DAM SAFETY 2021
SEPTEMBER 12-15 · NASHVILLE · TN

CAUSE AND CONSEQUENCE OF THE FUJINUMA DAM FAILURE FROM THE 2011 TOHOKU EARTHQUAKE

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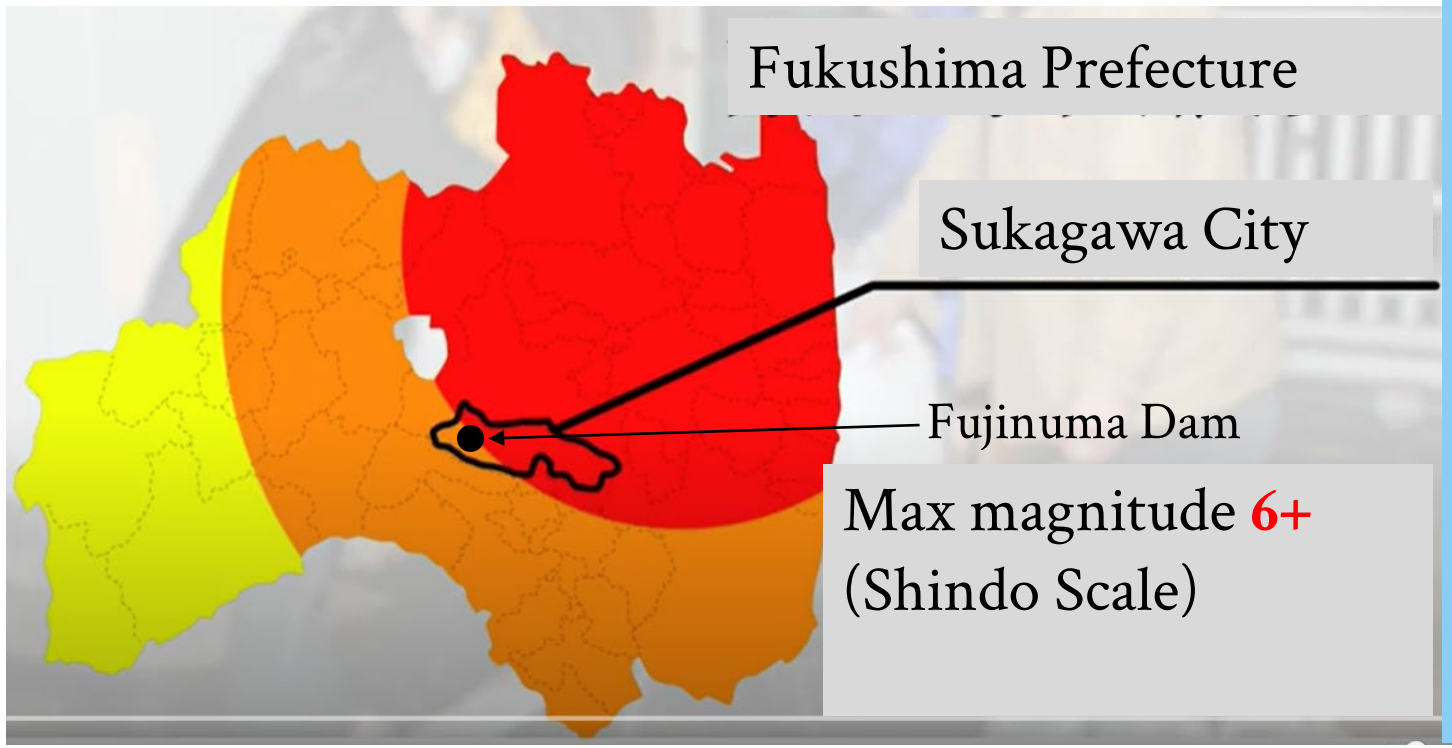
September 13, 2021 ● ASDSO Dam Safety National Conference

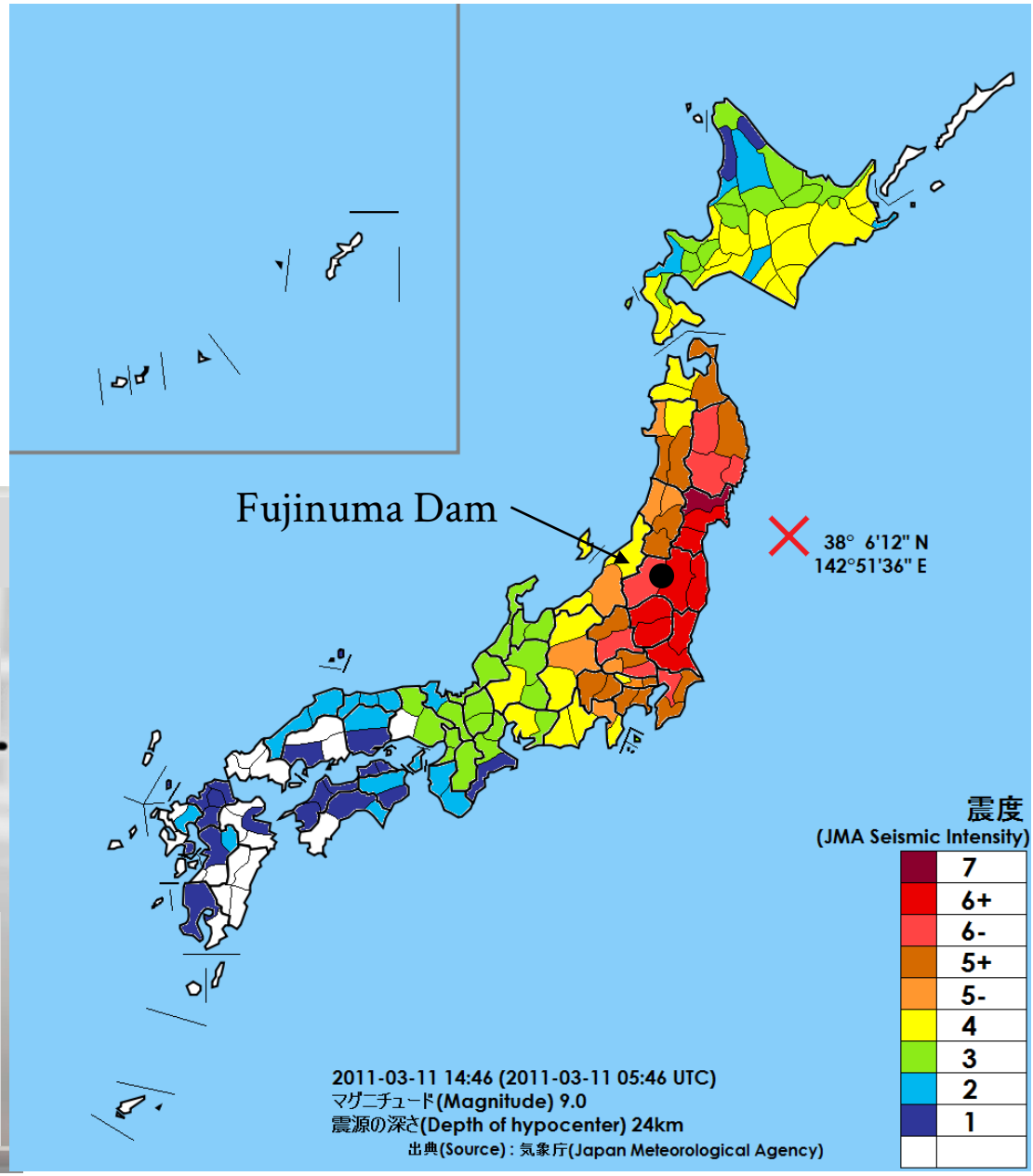
2011 Tohoku Earthquake

Magnitude 9.1

2:46 PM, March 11, 2011

500 km subduction zone, fault rupture



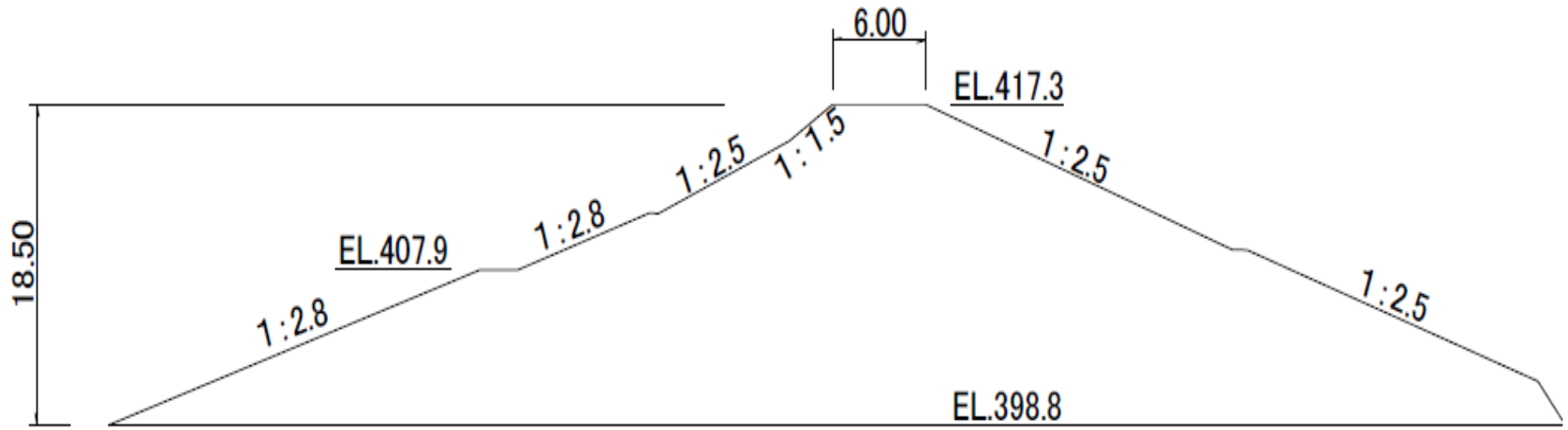


Fujinuma Dam

- Earthfill embankment dam
- Irrigation storage of 1.5 Mm^3 (1,200 AF)

- Height = 18.5 m (60.7 ft)
- Crest = L: 133 m x W: 6 m (436 x 19.7 ft)
- Freeboard = 1.8 - 2.4 m (5.9 - 7.9 ft)

Discrete layers of different materials noted by field investigators. Mostly cohesive, w/ sandier upper zone. Highly organic layer in foundation.



Before the Earthquake

Downstream

Upstream

Dam Master, 2011.Fuinuma Dam photos. Damnet.or.jp

Construction and Remediation

Offline "pond retaining structure"

1937 Construction begins

WWII Construction suspended

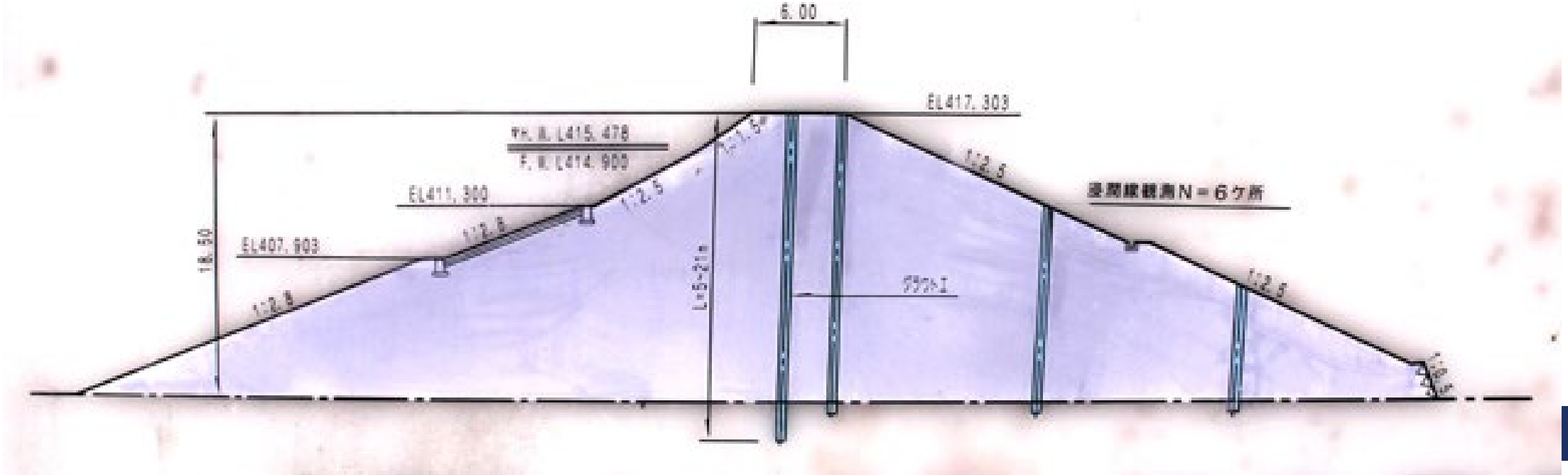
1949 Dam completed

Not regulated by Rivers Act

1977-79 Repair of spillway and surface erosion protection

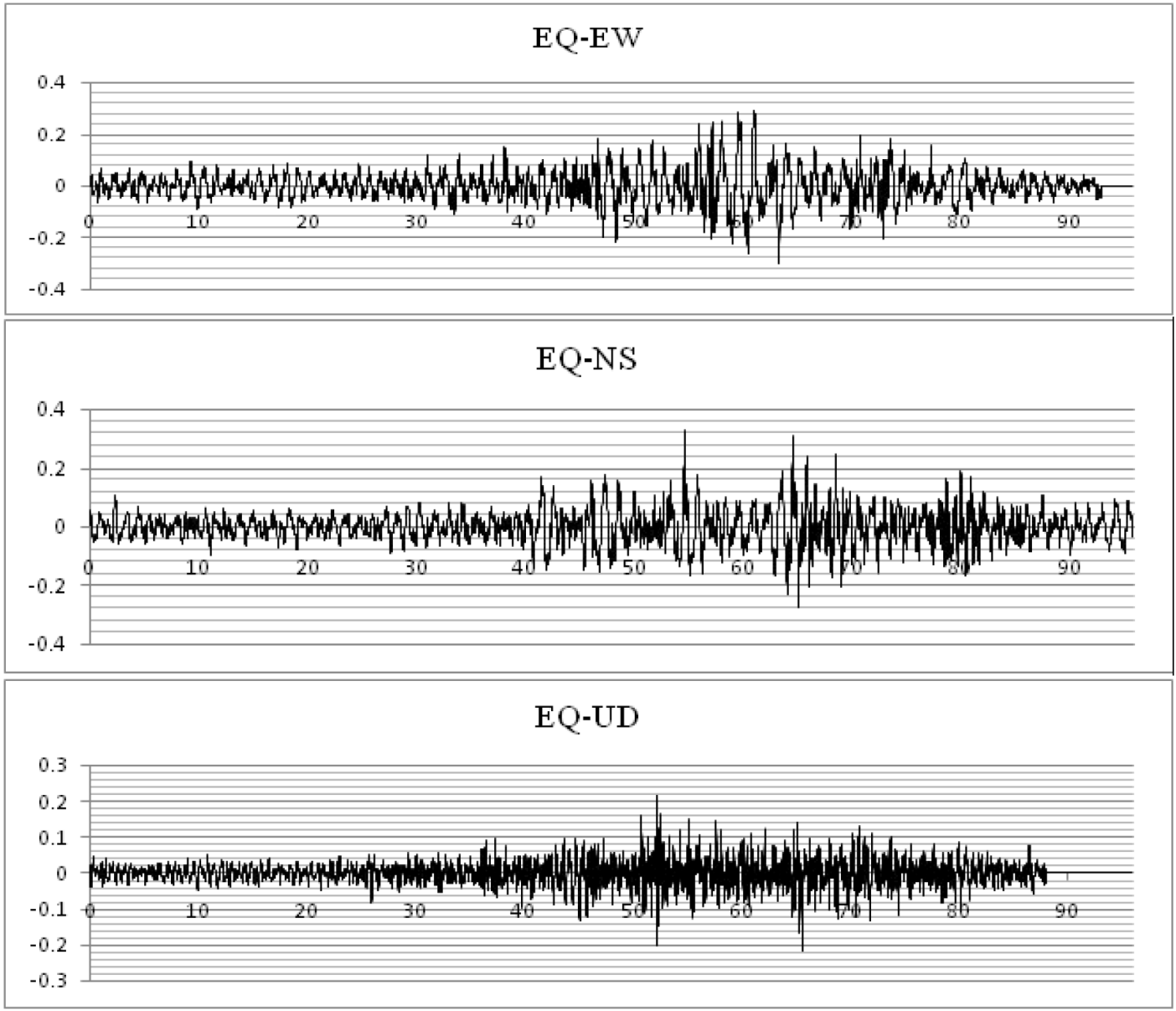
1984-92 Grouting against seepage, upgraded intakes

<1994 Piezometers installed



Shaking

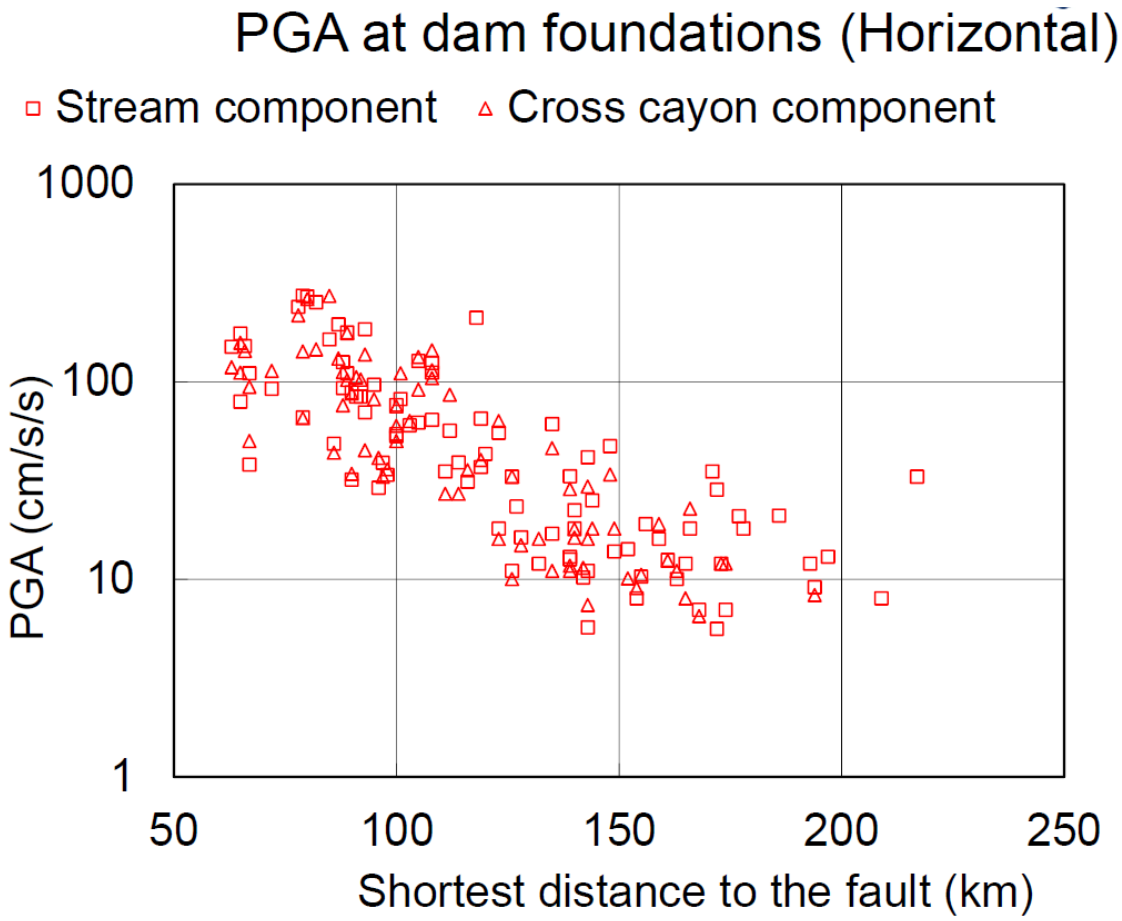
- Seismograph 2.8 Km away
- Max 0.315g
- Shaking lasted up to 300 sec.



M Abbas, S Takada, & S Sepand, 2012. Fujinuma Dam Performance during 2011 Tohoku Earthquake Japan and Failure Mechanism by FEM. 15 WCEE

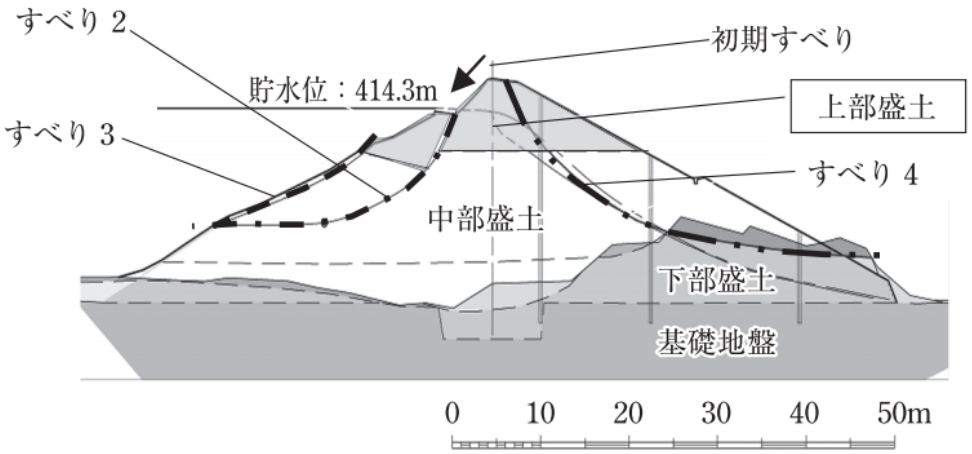
Regional Dam Impacts

- 750 of 3730 agricultural dams were damaged in Fukushima, 1 failure
- Only 2nd known type of seismic induced dam failure in Japan (1st since 1854)
- Others have failed by seepage through large cracks (hours to days later)
- Embankment dams had the worst damage
  - Some bad longitudinal cracking
- Some concrete dams also damaged



N Matsumoto, T Sasaki, T Ohmachi, 2011. The 2011 Tohoku Earthquake and Dams. JCOLD presentation at 89th ICOLD, Lucerne, CH.

Slope Failure and Overtopping



EERI, 2011. Overtopping photo.

T Watanabe and H Watanabe, 2015. Breach Factors and Restoration Method of Construction of the Fujinuma Dam. J Water Land and Environment Engineering (in Japanese).

Final Breach Opening

120 m top width

Some residual did not erode

Dam Master, 2011.Fuinuma Dam photo. Damnet.or.jp

N Matsumoto, T Sasaki, T Ohmachi, 2011. The 2011 Tohoku Earthquake and Dams. JCOLD presentation at 89th ICOLD, Lucerne, CH.

Saddle Dam

Rapid drawdown failure postulated

Several slope failures also observed around the reservoir rim

Photo from Damnet.or.jp

Failure Investigations

March 2011

13th, MLIT and others fly over dam site

29th, Japan Society of Dam Engineers

- Rapid dam investigations

April

GEER, ASCE-EDS, Japan Geotechnical Society (independently)

- Detailed site visit, soil samples, testing, LiDAR, Slope stability modeling

Before August

Japan Society of Hydrology and Water Resources

- Site visit, *interview flood victims*

August to January 2012

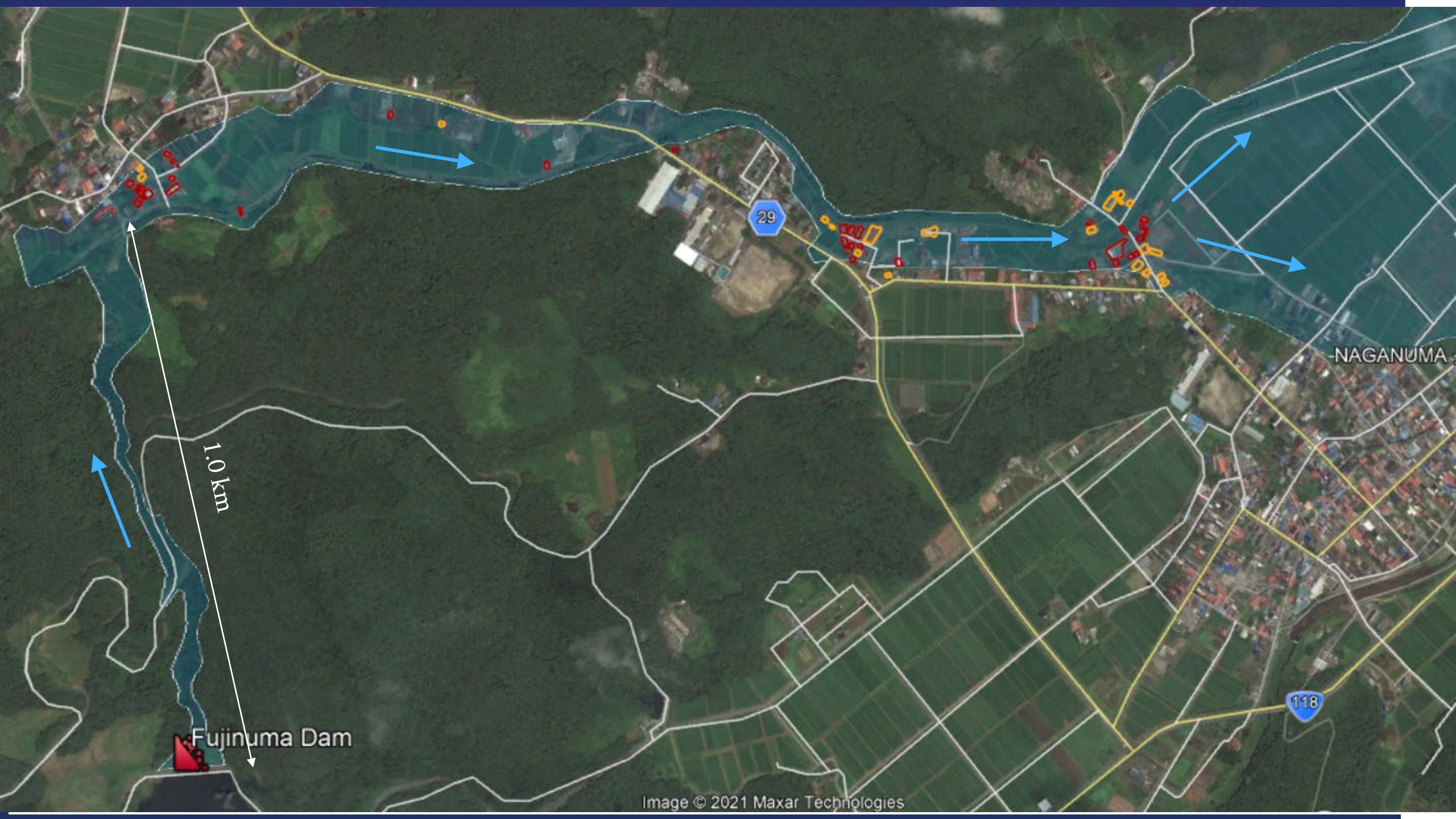
Fukushima Prefecture Investigation Panel on small dams

- Debris mapping, borings, construction and maintenance review, stability modeling

Charatpangoon PhD Thesis

- Microtremor testing, soil tests, permeability, FEM, natural frequency, *interviews*

Watanabe & Watanabe


29
NAGANUMA
1.0 km
Fujinuma Dam
118
Image © 2021 Maxar Technologies

Dam Failure Consequences

- 19 homes destroyed
- 32 homes flooded inside
- 30 with flooding below the first floor
- Other buildings damaged

- 3.78 people / HH in 2010 (census)
- PAR = ~306

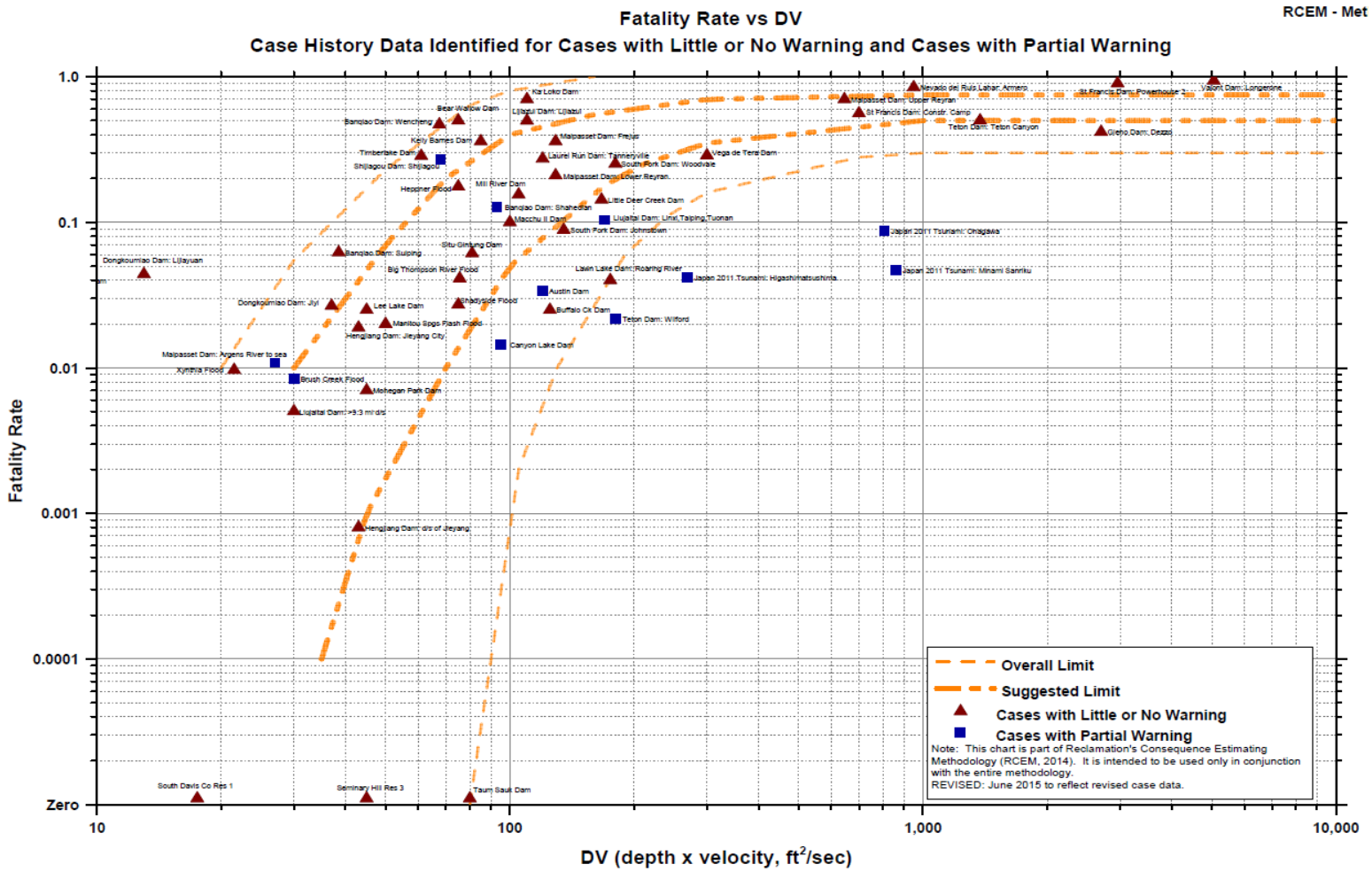
- 8 flood fatalities (2.6% of PAR)
- 4 others from the earthquake

I Towhata, et al, 2011. Geotechnical Damage Caused by the Recent Gigantic Earthquake in Japan. GEDMAR Conference.

Expected Life Loss

RCEM Chart

DxV (ft^2/s)	Stability Threshold Exceeded
2-5	Vehicles wash off road
6-10	Pedestrian topples
30-70	House collapses
~160	Trees, structures washed away



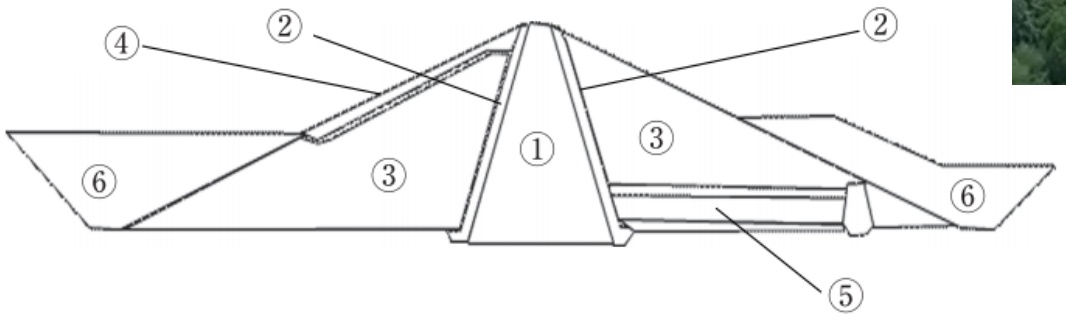
Reconstructed Dam

Started 2013

Refilled 2017

Modern zoned structure with filters and buttresses

Sukagawa City 10th Anniversary Remembrance
https://youtu.be/2fYQXjdJQa4



T Watanabe and H Watanabe, 2015. Breach Factors and Restoration Method of Construction of the Fujinuma Dam. J Water Land and Environment Engineering (in Japanese).

Nationwide all unregulated dams were assessed for this failure.

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THANK YOU

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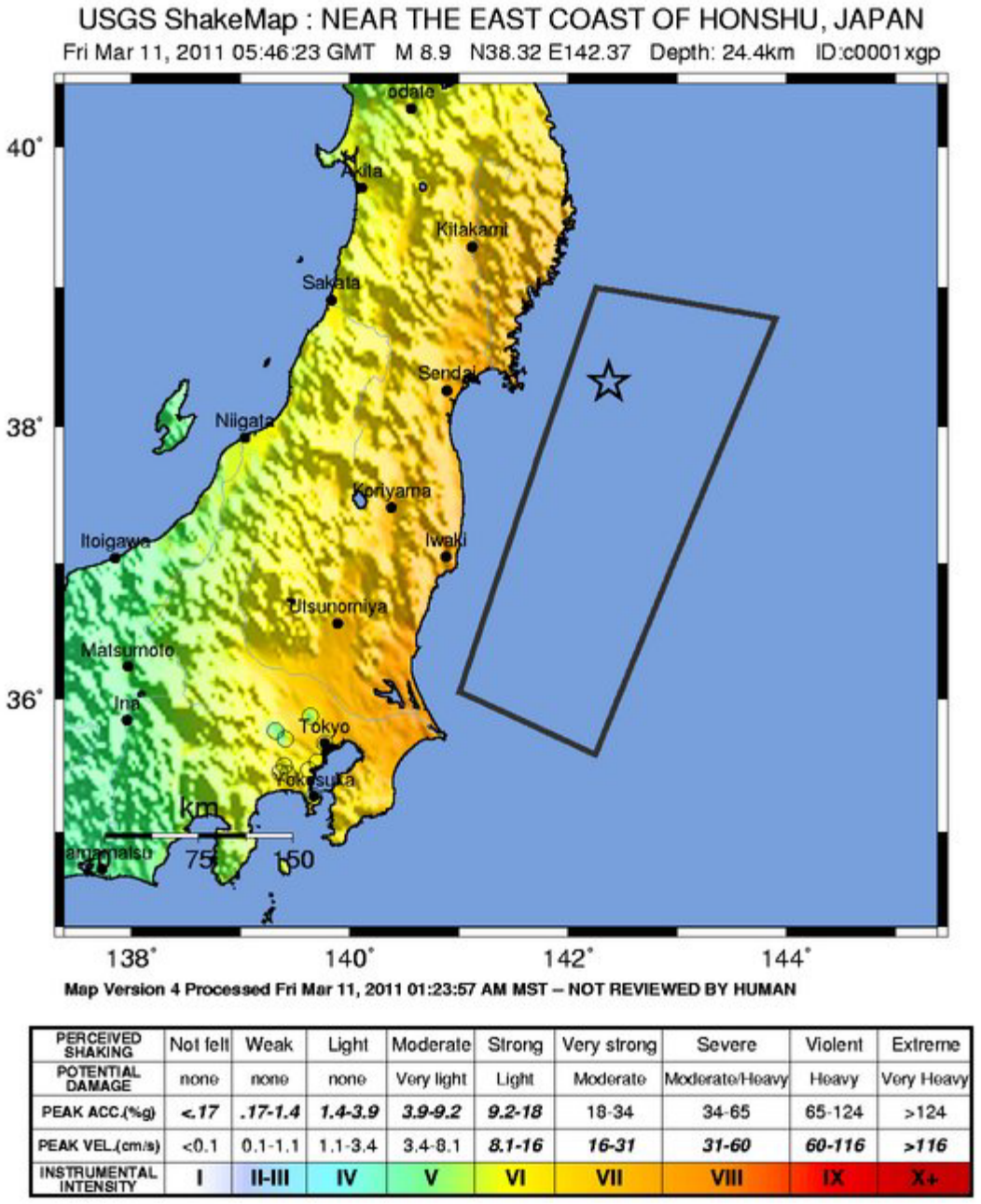
Bridge Failure

2009 Wikipedia image looking US



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	*8.1-16*	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Spillway inlet and upstream side of dam

Flood Path

Y Sato, H Mizuno, S Hiyashi, H Sugimoto, 2011. Tohoku Offshore Earthquake Helicopter Survey Report. MLIT