The 2011 Tohoku Earthquake and Dams

ICOLD 89th Annual Meeting in Lucerne
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Japan Commission on Large Dams
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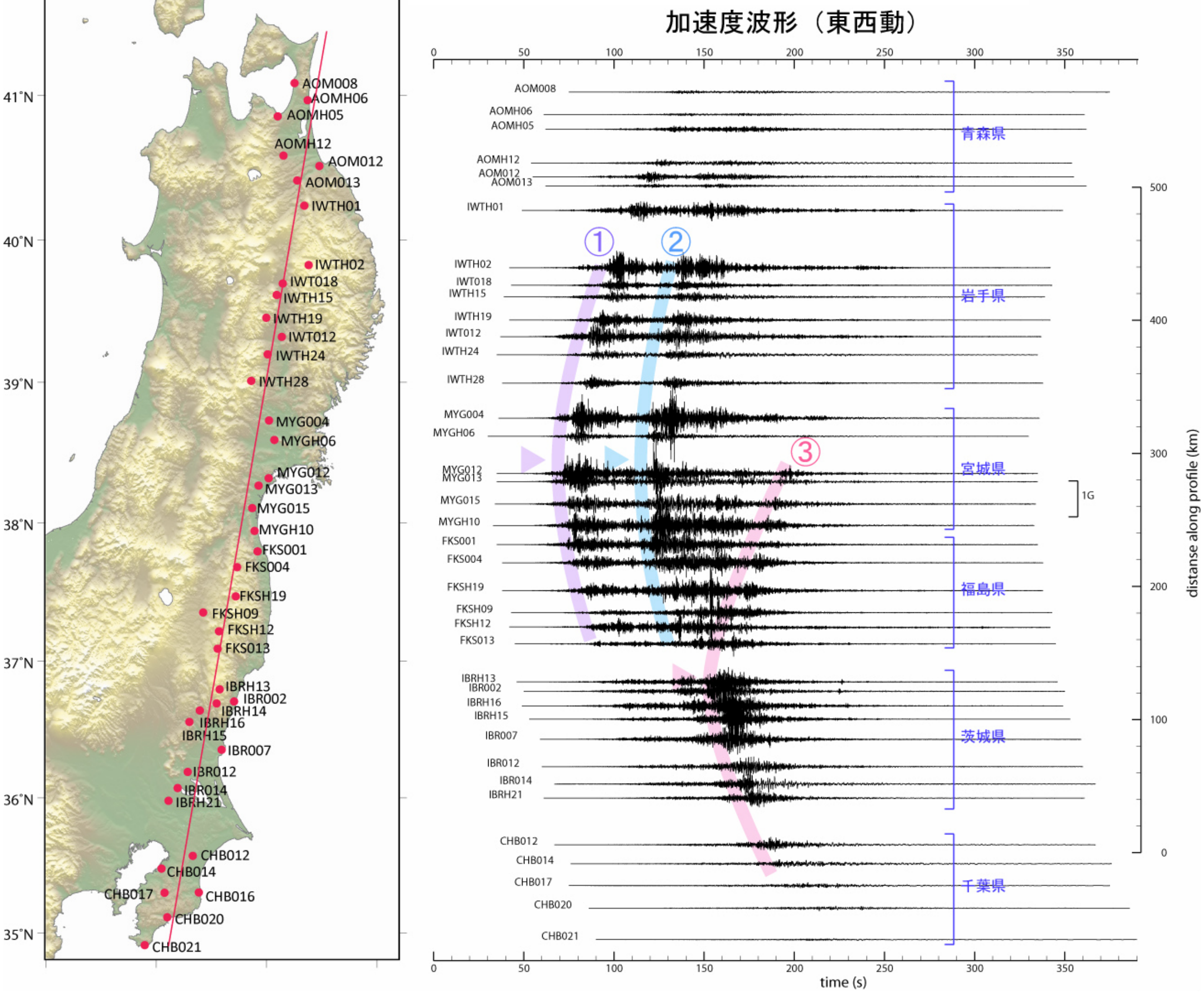
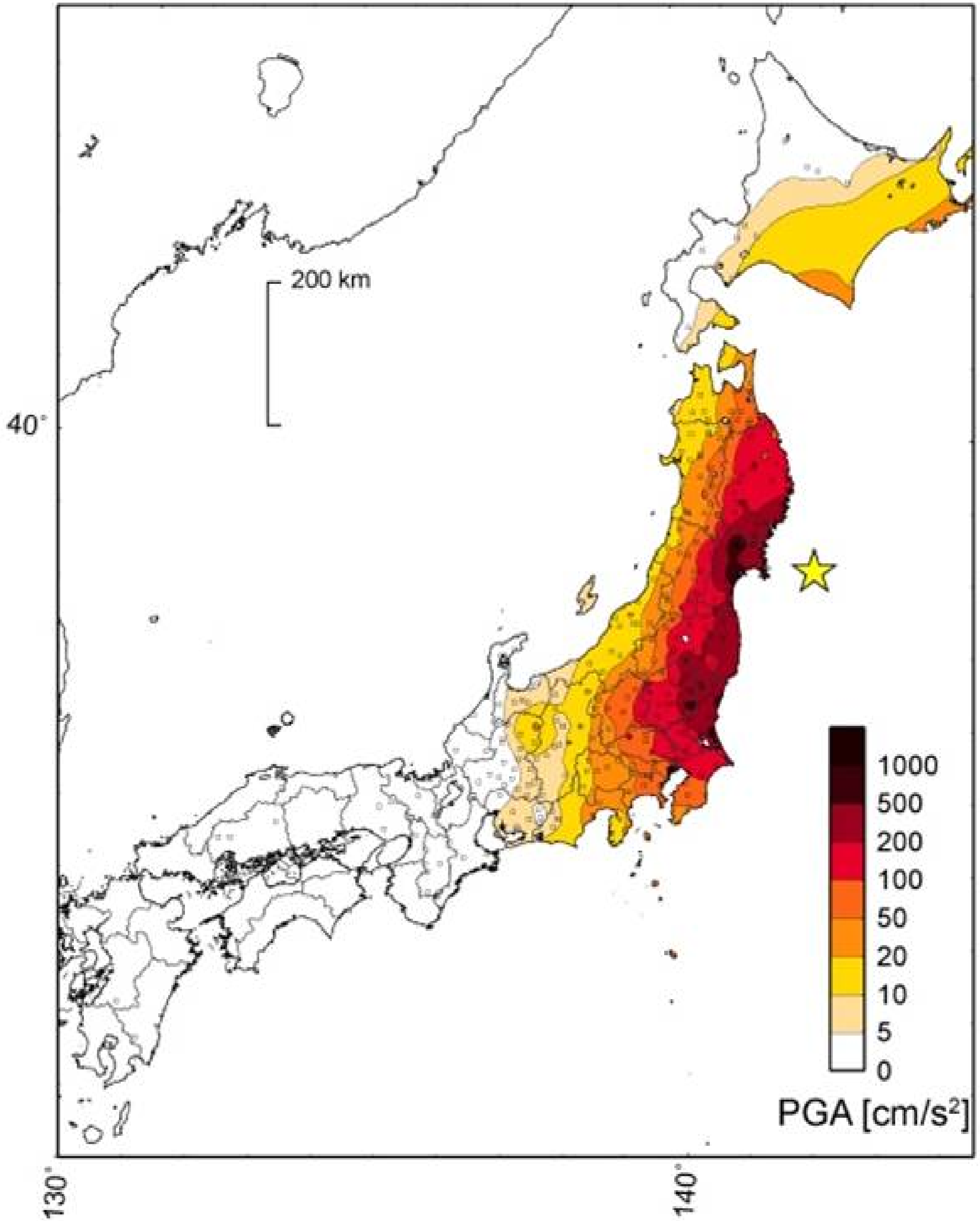
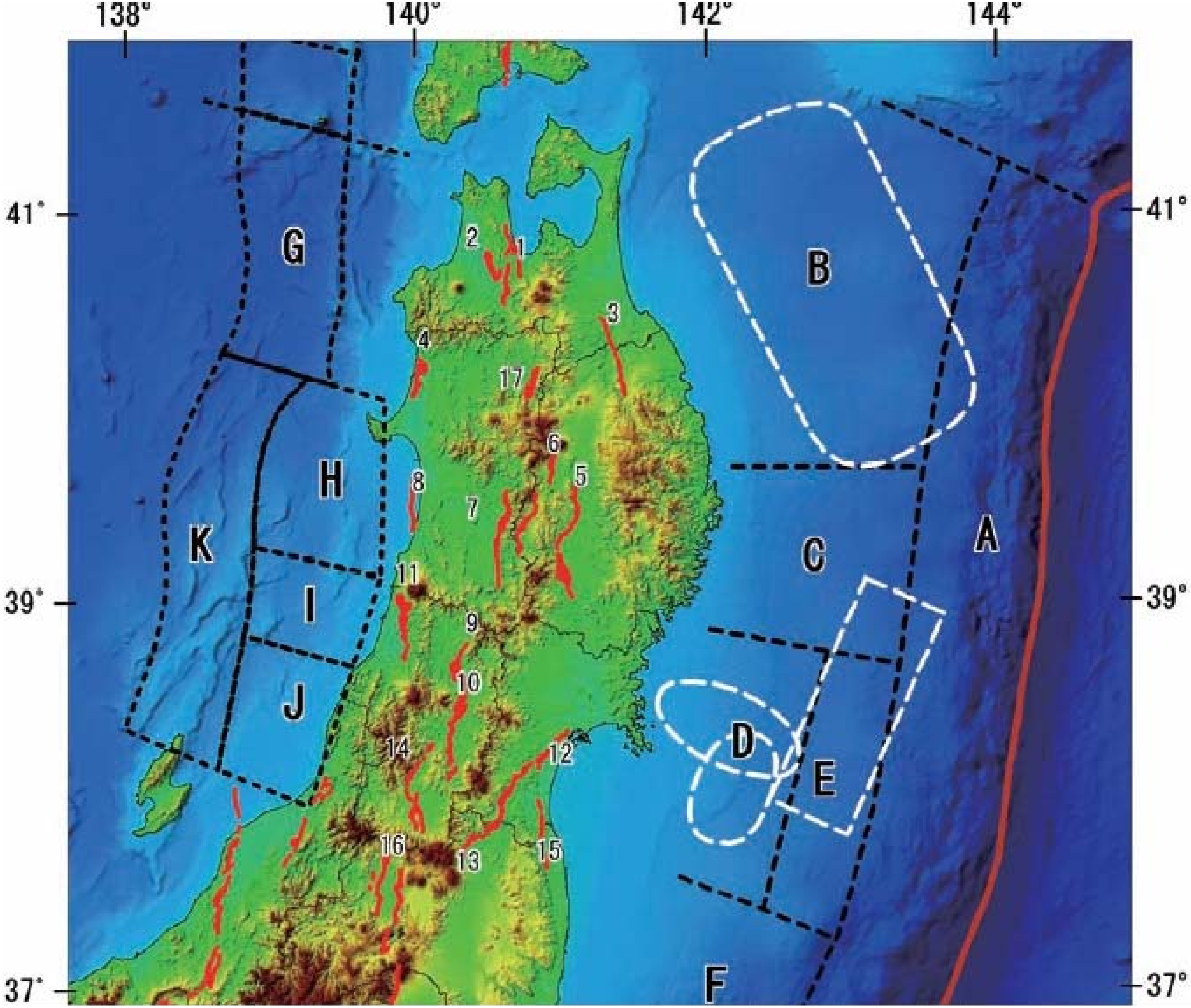
Acceleration EW component



ERI (Earthquake Research Institute, Univ. of Tokyo)



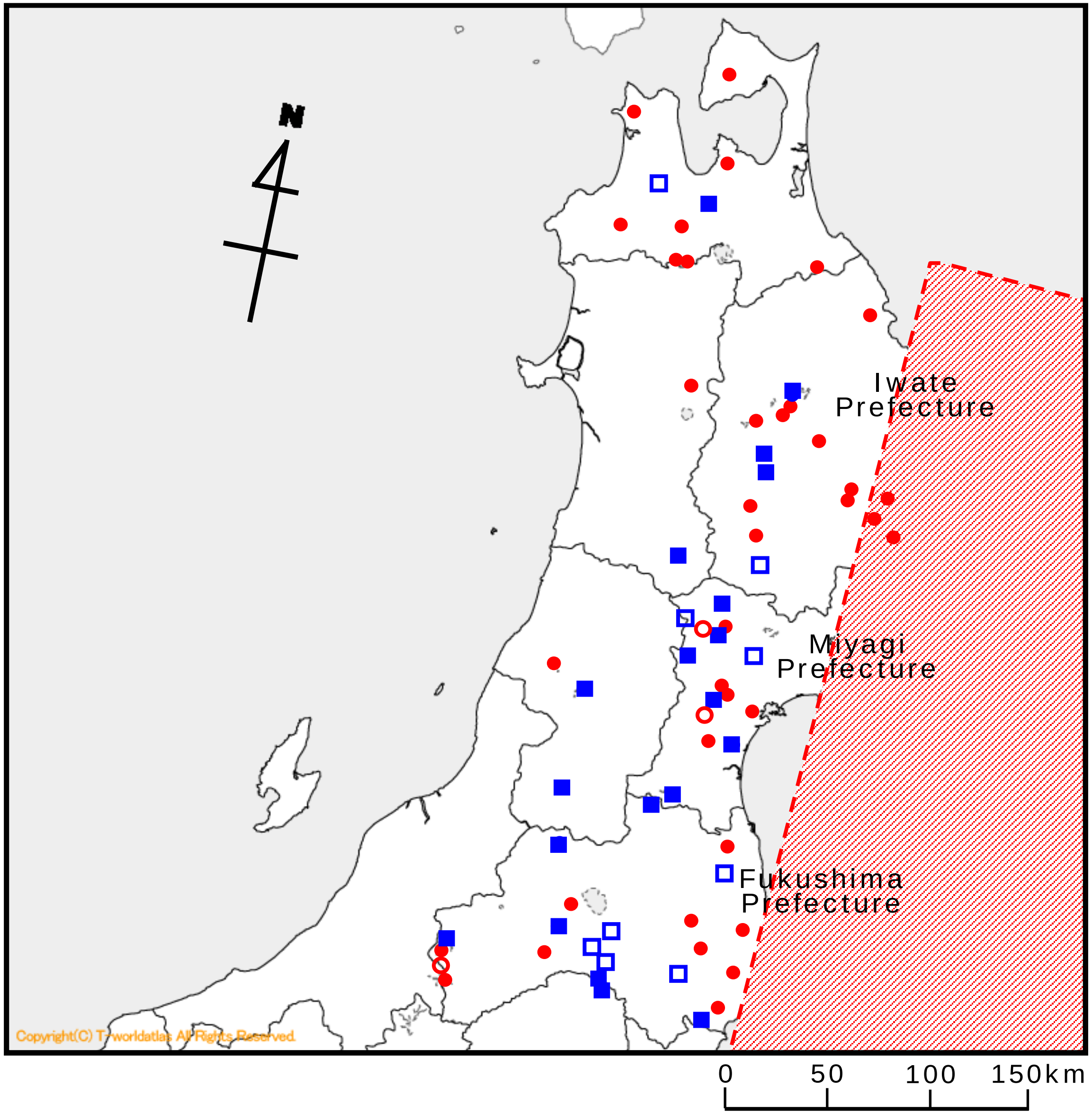
PGA distribution
by ERI



Headquarters for Earthquake Research Promotion

D: Occurrence probability more than 99% in 30 years M=8.0 at most

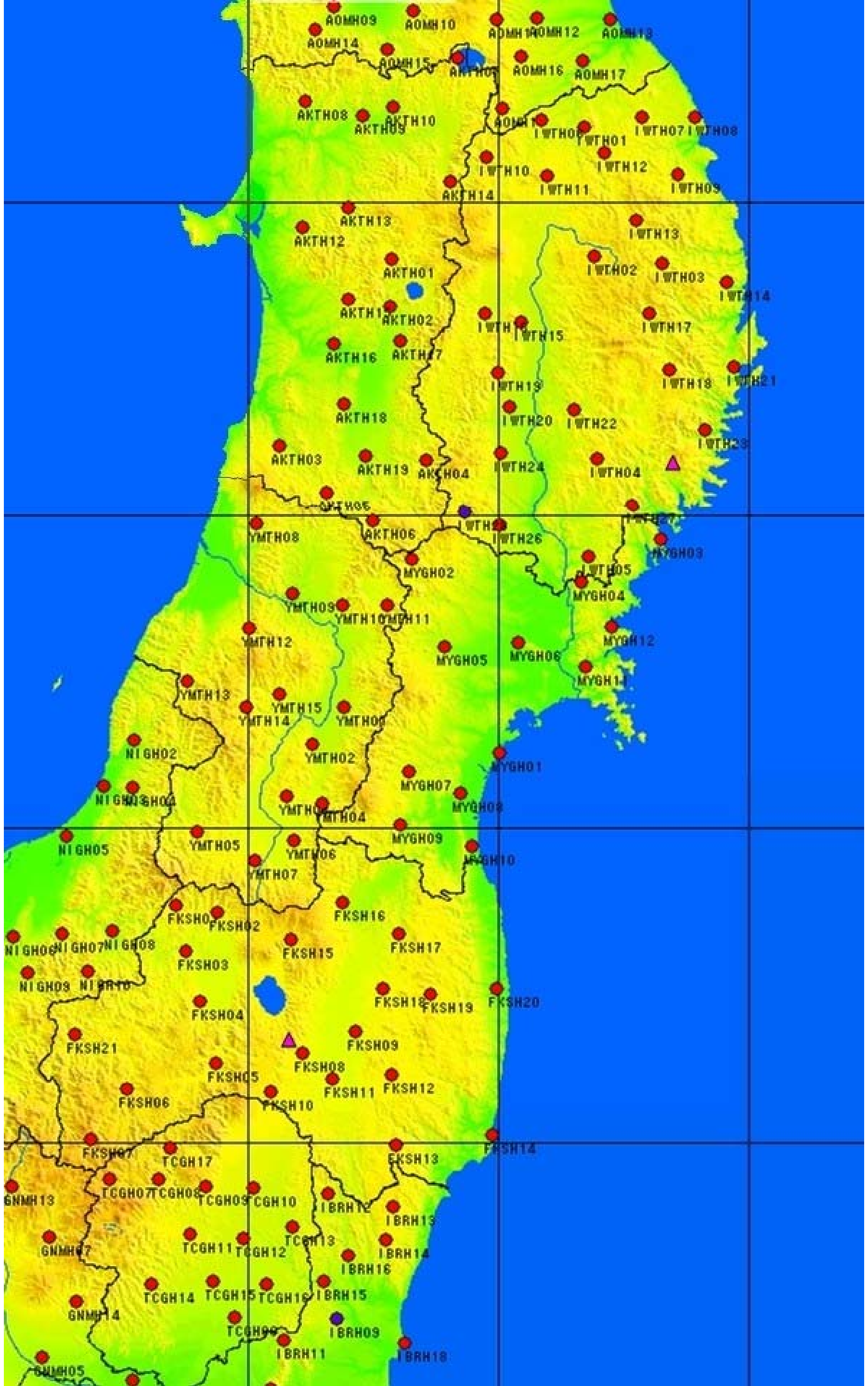
Faulted area and dams



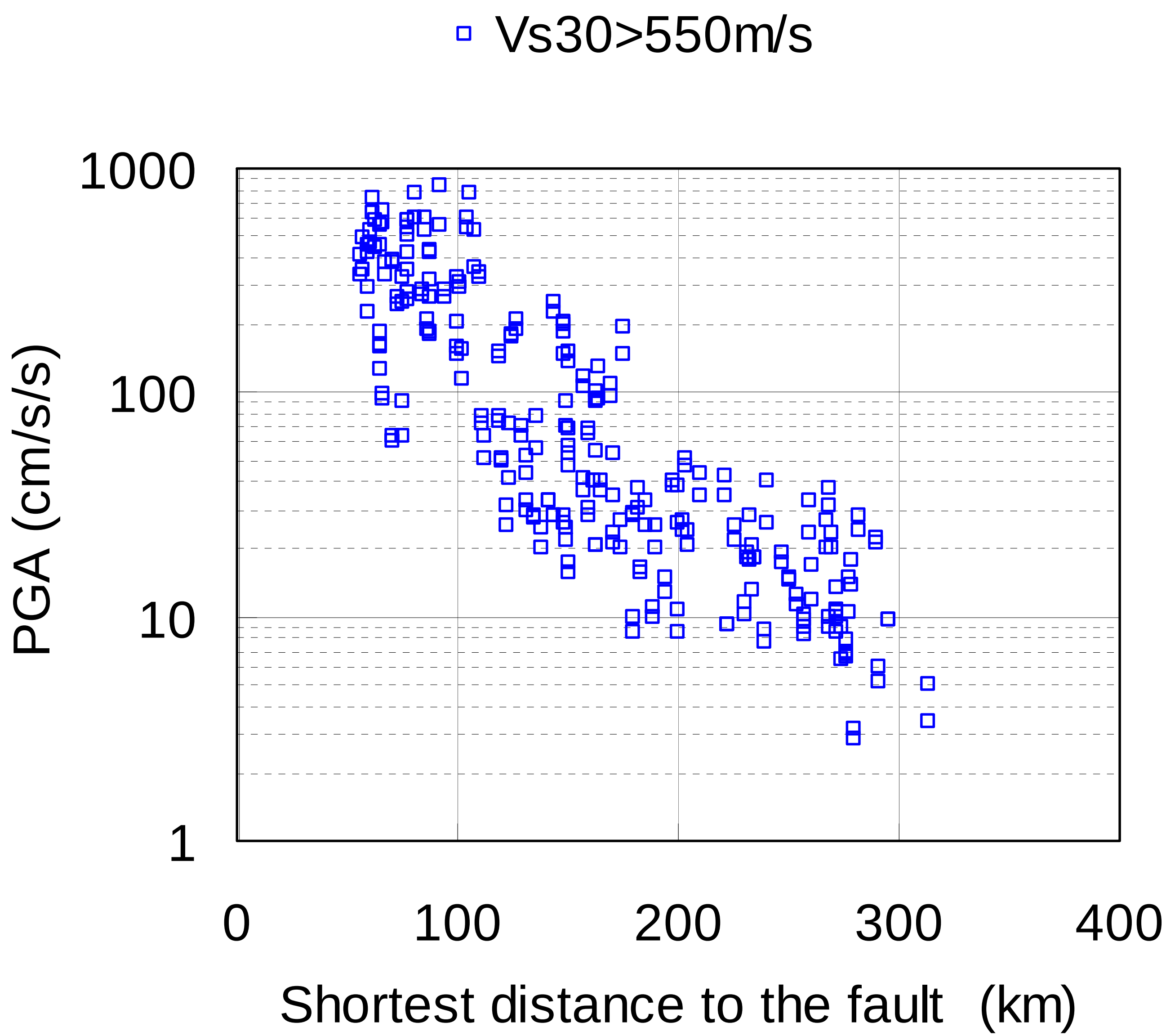
Projection of fault surface
(NIED Fault Model)

● Concrete gravity ○ concrete arch ■ Rockfil □ Earthfill

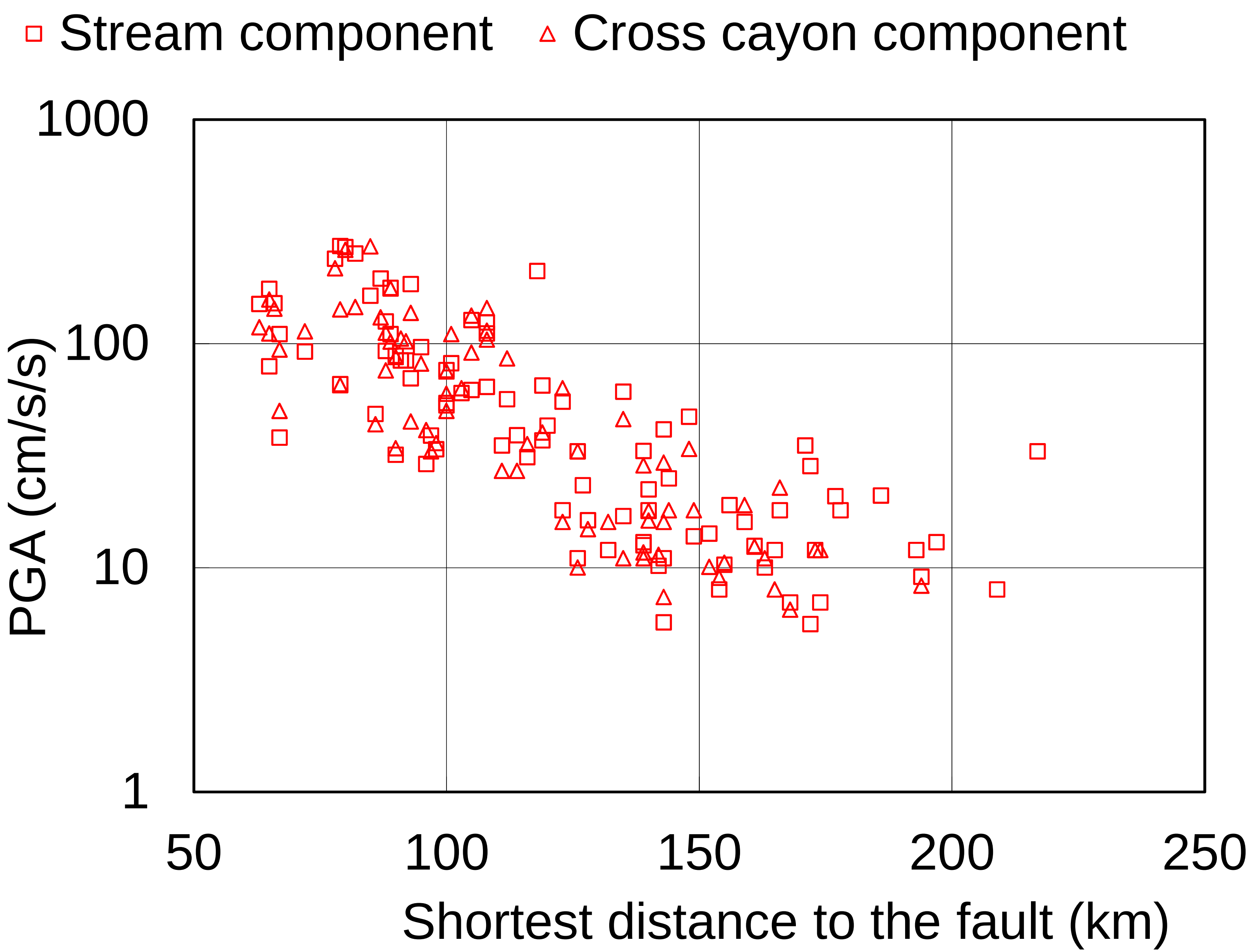
Location of Kik-net stations
NIED



PGA attenuation (Horizontal) Kik-net (NIED)



PGA at dam foundations (Horizontal)



Inspection of dams after the main shock

Jurisdiction (Number of dams)	Ower	Number of dams	
		inspected	suffered unusual behavior* or damage (failure)
Ministry of Land, Infrastructure, Transport and Tourism (150)	Central Gov.	46	11
	Local Gov.	104	8
Ministry of Agriculture, Forestry and Fisheries (172)	Central Gov.	51	4
	Local Gov.	121	23(1**)
Electric Power Companies (69)	Hokkaido	8	0
	Tohoku	24	0
	Tokyo	29	1
	J-Power	7	1
	Kansai	1	0
Total		391	48(1)

*unusaul behavior: small increase of leakage & uplift, nominal settlement and others

**The failed one was on a non regulated river.

Takou Dam Concrete Gravity   H=77m completed in 2006

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Takou Dam: The wall of gate house was cracked.

Inside the house, bolts were cut off and the hoist was displaced.

Minamikawa Dam

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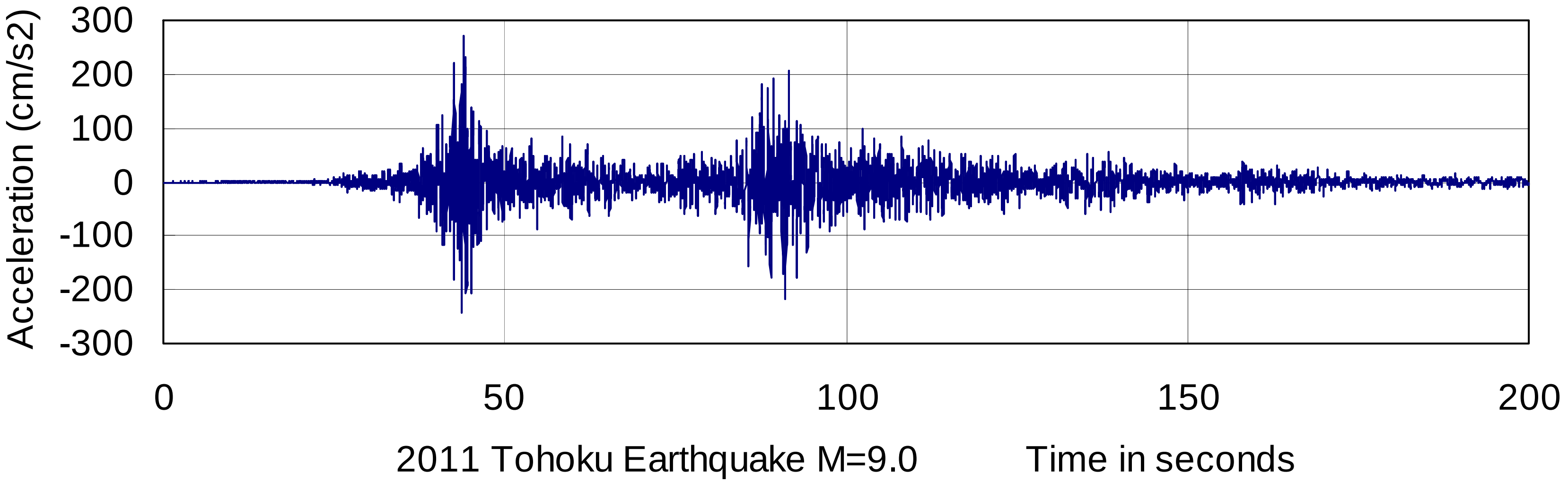
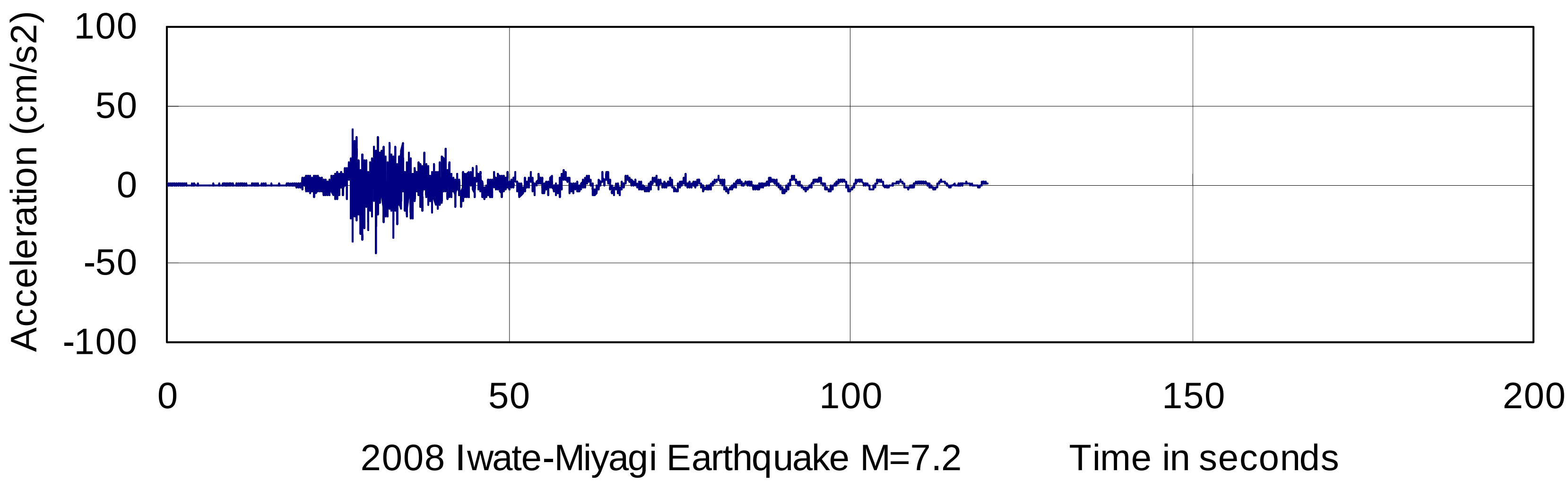
Main dam: concrete gravity

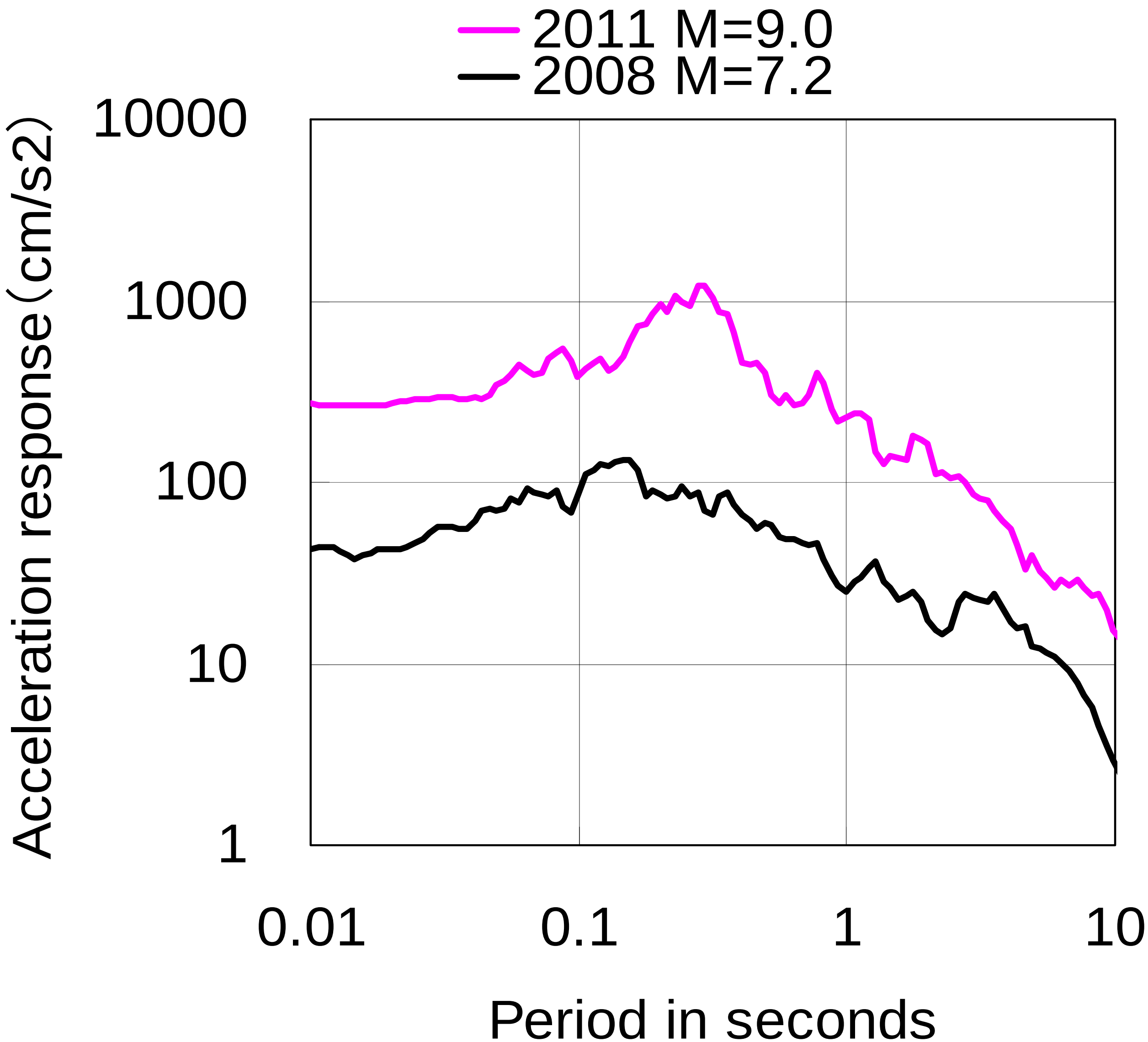
Saddle dam: asphalt concrete face rockfill

Foundation ground motions at Minamikawa Dam

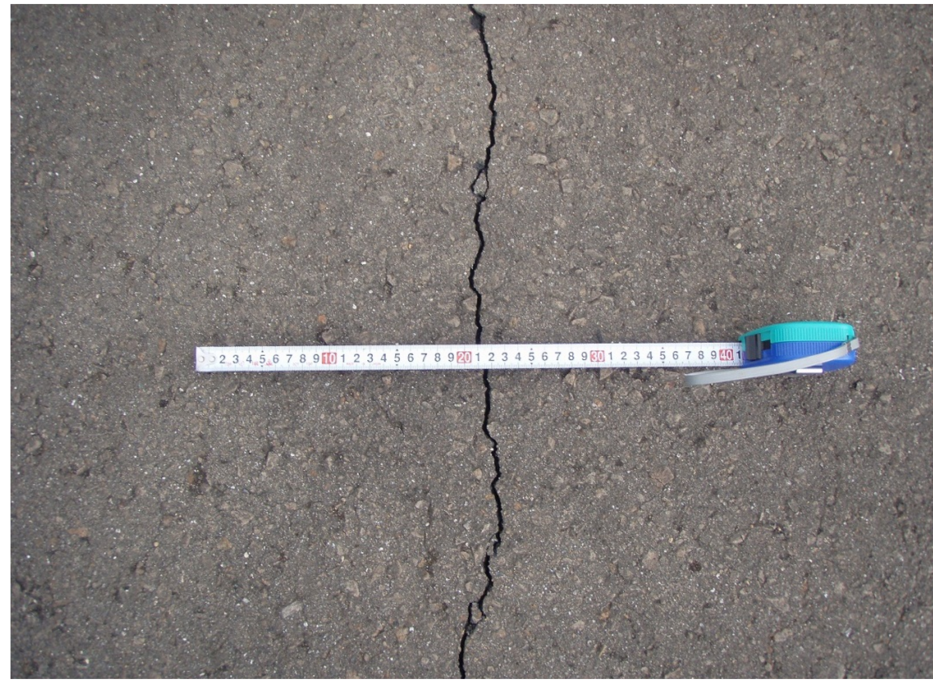




Acceleration response spectrum



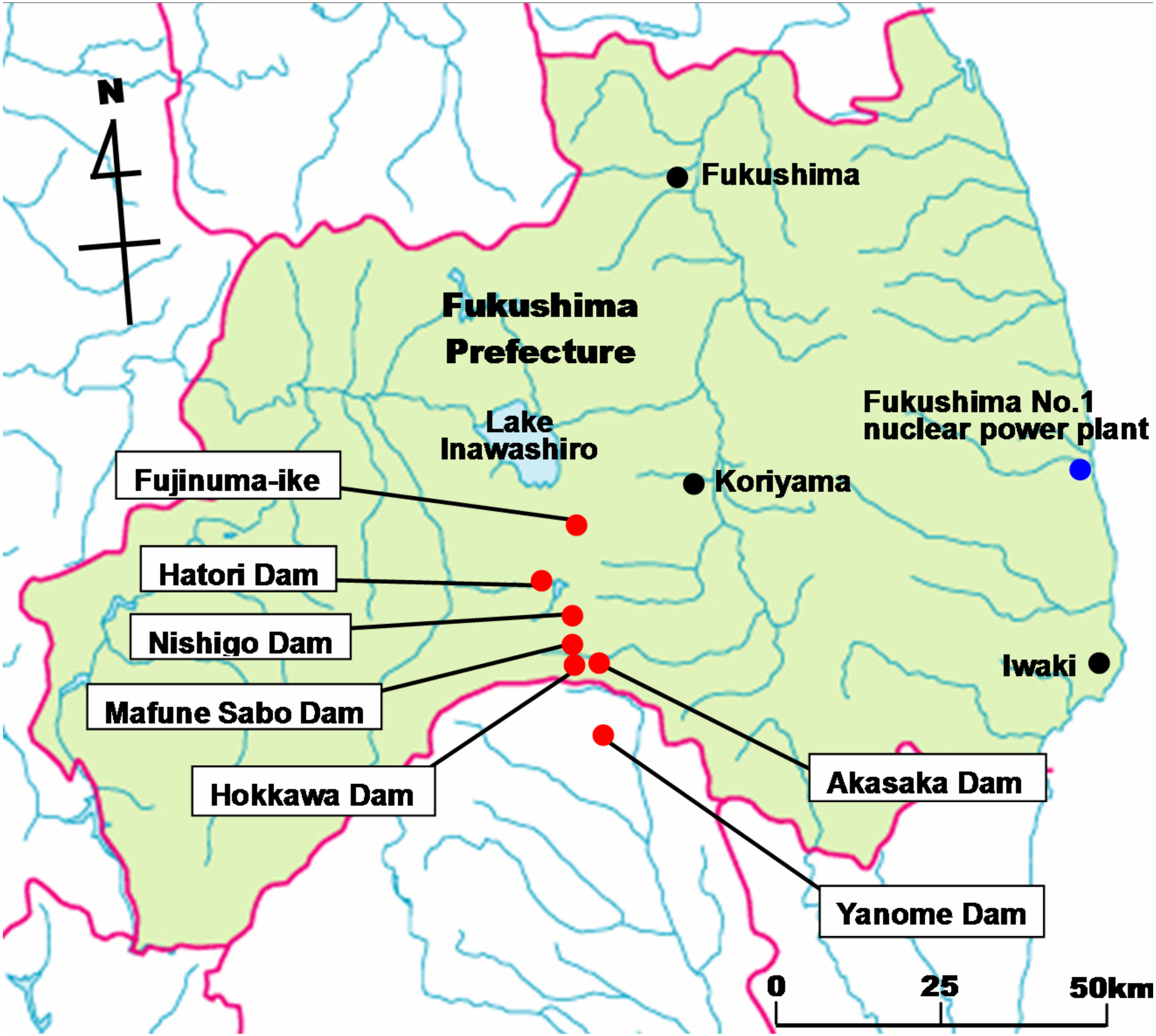
Cracking on the asphaltic concrete face --the width is 3 mm.



Cracking on the asphalt concrete face Numappara Dam JCOLD

H=38m PGA(fondation)=0.21g PGA (crest)=0.35g

Koromogawa No. 1 Dam
2011 Tohoku Earthquake


N
Fukushima
Fukushima
Prefecture
Lake
Inawashiro
Fukushima No.1
nuclear power plant
Koriyama
Iwaki
Fujinuma-ike
Hatori Dam
Nishigo Dam
Mafune Sabo Dam
Hokkawa Dam
Akasaka Dam
Yanome Dam
0
25
50km

Nishigo Dam H=32.5m completed in 1955
March 11, 2011 on the day

Nishigo Dam April 11, 2011
one month after the event, drawdown of water

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Fujinuma-ike Nov. 2006

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Fujinuma-ike after breach

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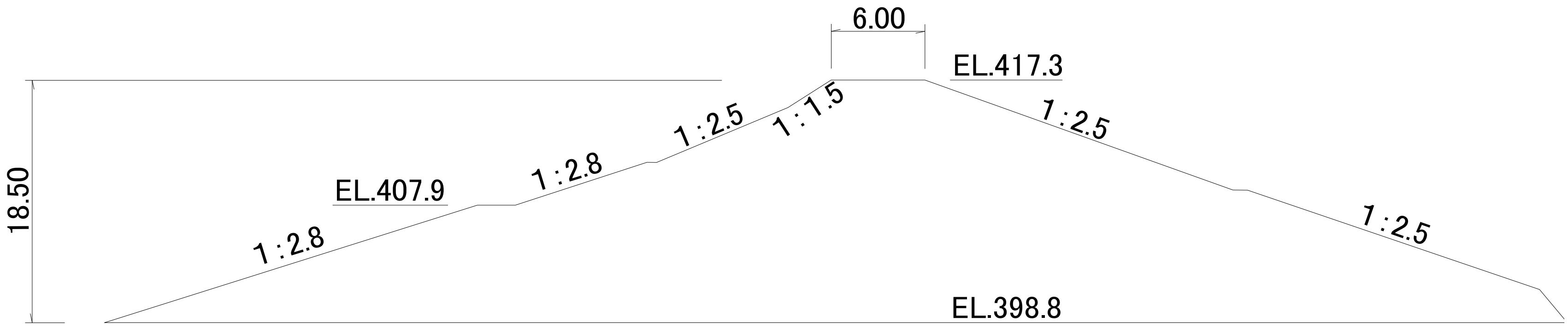
Fujinuma-ike was breached shortly after the earthquake. It was an eathfill type embankment with the height of 18.5 m and the length of 133 m. The reservoir capacity was 1.5 million m^3.



Looking towards right abutment

Right abutment

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Fujinuma-ike saddle embankment

http://www.nilim.go.jp/lab/bbg/saigai/h23tohoku/110314sabo.pdf

Conclusions

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- Generally dams performed well with minor or moderate damage. They withstood severe ground motion.
- However, one earthfill dam type embankment failed. It was constructed in 1949. Ensuring the safety of not well engineered old structures is our primary concern.
- MCE is a really maximum earthquake?
- What will happen, when the event exceeding MCE would occur?
- PGA's were not extraordinary large, but the duration of the motion was extraordinary long. The frequency of the ground motion was in the range of natural frequency of dams. The preliminary study suggests that a very long duration of the motion and not a few strong aftershocks rendered more impacts on fill dams than on concrete dams.

JCOLD thanks

- National Research Institute for Earth Science and Disaster Prevention (NIED)
- Earthquake Research Institute, Univ. of Tokyo (ERI)
- Ministry of Land, Infrastructure, Transport and Tourism (MLIT)
- Ministry of Agriculture, Forest and Fishery (MAFF)
- Japan Meteorological Agency (JMA)
- Iwate, Miyagi and Fukushima Prefectures
- Hokkaido, Tohoku, Tokyo, J-Power, Kansai and Hokuriku Electric Power Companies
- National Institute of Land and Infrastructure Management (NILIM)
- Public Works Research Institute (PWRI)
- Japan Water Agency (JMA)
- Japan Society of Dam Engineers (JSDE)
- Japan Dam Engineering Center (JDEC)

for their providing information and assistance.

The 2011 Tohoku earthquake and dams

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ABSTRACT: The magnitude 9.0 Tohoku earthquake occurred on March 11, 2011 near the northeast coast of Japan. The earthquake and tsunami caused enormous damage to Japan. As of April 8, 12,731 people were dead, 14,706 people are still missing and 216,818 houses or buildings were damaged or destroyed (National Police Agency, NPA). Fukushima No.1 nuclear power station had accidents. This paper is a preliminary report of the behavior of dams during the earthquake.

1 THE EARTHQUAKE AND GROUND MOTIONS

1.1 *The earthquake*

The 2011 Tohoku earthquake resulted from thrust faulting which plane is parallel to the surface of the subducting Pacific plate (Japan Meteorological Agency, JMA). According to JMA the size of the main fault was 450km in length and 150km in width. Rupture gradually extended near the hypocenter (0-50s) and propagated towards both south and north directions. The maximum slip was amounted to 25m. After the main shock, numerous after shocks including several events of the magnitude greater than 7 have been following.

Since 1793, six earthquakes with the magnitude greater than 7.3 had occurred near the coast of Miyagi Prefecture before the 2011 Tohoku earthquake. The occurrence probability of magnitude around 7.5 event (the magnitude is 8.0, in case the southern plate is associated) had been estimated to be 99 % in coming 30 years by the Headquarters for Earthquake Research Promotion (HERP). The magnitude 9.0 was beyond its prediction. The Jogan earthquake of magnitude 8.4 which is now considered to be the predecessor of the 2011 Tohoku earthquake occurred on July 13, 869 in this region, when Sendai area was swept by a big tsunami.

1.2 *Earthquake ground motion*

National Institute of Earth Science and Disaster Prevention (NIED) recorded strong motion at about 400 locations. Figure 1 shows PGA and the shortest distance to the fault. Peak ground accelerations in excess of 1.0g were measured at about 10 locations. Strong motion was also recorded at more than 70 dams. PGA at dam foundations ranges mostly 0.1 to 0.5g in three prefectures of Iwate, Miyagi and Fukushima. Figure 2 shows the comparison of PGA at dam foundations and NIED ground motion of past earthquakes (Matsumoto). The figure indicates that PGA at dam foundation is about half of PGA of NIED ground motion reflecting the nature of ground conditions. Therefore, the measured PGAs at dam foundations are consistent with the PGAs recorded by NIED.

The duration of motion was from 150 to 300 seconds which are extraordinary long. This was caused due to the consecutive rupture of two plates of north and south.

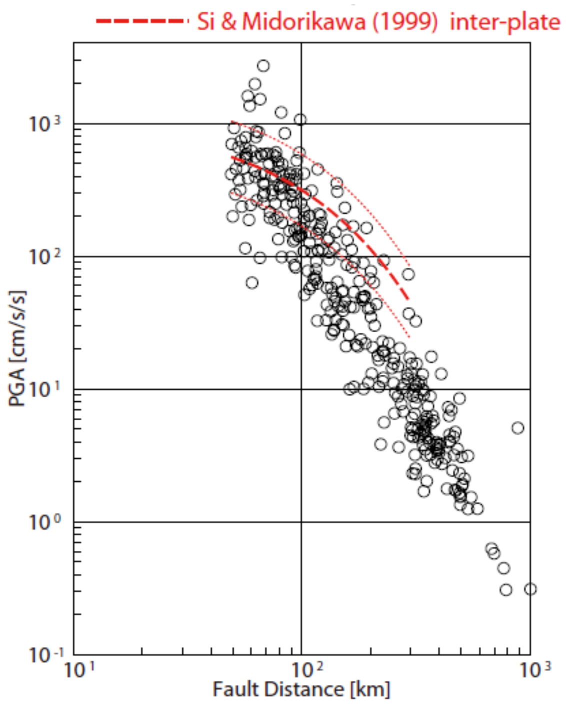


Figure 1. PGA and Fault Distance (NIED)

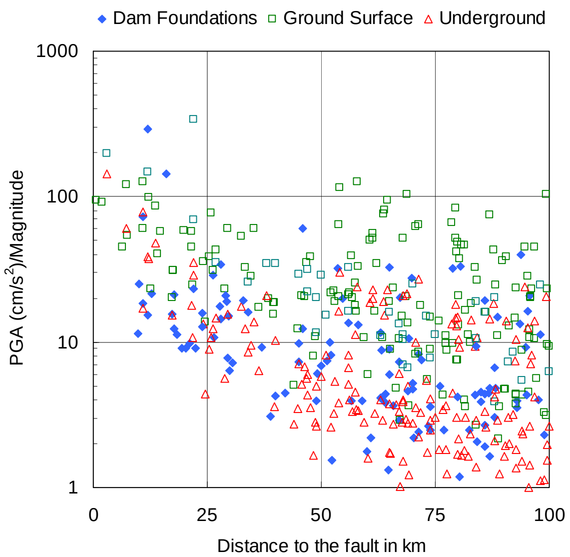


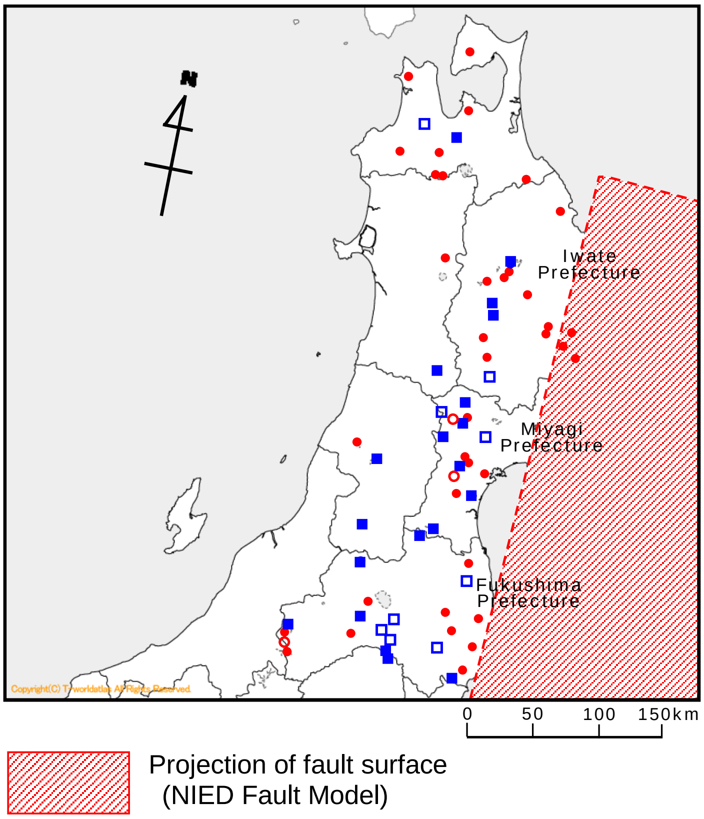
Figure 2. Comparison of PGA attenuation between dam foundations and NIED records in the past earthquakes (Matsumoto)

2 INSPECTION OF DAMS

Immediately after the earthquake, inspection of dams was started. As of March 31, more than 400 dams were inspected. Generally dams performed well with minor or moderate cracking occurring at embankment dams. However, one earthfill dam for irrigation failed. Fujinuma-ike ("ike" means pond, it was not called as "dam") was an 18.5 meter high earthfill structure. Fujinuma-ike was on a non regulated river and hence Fujinuma-ike does not fall under the regulation of River Act.

3 PERFORMANCE OF SOME DAMS

At the time documenting this paper, it is impossible to describe the performance of all dams in the affected areas during this earthquake. This is a very preliminary report. Figure 3 sows the location of major dams and the projection of fault surface. Iwate, Miyagi and Fukushima are severely affected three prefectures. The shortest distance to the fault of these dams ranges 70 to 160 km, if the dip of the fault is taken into account. Figure 4 is Takou dam in Iwate Prefecture. The dam performed very well, but the gate house was cracked as shown in Figure 5. Figure 6 is the photo of crest of Nanakita dam in Miyagi Prefecture. Three filldams suffered cracking in asphaltic concrete face. Minamikawa Saddle dam is one of them as shown in Figure 7.



● Concrete gravity ○ concrete arch ■ Rockfil □ Earthfill

Figure 3. Location of major dams in affected area

Figure 4. Takou Dam after the quake

Figure 5. Cracking at gate house

Figure 6. Bump on the crest of Nanakita Dam

Figure 7 Asphaltic concrete face of Minamikawa Saddle Dam

Japan Society of Dam Engineers (JSDE) sent a field investigation team to several dams in Fukushima Prefecture on March 29 and 30, 2011. The study team consisted of three engineers of N. Matsumoto, T. Sasaki and H. Amamiya. They met local officials of Fukushima Prefecture and Sukagawa City. Hokkawa Dam is a 57 meter high gravel fill dam for flood control, environmental water and municipal water. A leakage increase slightly, but it looked in good shape as shown in Figure 9. Hatori-ko (“ko means lake) is a 37.1 meter high earthfill dam which was completed in 1956 for irrigation. Its reservoir capacity is 27 Mm^3. The dam crest and downstream slope were protected by tarp to prevent rain percolation as shown in Figure 10. Nishigo dam is also a 32.5 meter high earthfill dam for irrigation. Figure 11 is its dam crest which suffered longitudinal cracking. There was bump on the upstream slope and the reservoir water was withdrawn for the safety of the dam after the earthquake. Akasaka dam and Yanome dam are an earthfill structure and also suffered cracking on the crest.

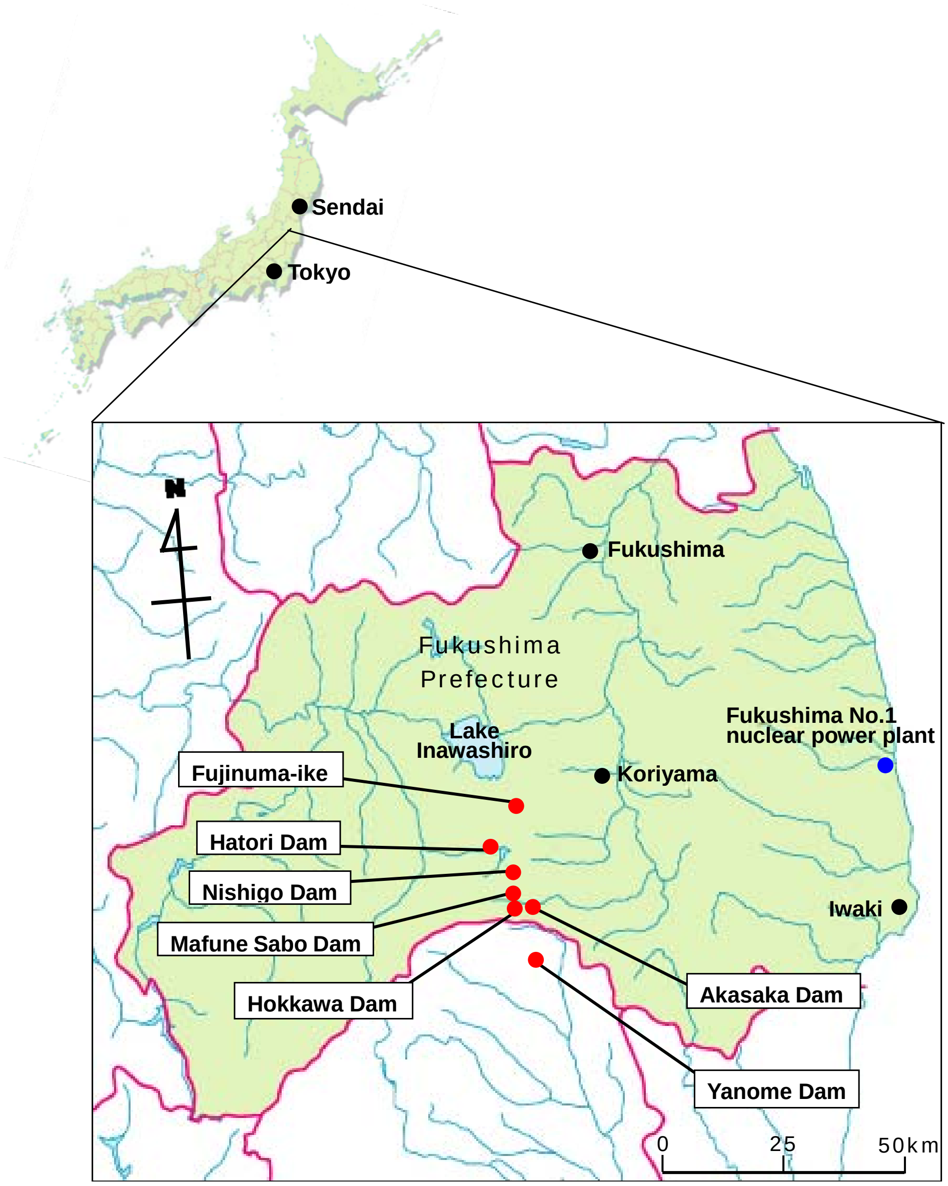


Figure 8. Location map JSDA team visited

Figure 9. View of Hokkawa dam from left abutment towards right abutment

Figure 10. Hatoriko downstream slope

Figure 11. Nishigo Dam; cracking on the crest

Fujinuma-ike was breached shortly after the earthquake. It is located in the southern Fukushima Prefecture. The epicentral distance is about 240km and the shortest distance to the fault is about 80km, in case the NIED fault model is employed. The accelerometer were not installed at the site. The attenuation relationship obtained from NIED strong motion network indicates that PGA at ground surface of the same fault distance is around 0.2 to 0.7g. According to the local officials of the irrigation department, 8 people were dead and 9 houses were swept. Fujinuma-ike is an earthfill structure with the height of 18.5 m as shown in Figure 12. The crest length is 133m, crest width is 6m and reservoir capacity is 1.5Mm^3. Spillway is ungated.

Construction began in 1937 for irrigation and was suspended during World War Ⅱ. It was competed in 1949. When the earthquake occurred, the reservoir level was almost full. According to witness, 20 to 25 minutes after the earthquake, the water was overflowing on the crest. Later big discharge occurred and it was breached completely as shown in Figures 13 & 14. The embankment had lost the height to retain water. The structure is a homogeneous type and most materials seem to be cohesive soil.

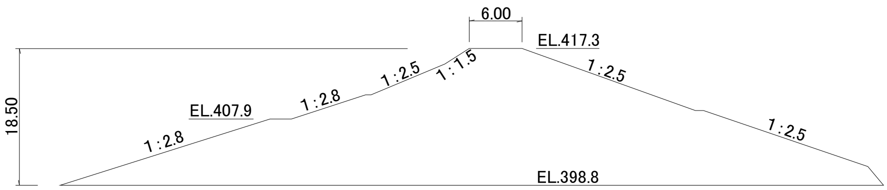


Figure 12. Typical section; dimension in meter

Figure 13. View from downstream toward the Fujinuma-ike

Figure 14. View from left abutment toward the breached portion

4 CONCLUSIONS

Immediately after the earthquake, inspection of dams was started. As of March 31, more than 400 dams were inspected. Generally dams performed well with minor or moderate cracking occurring at embankment dams. They withstood severe ground motion. However, one earthfill dam for irrigation failed. Fujinuma-ike ("ike" means pond, it was not called as "dam") was an 18.5 meter high earthfill structure which was completed in 1949. Fujinuma-ike was on a non regulated river and hence Fujinuma-ike does not fall under the regulation of River Act.

The preliminary investigation suggests that a very long duration of ground motion and a number of subsequent strong aftershocks rendered more effects on embankment dams than on concrete dams.

ACKNOWLEDGEMENTS

The authors thank NIED for Figure 1. They are grateful to the personnel of Fukushima, Iwate and Miyagi Prefecture for their help.

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http://www.bosai.go.jp/e/international/Preliminary_report110328.pdf

NPA http://www.npa.go.jp/archive/keibi/biki/higaijokyo.pdf