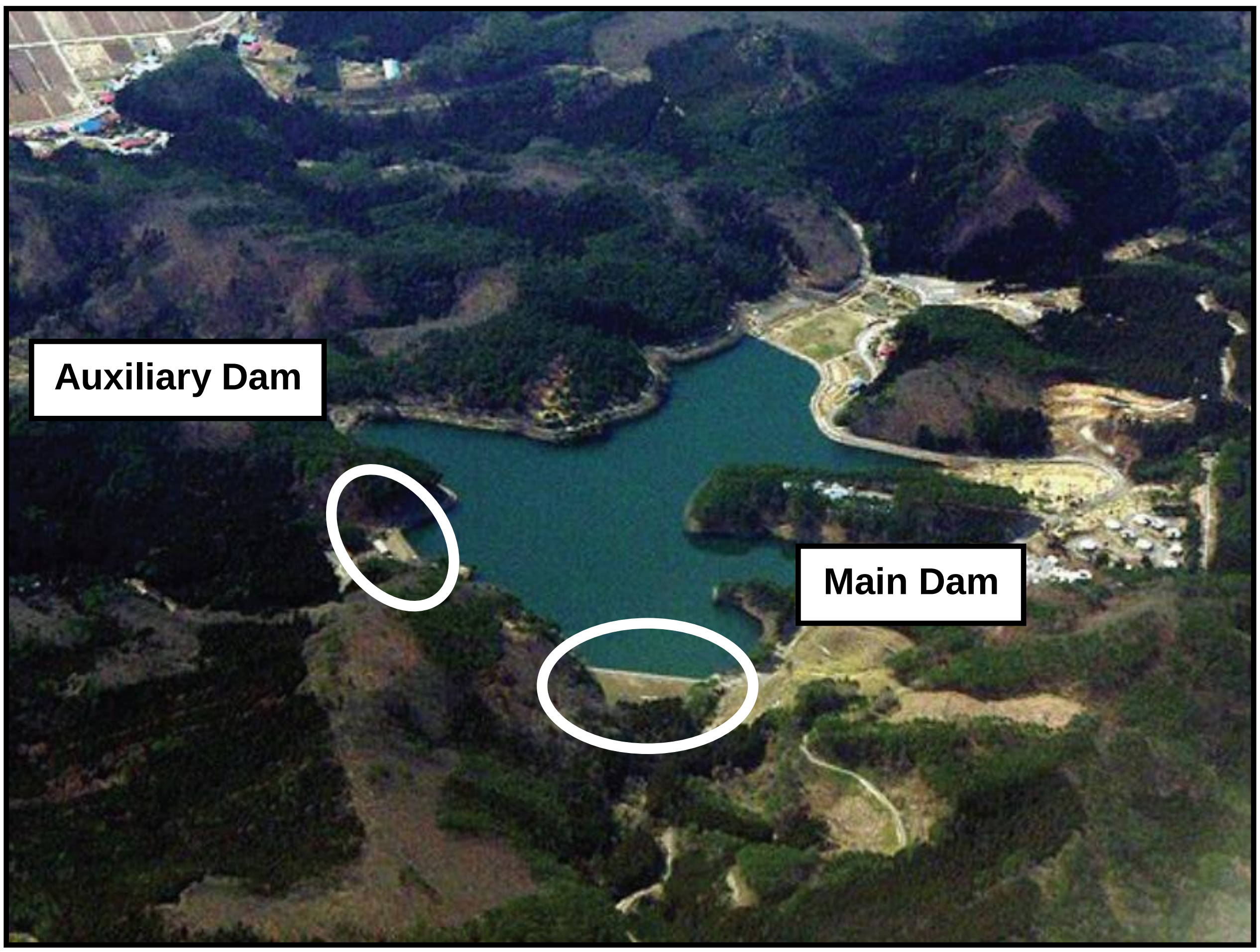

Figure 2: Aerial View of Fujinuma Main Dam and Auxiliary Dam in 2009
(modified from Wikipedia/JAC, 2011)

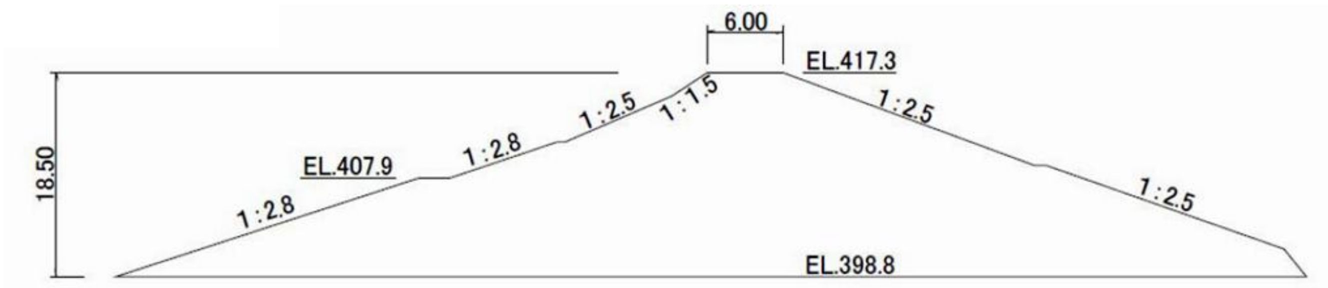

Figure 3: Cross Section of Fujinuma Dam
(from Matsumoto, 2011)

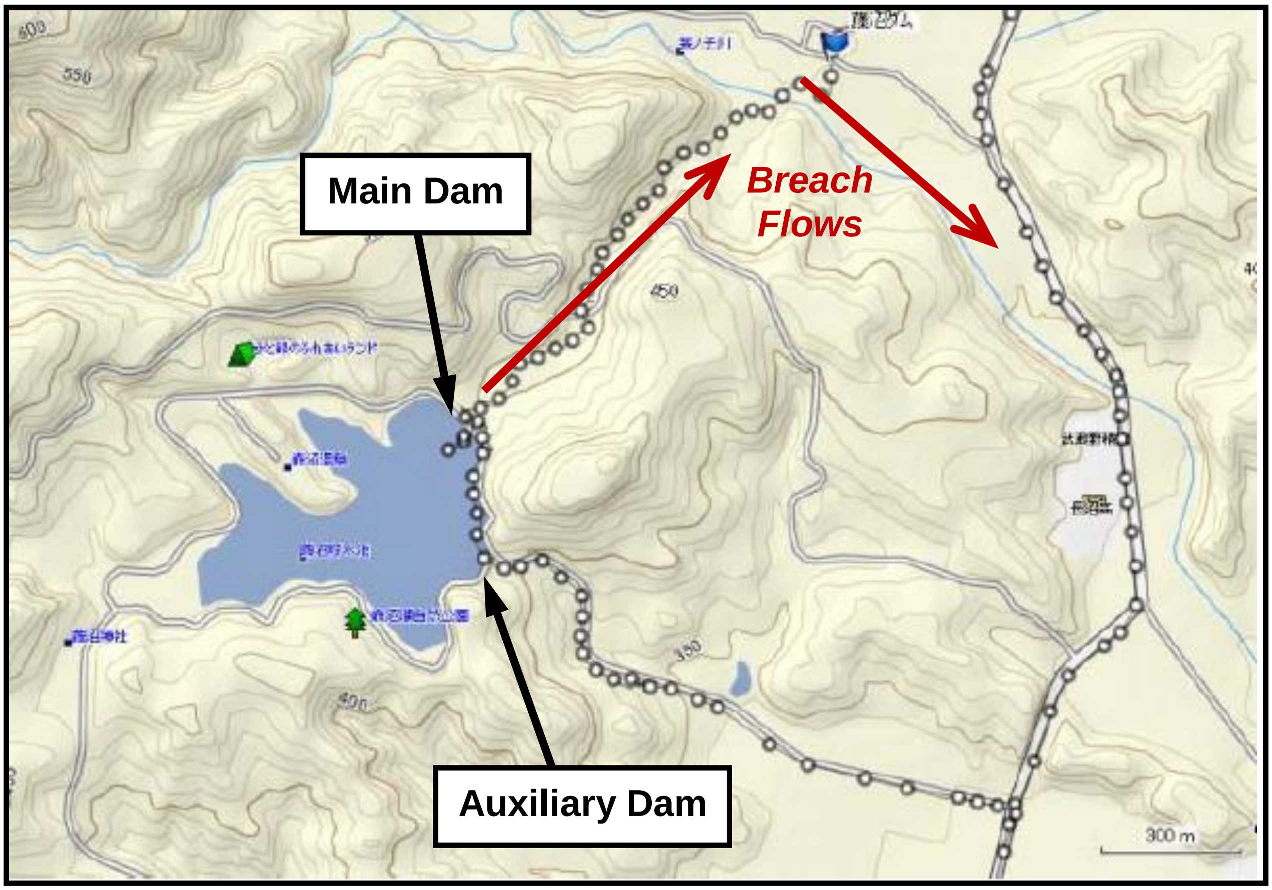

Figure 4: Topography of Fujinuma Dam and Reservoir Area
(from Chigira et al., 2011)

The performance history of Fujinuma Dam is not available at the time of this writing. However, a diagram posted on the left abutment of the main dam (see Figure 5) indicates that the main dam has had a seepage problem in either the upper foundation or lower embankment materials. As shown in Figure 6, the diagram suggests that a series of grout holes was

Figure 5: Photograph of a Diagram Posted on Left Abutment of Fujinuma Dam (N37.3025°, E140.1943°, April 23, 2011)

completed through the crest of the main dam in 1994 and into the upper foundation, presumably to control seepage. In addition, two lines of three piezometers appear to have been drilled and installed in the downstream slope down to the foundation contact. Information from this remedial program and the data from the piezometers over time are not currently available. Figure 7 presents a photograph of the downstream slope of the main dam taken in 2009.

March 11, 2011 M9.0 Earthquake and Failure

The March 11, 2011 M9.0 earthquake occurred at approximately 2:46 p.m. local time. The dam was located approximately 80 kilometers from the fault rupture and directly opposite the approximate middle of the 600-kilometer fault rupture zone. The nearest strong motion seismograph, a surface instrument located 2.8 kilometers away in the community of Naganuma, registered a peak ground acceleration of 0.315g. According to Matsumoto (2011), the reservoir was nearly full when the earthquake occurred. The dam crest reportedly was overtopped

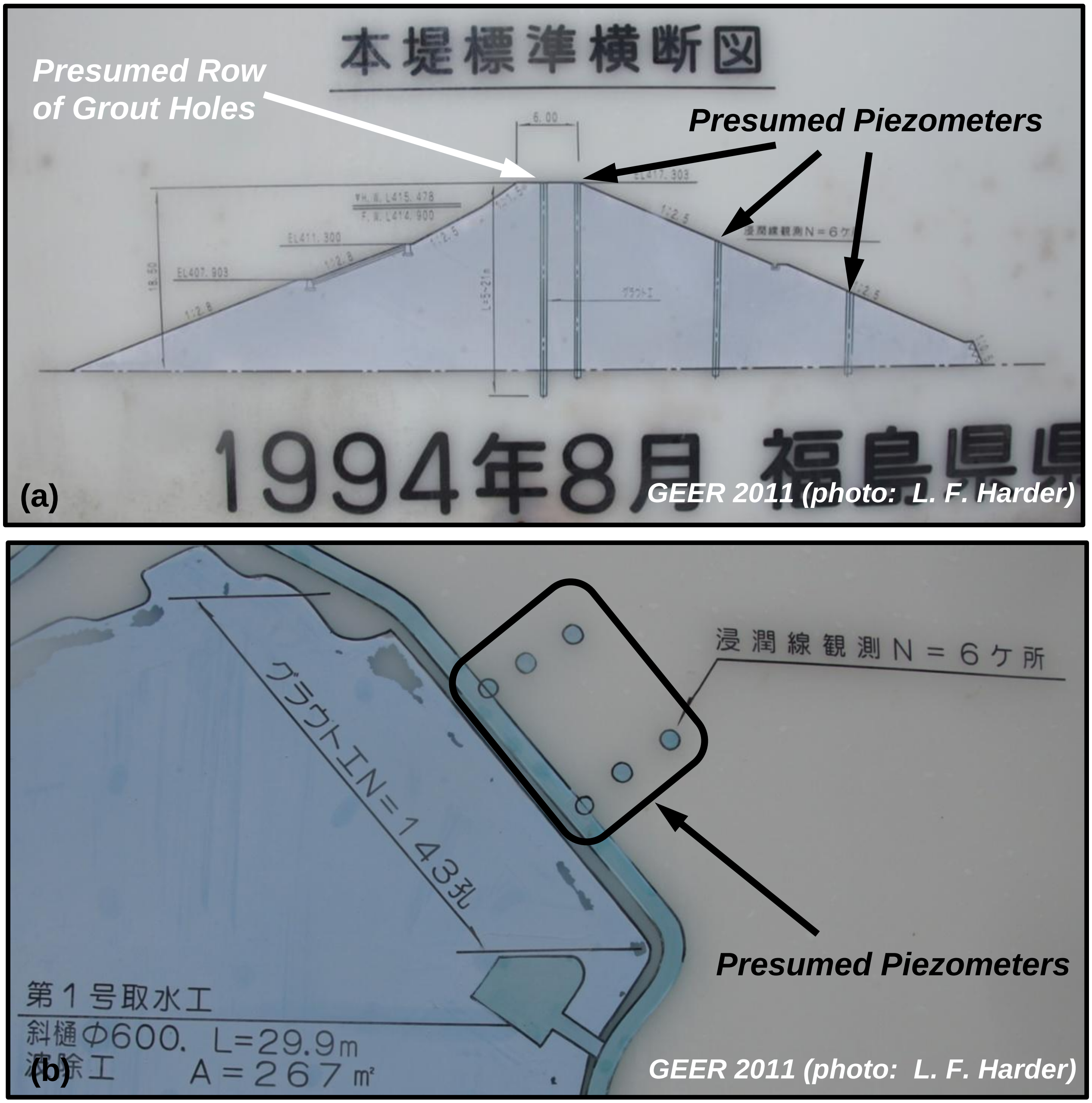

Figure 6: Photographs of (a) Cross Section and (b) Plan View of Fujinuma Main Dam Taken from a Diagram Posted on Left Abutment of Fujinuma Dam Suggesting a 1994 Foundation Treatment and Monitoring Program (N37.3025^{o}, E140.1943^{o}, April 23, 2011)

approximately 20-25 minutes after the earthquake with a larger discharge developing later. Another report (cited in Wikipedia, 2011) stated that a loud burst was heard before seeing a flood. The resulting breach flows travelled down a narrow canyon down to the village of Naganuma, where 5 houses were washed away and other houses and at least one bridge were damaged (Wikipedia, 2011). Eight people were reported to have lost their lives (Matsumoto, 2011; Wikipedia, 2011).

Figure 7: Pre-Earthquake Photograph of Crest and Downstream Slope of Fujinuma Main Dam (from Dam Association of Japan, 2009)

Reconnaissance Observations of Main Dam

The brief reconnaissance by the GEER team resulted in the following observations of the main dam and the breach within it:

1. The breach of the main dam appeared to be in the maximum section near the right abutment.
2. There was a dark brown embankment fill remaining for most of main dam (see Figures 8 through 13). Breach flows had cut through this material in the area of the breach, but had also overtopped this material for most of the dam's length. Where it had been overtopped, the upper, residual surface of this dark brown embankment fill was left almost uniformly flat at a level approximately 6 meters below the pre-earthquake crest of the dam. The uniform, regular nature of the upper portion of the remaining section of this dark brown embankment fill where it had been overtopped, together with the regular nature of the downstream slope of this material, suggested that this was either a man-made core section, or perhaps a zone that had been placed during an early phase of the dam construction.
3. On top of and downstream of the dark brown fill appeared to be another embankment fill material with a lighter gray-brown color (see Figures 12 and 13).

4. Embankment fill materials appeared to be generally cohesive and placed in lift thicknesses ranging between 20 and 45 centimeters (see Figures 14 and 19).

5. Beneath the embankment, fill material appears to have been placed directly on top of a black, organic silt/clay residual foundation soil. This organic residual soil appeared to have general thicknesses of approximately 1 to 2 meters across the dam footprint. Within the residual soil, small, decomposed tree trunks and branches were found. The black residual soil was observed throughout the damsite and in the reservoir basin. In some areas, it also appeared that this organic soil was used in the embankment fill as well (see Figure 19).

6. The black residual soil was developed locally on either weathered tuff bedrock or coarse-grained colluvial or alluvial deposits derived from the tuff bedrock.

7. There was no sign in the breach area that a cutoff trench through the black residual soil and into the tuff bedrock had been constructed. This observation matches the drawings and the diagram found on the left abutment (see Figures 3 and 6).

8. The presence of the residual soil developed on alluvium in areas formerly overlain by embankment fill indicates that dam construction did not include complete removal of unconsolidated foundation materials. There also appeared to have been an incomplete effort, or perhaps no effort, made at clearing and grubbing the foundation as a small, intact tree stump was found in the top of the black residual soil within the breach area. Small paleo-rootlets from this stump were present in the residual soil and underlying tuff bedrock (see Figure 18).

9. Within the breach area, a small spring was found in the volcanic tuff exposed directly beneath the black residual soil near the upstream toe (see Figures 8, 9, 21, and 22).

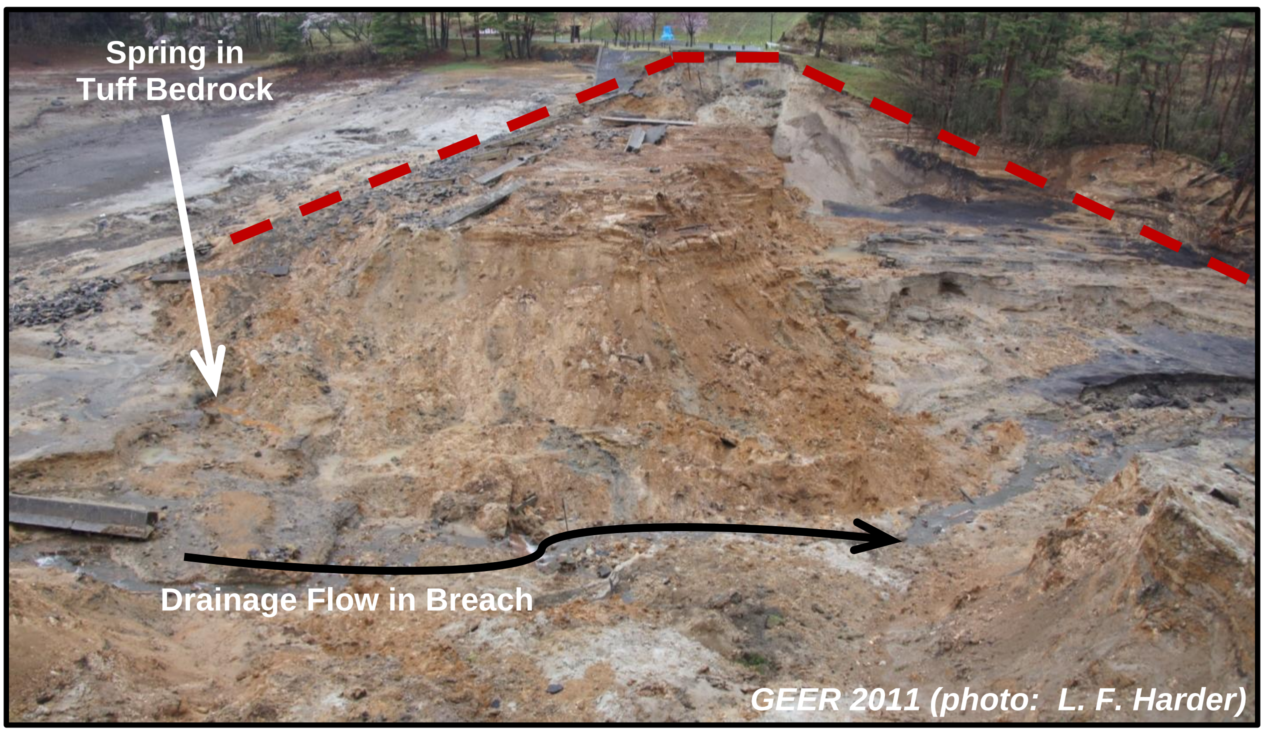

Figure 8: View of Breach in Fujinuma Main Dam from Right Abutment
(N37.3014˚, E140.1957˚, April 23, 2011)

Figure 9: View of Breach in Fujinuma Main Dam Looking Upstream towards Empty Reservoir (N37.3021˚, E140.1958˚, April 23, 2011)

Figure 10: View of Breach in Fujinuma Main Dam from Left Abutment Looking Upstream (N37.3021˚, E140.1952˚, April 23, 2011)

Figure 11: View of Breach in Fujinuma Main Dam from Left Abutment
(N37.3024˚, E140.1946˚, April 23, 2011)

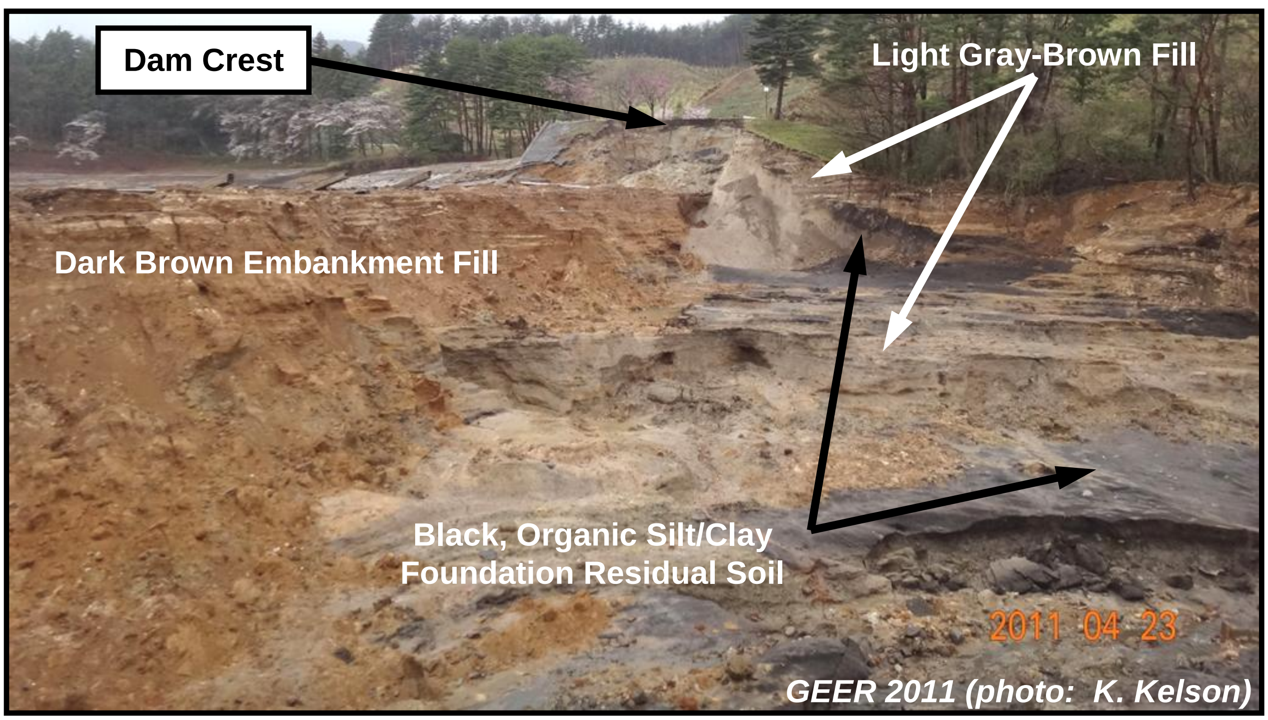

Figure 12: View of Eroded Downstream Slope of Fujinuma Main Dam from Right Abutment – Note Uniform Top Surface of Dark Brown Embankment Fill Zone Below Dam Crest
(N37.3020˚, E140.1959˚, April 23, 2011)

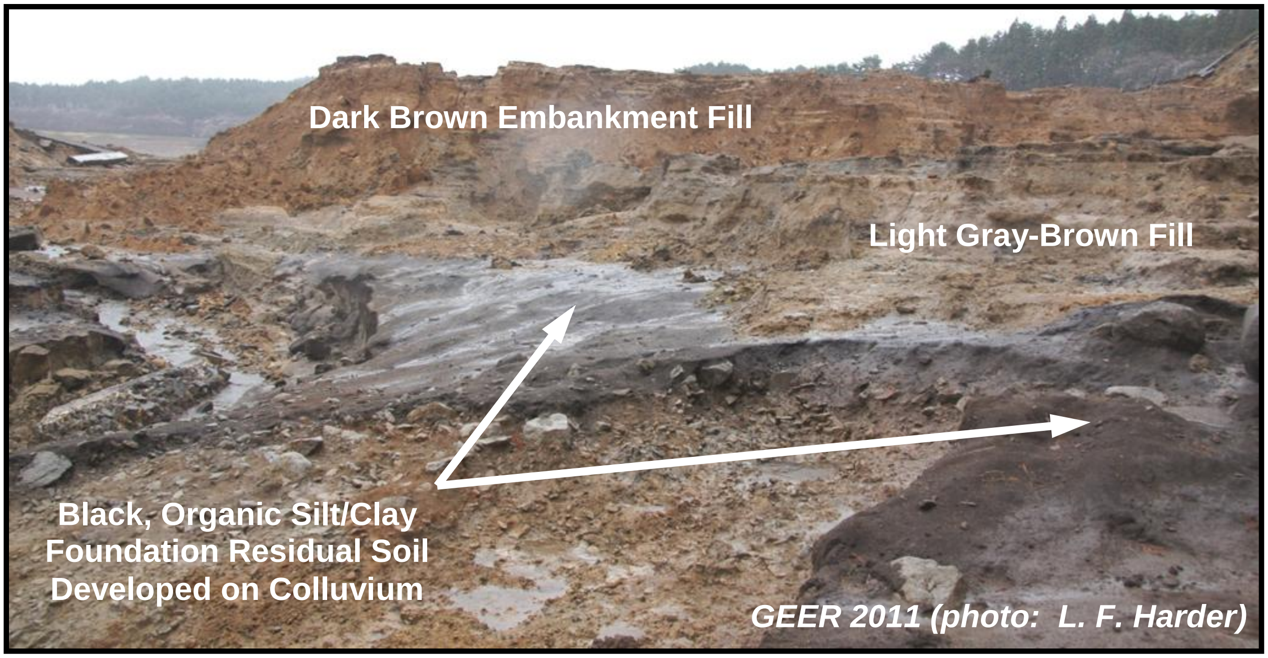

Figure 13: View of Eroded Downstream Slope of Fujinuma Main Dam from Downstream Toe – Note Uniform Top Surface of Dark Brown Embankment Fill Zone below Dam Crest and Lighter Gray-Brown Embankment Fill Overlying Black Organic Foundation Residual Soil (N37.3023˚, E140.1955˚, April 23, 2011)

Figure 14: View of Fujinuma Dam Embankment Fill Layers On Top of Black Organic Foundation Residual Soil Exposed within Downstream Slope at Left Abutment (N37.3024˚, E140.1951˚, April 23, 2011)

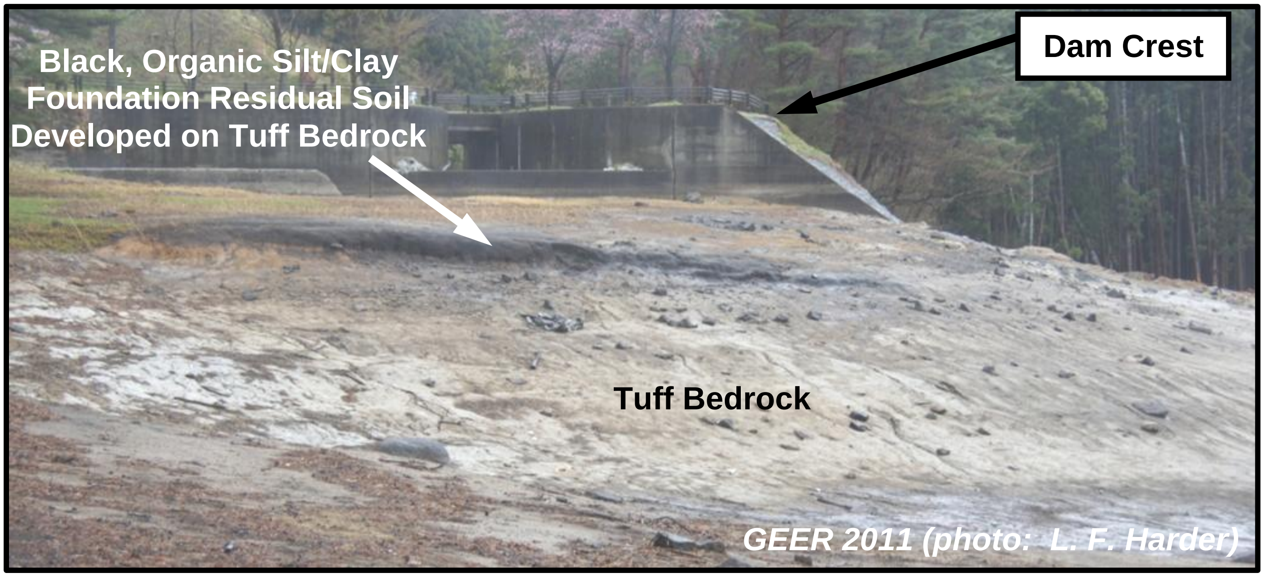

Figure 15: View of Black Organic Foundation Residual Soil and Underlying Tuff Bedrock Exposed Upstream of Concrete Spillway on Fujinuma Main Dam Left Abutment (N37.3022˚, E140.1942˚, April 23, 2011)

Figure 16: View of Black Organic Foundation Residual Soil Exposed in Eroded Channel Downstream of Breach in Fujinuma Main Dam (N37.3022˚, E140.1959˚, April 23, 2011)

Figure 17: View of Old, Rotted Small Tree Trunks Embedded within Black Organic Foundation Residual Soil Exposed in Eroded Channel Downstream of Breach in Fujinuma Main Dam (N37.3022˚, E140.1959˚, April 23, 2011)

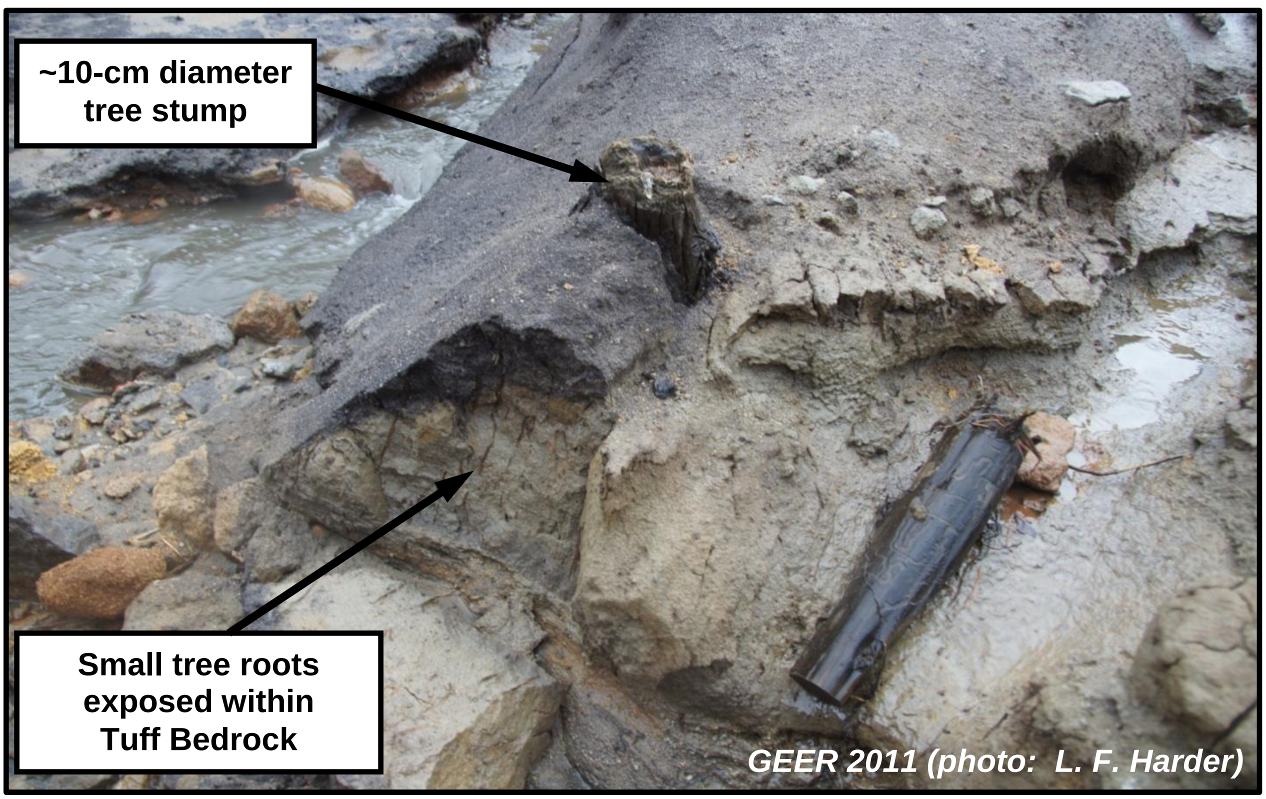

Figure 18: View of Small Tree Stump in Black Organic Foundation Residual Soil Overlying Tuff Bedrock within Breach in Fujinuma Main Dam (N37.3019˚, E140.1954˚, April 23, 2011)

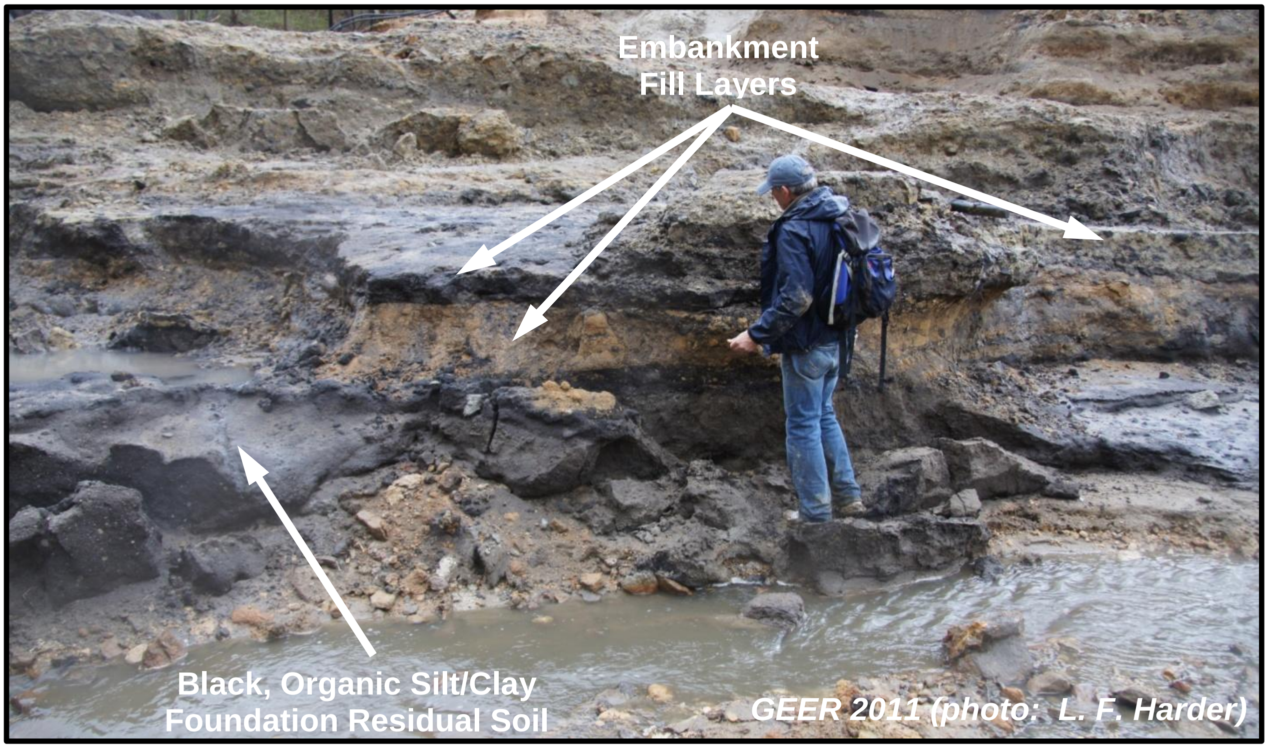

Figure 19: View of Embankment Layers Placed on top of Black Organic Foundation Residual Soil Exposed within Breach in Fujinuma Main Dam – Note Use of Black Residual Soil as Fill (N37.3019˚, E140.1954˚, April 23, 2011)

Figure 20: View of Timber Exposed in Embankment Debris Overlying Tuff Bedrock within Breach in Fujinuma Main Dam (N37.3019˚, E140.1954˚, April 23, 2011)

Figure 21: View of Spring within Tuff Bedrock Immediately Below Black Organic Foundation Residual Soil Exposed within Breach of Fujinuma Main Dam (N37.3017˚, E140.1953˚, April 23, 2011)

Figure 22: View of Spring within Tuff Bedrock Immediately Below Black Organic Foundation Residual Soil Exposed within Breach in Fujinuma Main Dam (N37.3017˚, E140.1953˚, April 23, 2011)

Figure 23 presents an image developed by a LiDAR scan of the main dam. The scan was taken from the reservoir area upstream of the dam and looking across the reservoir area at the breach. The image clearly shows the uniform top surface of the overtopped dark brown embankment remaining across the dam site to the left of the breach, together with details of the breach geometry. The LiDAR data can be used to develop detailed cross sections of the remaining dam and of the breach at various locations and directions.

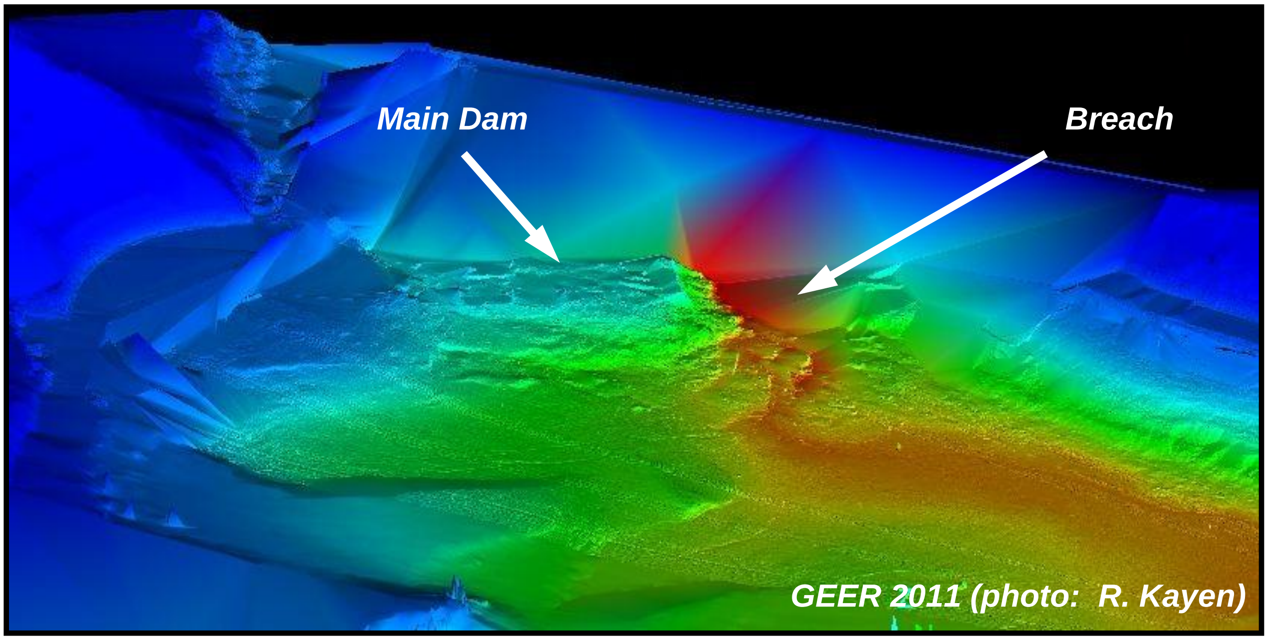

Figure 23: LiDAR Image of Fujinuma Main Dam and Breach Surveyed from Reservoir Area Upstream of the Dam Site (April 2011)

Reconnaissance Observations of Auxiliary Dam

The brief reconnaissance by the GEER team resulted in the following observations related to the auxiliary dam:

1. The auxiliary dam appeared to have been approximately 6 meters high and about 60 meters long prior to the earthquake.
2. There was a large upstream slide within the auxiliary dam which removed almost the entire upstream half of the embankment. The slide had the appearance of a flow slide (see Figures 24 through 28).
3. There was no obvious distress to the landside slope of the auxiliary dam (see Figure 27).

Figure 29 presents an image developed by a LiDAR scan of the upstream slide in the auxiliary dam. The scan was taken from the reservoir area across from the auxiliary dam and looking downstream at the surface of the upstream slide. As with the images of the main dam, the LiDAR data can be used to develop detailed cross sections of the auxiliary dam and slide.

Figure 24: View of Upstream Slide in Fujinuma Auxiliary Dam from Empty Reservoir Area (N37.3011˚, E140.1933˚, April 23, 2011)

Figure 25: View of Upstream Slide in Fujinuma Auxiliary Dam from Location Upstream of Auxiliary Dam Left Abutment (N37.3011˚, E140.1933˚, April 23, 2011)

Figure 26: View of Upstream Slide in Fujinuma Auxiliary Dam from Left Abutment
(N37.2995˚, E140.1956˚, April 23, 2011)

Figure 27: View of Downstream Slope of Fujinuma Auxiliary Dam from Left Abutment
(N37.2995˚, E140.1956˚, April 23, 2011)

Figure 28: View of Upstream Slide in Fujinuma Auxiliary Dam
from Auxiliary Dam Right Abutment
(N37.2990˚, E140.1952˚, April 5, 2011)

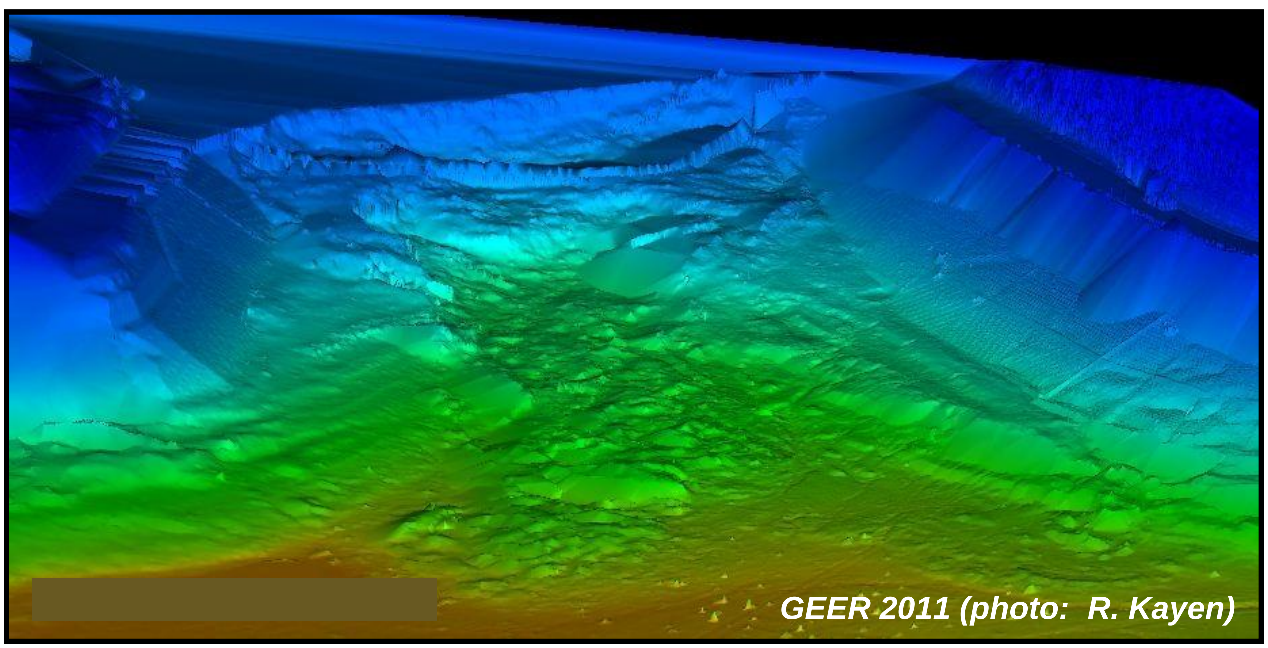

Figure 29: LiDAR Image of Upstream Slide in Fujinuma Auxiliary Dam Surveyed
from Reservoir Area Across from Auxiliary Dam (April 2011)

<u>Reconnaissance Observations of Reservoir Rim Areas</u>

There were areas along the reservoir rim where minor to moderate slope distress, together with intermittent slope failures occurred. Some of these areas were covered with concrete revetments such as the areas near the auxiliary dam and across the reservoir from the auxiliary dam. However, other areas had just bare soil or rock exposed. The slope distress in these areas appeared to have generally occurred within the natural soils and rock around the reservoir rim. However, in some cases, the slope distress also involved manmade fill that had been placed over natural soils. Figures 30 and 31 present photographs of two of the revetted slopes along the reservoir rim that experienced distress. As with the upstream slide in the auxiliary dam, it couldn’t be determined whether it was earthquake shaking or the rapid reservoir drawdown that caused the slope distress and sliding along the reservoir rim. Figure 32 presents an image developed by a LiDAR scan of one of the slides in the reservoir rim.

Figure 30: View of Slope Distress in Revetted Reservoir Rim Slope
Across from Fujinuma Auxiliary Dam
(April 5, 2011)

Figure 31: View of Slope Distress in Revetted Reservoir Rim Slope Upstream of Fujinuma Auxiliary Dam Right Abutment (N37.2990˚, E140.1945˚, April 23, 2011)

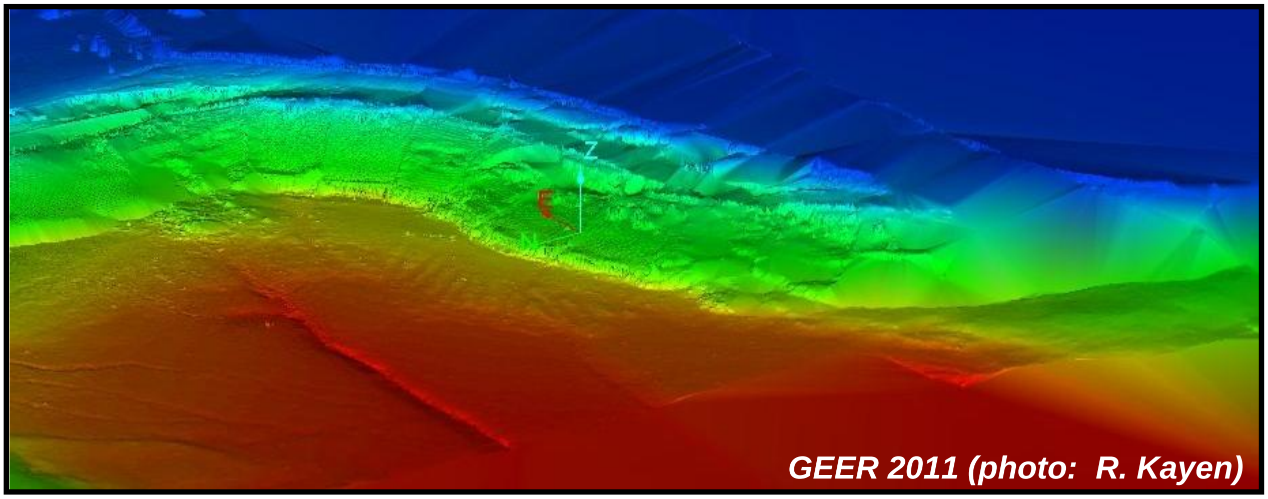

Figure 32: LiDAR Image of Slope Distress in Revetted Reservoir Rim Slope Across from Fujinuma Auxiliary Dam (April 2011)

Reconnaissance Observations of Downstream Flooded Area

Directly below the breach in the main dam, the small natural drainage had been catastrophically eroded and there was significant debris present (see Figures 33 and 34). Flood flows resulting from the breach traveled downstream in a northeasterly direction within this small drainage channel for almost a kilometer until they met a river channel and then turned 90 degrees to the southeast along the river channel (see Figures 4 and 35). Portions of the channel had been lined with concrete revetments. The breach flows exceeded the capacity of the revetted river channel and resulted in damage to farmland, homes, buildings, a bridge, and to the channel revetments themselves (see Figures 36 and 37). Eight people lost their lives due to these breach flows that resulted when the Fujinuma Main Dam failed.

Figure 33: View of Breach Flow Path within Natural Drainage Channel
Below Breach in Fujinuma Main Dam
(N37.3025˚, E140.1961˚, April 23, 2011)

Figure 34: Views of Downstream Erosion within Natural Drainage Channel
Below Breach in Fujinuma Main Dam
(N37.3025˚, E140.1961˚, April 23, 2011)

Figure 35: Aerial View of Breach Flow Path below Fujinuma Main Dam towards Naganuma (adapted from Japanese National Institute for Land and Infrastructure Management, 2011)

Figure 36: Views of Erosion and Damage within River Channel in Naganuma Below Breach in Fujinuma Main Dam (N37.3062˚, E140.2064˚, April 23, 2011)

Figure 37: Views Looking Downstream of Debris, Erosion, and Damage within River Channel in Naganuma below Breach in Fujinuma Main Dam (N37.3044˚, E140.2076˚, April 23, 2011)

Discussion of Potential Failure Modes

The reconnaissance by the GEER team in April 2011 was too brief and too limited to result in any definitive conclusions regarding the failure of the Fujinuma main dam and the upstream slide in the Fujinuma auxiliary dam. We expect that detailed investigations by our Japanese colleagues in the coming months will identify the most likely causes of these events. Nevertheless, it occurs to the team that the following potential failure modes should receive particular attention during these anticipated investigations:

Failure of Fujinuma Main Dam

A. Potential breach resulting from a slope failure - potential contributors or events lending support for this potential failure mode include:

- The foundation for the dam did not appear to have received the level of preparatory treatment that modern dams typically receive. An organic-rich residual soil was left in place and did not appear to have been completely cleared and grubbed. There may be portions of the residual soil, or the contacts between the residual soil and the embankment fill, which presented relatively weak sliding surfaces, or were subject to strength losses during the long duration of earthquake shaking.
- There appeared to be different types or zones of fill within the embankment, perhaps placed at different times during the intermittent construction periods. If the different materials were not properly keyed together, then the interfaces between the different fills may be relatively weak or subject to strength losses during the long duration of earthquake shaking.
- At least some of the fill was placed in relatively thick lifts, so the degree of compaction may have been relatively small compared to the level of compaction required for modern dams. Even though most of the fill material appeared to be cohesive in nature, thick lifts of this material may still be relatively loose, weak, and/or subject to strength losses during a long duration of earthquake shaking.
- The auxiliary dam developed an upstream slide, and portions of natural ground along the reservoir rim also developed upstream slides.
- The level of earthquake shaking was moderately strong, estimated at a peak ground acceleration of approximately 0.3g, and the estimated duration of strong shaking could easily have exceeded a minute. This very strong seismic shaking could have induced significant deformations within an embankment.
- The reservoir was believed to be relatively high at the time of the earthquake, leaving relatively little freeboard in the event of large deformations.
- The failure of the dam reportedly occurred soon after the earthquake, consistent with a slope stability failure leading to a breach of the dam.

B. Potential breach resulting from an internal erosion, or piping failure - potential contributors or events lending support for this potential failure mode include:

- There did not appear to be any filters constructed within the dam embankment or foundation. If the dam deformed significantly during the earthquake shaking, transverse cracks could have developed and promoted internal erosion.
- Because of intermittent dam construction, it is possible that an area of the embankment fill or foundation was left open for drainage for several years. If such a drainage feature actually existed and was not properly removed and the adjacent fill adequately treated, this may have left a defect in the lower portion of the dam and a path for preferred seepage and piping (see old timber found within breach area in Figure 20).
- The apparent lack of foundation treatment cited above could also lead to a preferred seepage path in the upper foundation and/or embankment/foundation contact.
- The diagram found on the left abutment of the main dam suggests that the dam has had a seepage problem within the upper foundation in the relatively recent past (1994).

It is also possible that a combination of failure modes lead to the failure.

Upstream Slide in Fujinuma Auxiliary Dam

Sliding of the upstream slope at the auxiliary dam could have occurred during the earthquake shaking for many of the reasons cited above for the slope stability potential failure mode for the main dam. Alternatively, the rapid emptying of the small reservoir through the breach in the main dam could have triggered a rapid drawdown failure of the auxiliary dam's upstream slope. Events supporting this latter alternative include the apparent lack of significant damage to the downstream slope of this embankment, and the various slides in natural ground along the reservoir rim.

Recommendations for Future Research

The GEER team believes that further investigation of the breach failure at the Fujinuma main dam and of the upstream slide at the Fujinuma auxiliary dam are warranted. Even though these dams are no doubt considered to be minor structures, eight people lost their lives and learning more about the causes of these events may save others in the future. The GEER team recommends consideration of the following for future investigations:

1. Research available records to learn more about the design of the embankments, how they were built, and how they were left during the interruption of construction during the 1940's.
2. Carefully interview witnesses and document any information regarding the nature and the timing of the failure and breach of the main dam, and any information possibly available regarding the timing of the upstream slide at the auxiliary dam.

3. Obtain grain size, plasticity (Atterberg Limits), in-place densities, and relative compaction laboratory test results for the following materials:
    - Organic, black silt/clay foundation residual soil at the main dam
    - Dark brown embankment fill at the main dam
    - Lighter gray-brown embankment fill at the main dam
    - Upstream slope embankment material at the auxiliary dam
    - Downstream slope embankment material at the auxiliary dam
    - Foundation material at the auxiliary dam
4. Research available records to learn more about the apparent seepage issue, grouting, and performance monitoring for the main dam. Review any information regarding the past performance of the dam, particularly during past earthquake events.
5. Consider trenching the foundation contact at the main dam, and the upstream slide in the auxiliary dam.
6. Map the slides in the natural ground along the reservoir rim and consider trenching if appropriate.
7. Consider obtaining undisturbed samples of the embankment fills and foundation materials at both dams to perform cyclic testing.
8. Downstream of Naganuma, the flood waters impinged on at least one highway bridge, partially damaging it and the river channel revetments. Characterization of the flood heights and flow velocities along the channel, and of the specific damage experienced at various locations, may provide information of value to bridge and hydraulics engineers.

Additional Acknowledgments

GEER is supported by the National Science Foundation (NSF) under CMMI-00323914. Planning and execution of the reconnaissance team efforts was supported by numerous individuals working to support a larger GEER effort. The authors are grateful for all of this assistance, together with the assistance of our Japanese colleagues. The opinions expressed in this report do not necessarily reflect the views of the authors' respective organizations.

References

Chigira, Masahiro; Nakasuji, Akito; Fujiwara, Shinya; and Sakagami, Masayuki," Reconnaissance Report for Landslide and Fault Rupture in Fukushima and Tochigi Prefecture Following the March 11, 2011 Tohoku Offshore Earthquake, Japan (in Japanese).

Dam Association of Japan (2011), "Fujinuma Dam – Dam Handbook," referenced through Wikipedia, http://damnet.or.jp/cgi-bin/binranA/All.cgi?db4=0483

Japanese Institute for Land and Infrastructure (2011), http://www.nilim.go.jp/lab/bbg/saigai/h23tohoku/11031sabo.pdf

Matsumoto, Norihisa (2011), "Amended 4th Quick Report on Dams," Japanese Committee on Large Dams, April 4, 2011.

Towhata, Ikuo; Goto, Hiroyuki; Kazama, Motoki; Kiyota, Takashi; Nakamura, Susumu; Wakamatsu, Kazue; Wakai, Akihiko; Yasuda, Susumu; and Yoshida, Nozomu (2011), "On Gigantic Tohoku Pacific Earthquake in Japan," Earthquake News, Bulletin of the International Society for Soil Mechanics and Geotechnical Engineering, Volume 5, Issue 2, April, 2011.

United States Geological Survey (2011), Shake Map for 2011 Tohoku Earthquake, March 13, 2011.

Wartman, Joseph, Tiwari, Binod, and Pradal, Daniel (2011), "2011 Embankment, Dams and Slopes Committee Team Reports on the Tohoku Japan Earthquake," Geo-Institute, American Society of Civil Engineers.

Wikipedia, http://en.wikipedia.org/wiki/Fujinuma_Dam