

The 2011 Tohoku earthquake and dams

N. Matsumoto & T. Sasaki
Japan Dam Engineering Center, Japan

T. Ohmachi
Tokyo Institute of Technology, Japan

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.

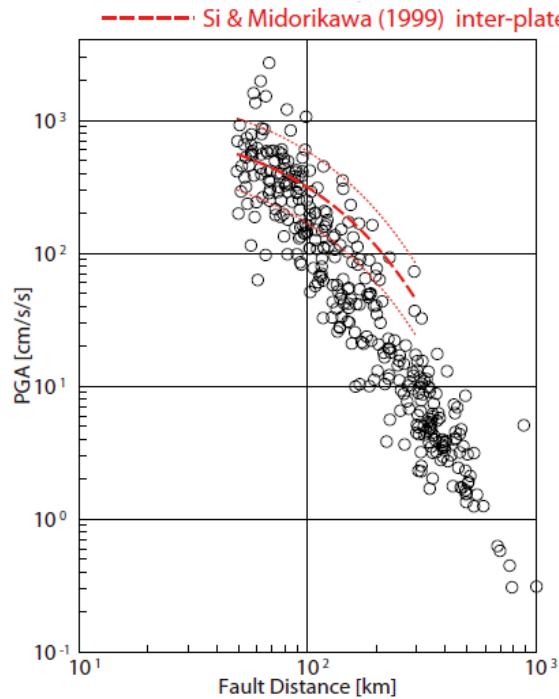


Figure 1. PGA and Fault Distance (NIED)

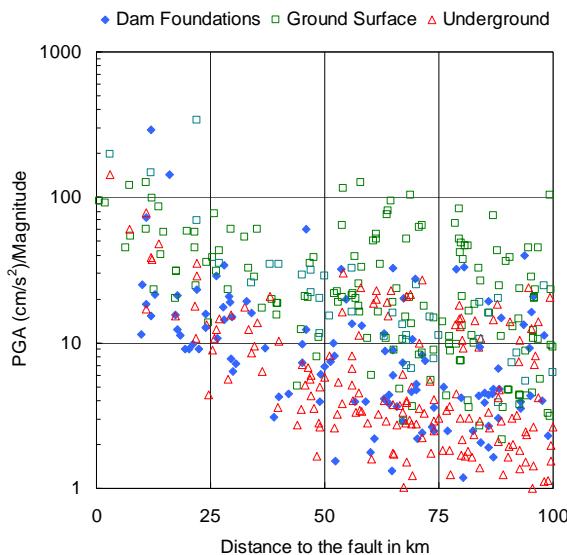


Figure 2. Comparison of PGA attenuation between dam foundations and NIED records in the past earthquakes (Matsumoto)

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.

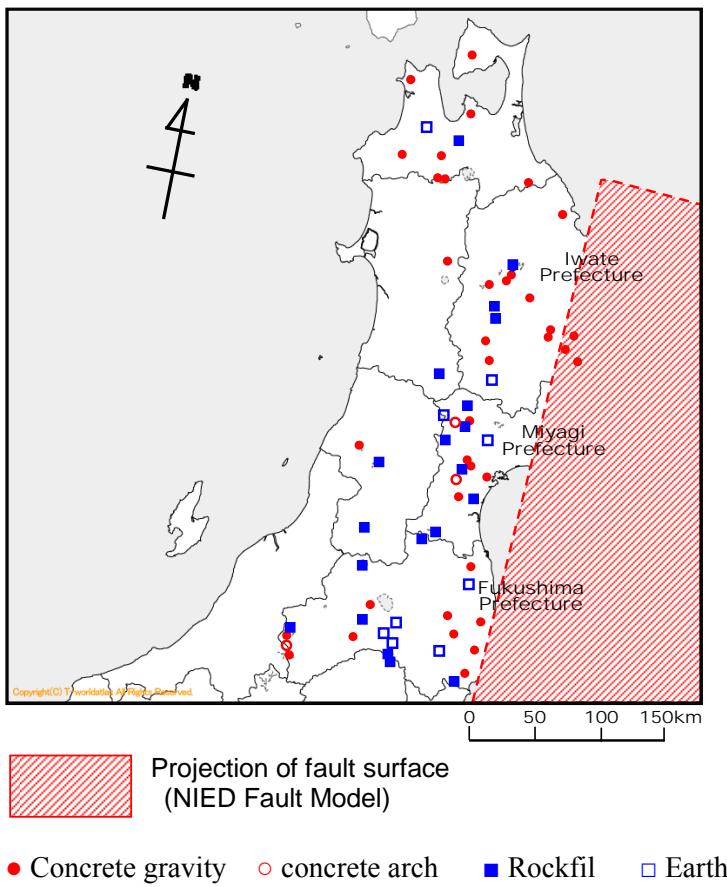


Figure 3. Location of major dams in affected area



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 Mm³. 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.

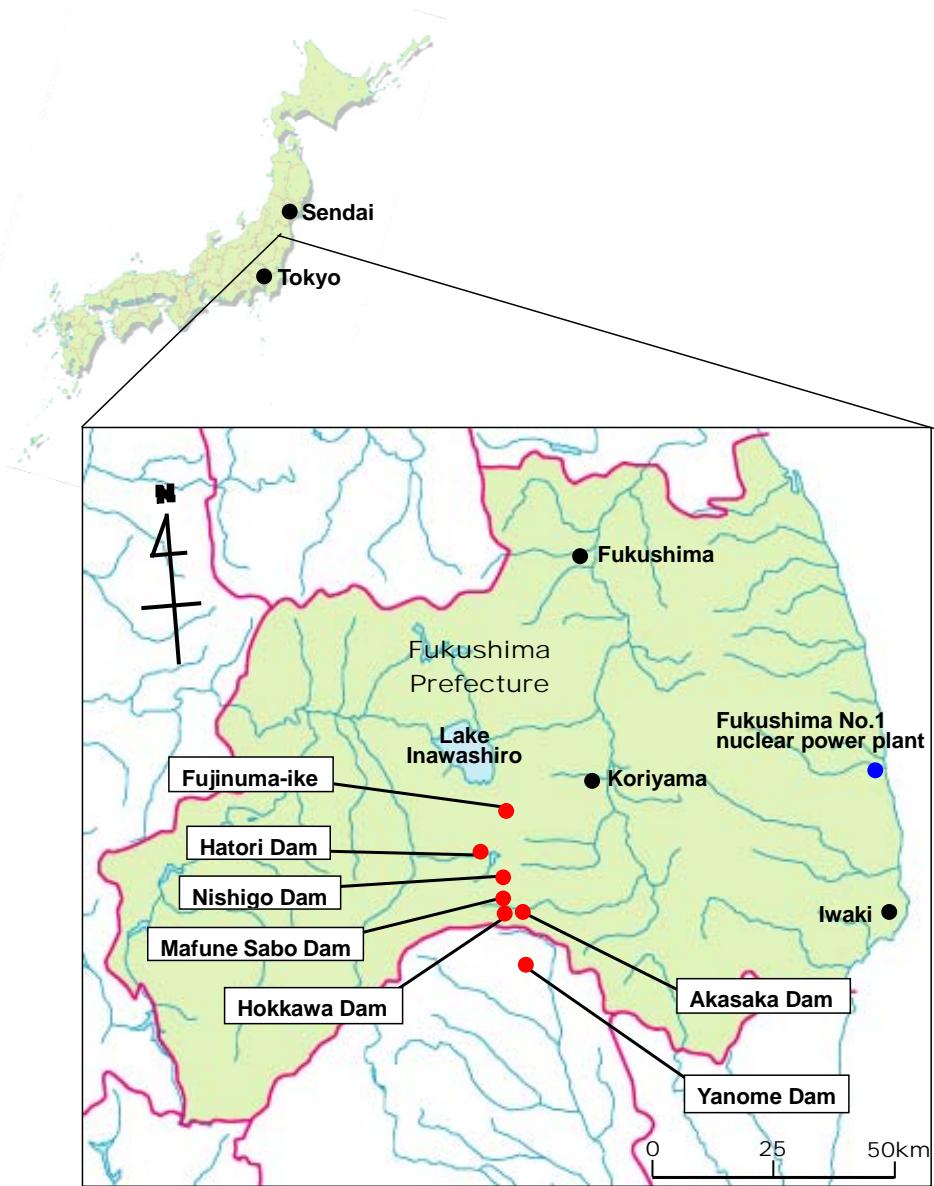


Figure 8. Location map JSDA team visited



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



Figure 10. Hatoriko downstream slope

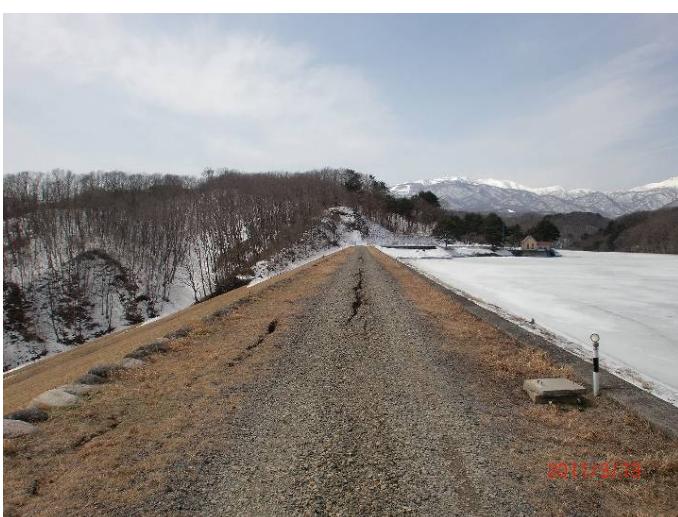


Figure 11. Nishigo Dam; cracking on the crest

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 1.5Mm³. Spillway is ungated.

Construction began in 1937 for irrigation and was suspended during World War II. It was completed 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.

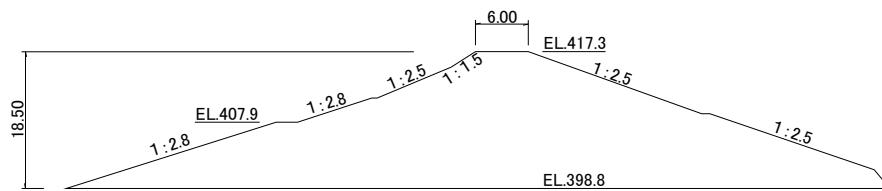


Figure 12. Typical section; dimension in meter



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.

REFERENCES

HERP:<http://www.jishin.go.jp/main/nihonjishin/2010/tohoku.pdf>, <http://www.jishin.go.jp/main/index-e.html>
JMA http://www.jma.go.jp/jma/en/2011_Earthquake/2011_Earthquake_SourceProcess.pdf
Matsumoto N. 2010. The recent earthquakes and dam safety in Japan, 8th European Club Symposium, Innsbruck pp. 571-576
NIED;http://www.bosai.go.jp/news/oshirase/20110315_01.pdf
http://www.bosai.go.jp/e/international/Preliminary_report110328.pdf
NPA <http://www.npa.go.jp/archive/keibi/biki/higajokyo.pdf>