Damage to Dams due to the Iwate-Miyagi Nairiku Earthquake in 2008

by

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ABSTRACT

The large earthquake, the Iwate-Miyagi Nairiku Earthquake in 2008 mainly struck the mid Tohoku Region in northeastern Honshu Island, Japan on June 14, 2008. The magnitude of the event was estimated as 7.2 in the JMA scale. Based on the results of the emergency inspections of 134 dams by the site officers immediately after the earthquake, on June 15 and 16, dam engineering experts carried out site investigation at the five dams where damage had been found. This paper described the outlines of the results of the preliminary investigations of the five dams. According to the investigation, no problems severe enough to threaten the structural safety of any of the five dams were found. This verified the high level of seismic resistance of the dams in Japan.

KEYWORDS: Dam, Damage, Deformation, Earthquake, Investigation, Leakage

1. INTRODUCTION

The large earthquake, the Iwate-Miyagi Nairiku Earthquake in 2008 mainly struck the mid Tohoku Region in northeastern Honshu Island, Japan at 8:43 am on Saturday morning, June 14, 2008. The strongest shaking was measured in Oshu City, Iwate Prefecture and Kurihara City, Miyagi Prefecture, both at 6 Upper of the Japan Meteorological Agency (JMA) seismic intensity.

Landslides triggered by this earthquake crushed structures, buried people, cut off road traffic, and isolated local communities. Mud from landslides dammed up rivers to form lakes, so called "quake lakes", which could threaten the safety of their downstream areas. By 13:30, July 30, 13 people were confirmed dead, 450 injured, and 10 still missing. A total of 28 homes were destroyed, 99 partly destroyed, and 1,382 partly damaged. (Fire and Disaster Management Agency, 2008) [1]

No nuclear power plant was shut down following this earthquake, unlike the case of Kashiwazaki-Kariwa nuclear power plant after the Niigataken Chuetsu-oki Earthquake in 2007. Several sections of express highways in the Tohoku Region were closed, then all were reopened by nightfall, except for one section where a traffic restriction was maintained because of repair works. Some JR East train services were suspended on Shinkansen, Japanese superexpress, and local lines, then resumed from the first trains on the following day. (Cabinet Office, 2008) [2]

The Technical Emergency Control Force (TEC-FORCE) organized by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) dispatched many experts to the event area to investigate damage to infrastructures and houses and provide technical support for emergency countermeasures on the day of the earthquake. To conduct emergency investigations of dams, the authors, all dam engineering experts, were dispatched to five dams damaged by this earthquake from June 14 through 16, 2008. This paper reports the results of the on-site survey of damage to and safety evaluation of the dams which were surveyed.

2. PROFILE OF THE EARTHQUAKE

The earthquake occurred at 8:43 am on June 14, 2008. The Japan Meteorological Agency (JMA) named the event the Iwate-Miyagi Nairiku

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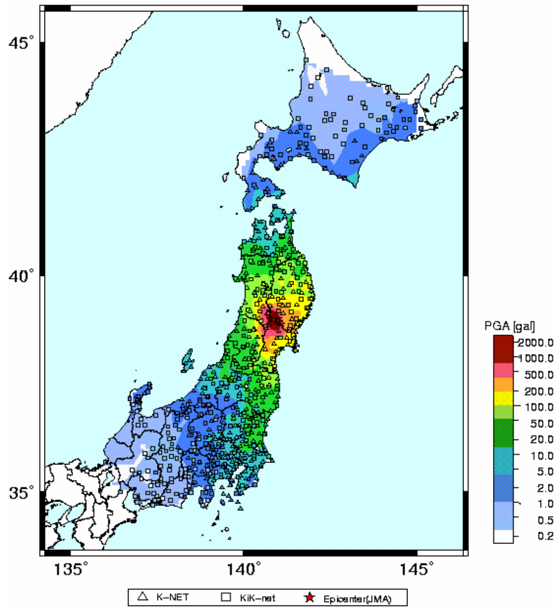

Fig.1 Peak ground acceleration contour map based on KiK-net and K-NET operated by NIED (NIED, 2008) [3]

Earthquake in 2008. Here, the term of "Nairiku" means inland. The magnitude of the event was estimated as 7.2 in the JMA scale and its epicenter was located at 39°01.7'N, 140°52.8'E, about 85 kilometres north of Sendai City and about 385 kilometres north-northeast of Tokyo. The depth of the epicenter is estimated at about 8km. The fault is a thrust fault in the compression in the WNW to ESE direction.

National Research Institute for Earth Science and Disaster Prevention (NIED) operates the strong motion instrumentation networks, K-NET and KiK-net. Strong motions were recorded at 330 and 325 stations respectively. Based on their data, a peak ground acceleration contour map was drawn as shown in Figure 1. The KIK-net station, IWTH25 almost on the earthquake fault recorded over 1g of peak acceleration at the location of underground level -260m where S-wave velocity is 1.8km.

3. SPECIAL SAFETY INSPECTION OF DAMS BY SITE OFFICERS

Immediately after the earthquake, special safety inspections of dams were made by the site officers within the river reaches administered under the River Act. The special safety inspections consisted of primary and secondary inspections; the former were visual inspections immediately after the earthquake, and the latter were detailed visual inspections and safety checks using data measured by installed instruments.

The primary emergency inspections were conducted at 134 dams, with secondary inspections performed at 77 of these dams. The results of the emergency inspection confirmed damage to the dam bodies and the slopes around dam reservoirs at 12 dams.

4. EMERGENCY INVESTIGATION OF DAMS BY TEC-FORCE EXPERTS

As a result of emergency inspections by dam site officers, of those dams reported to be damaged, the authors who were expert members of TEC-FORCE, performed site surveys of dams managed and operated directly by the national or prefectural government which were reported damaged, in response to requests by site officers to perform surveys. The on-site surveys were performed on June 15 and 16 at five dams operated by MLIT, Miyagi Prefecture, and Akita Prefecture. The locations of five dams surveyed are shown in Figure 2. The following are outlines of the results of the surveys of the five dams. Note that because this paper reports the results of the preliminary investigation, the information and the observed data could be corrected afterwards.

4.1 Ishibuchi Dam

Ishibuchi Dam is a concrete faced rockfill dam (CFRD) with a dam height of 53m completed in 1953, and managed by Tohoku Regional Bureau, MLIT. Figure 3 is the cross section and longitudinal section of the dam. The upstream concrete face maintains the watertightness of dam body of this type of dam. No severe damage was found in the concrete face and its joints shown in Photo. 1.

At the crest of the dam, the pavement was waved and cracked shown in Photos. 2 and 3. And gaps appeared on the boundary between the

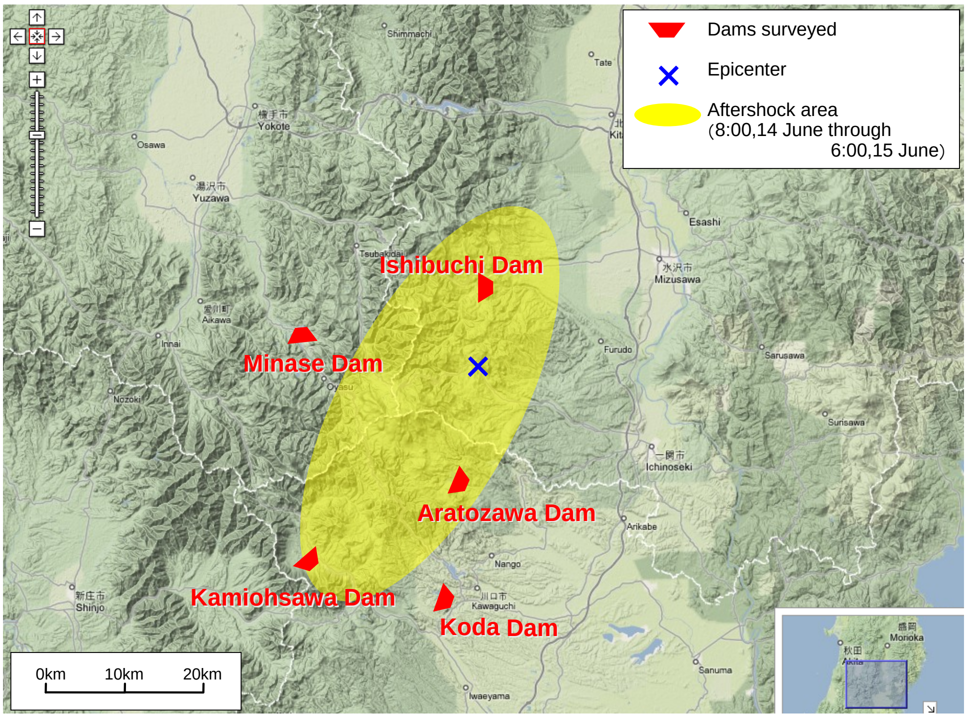

Fig. 2 Location map of the five dams surveyed immediately after the earthquake by TEC-FORCE experts

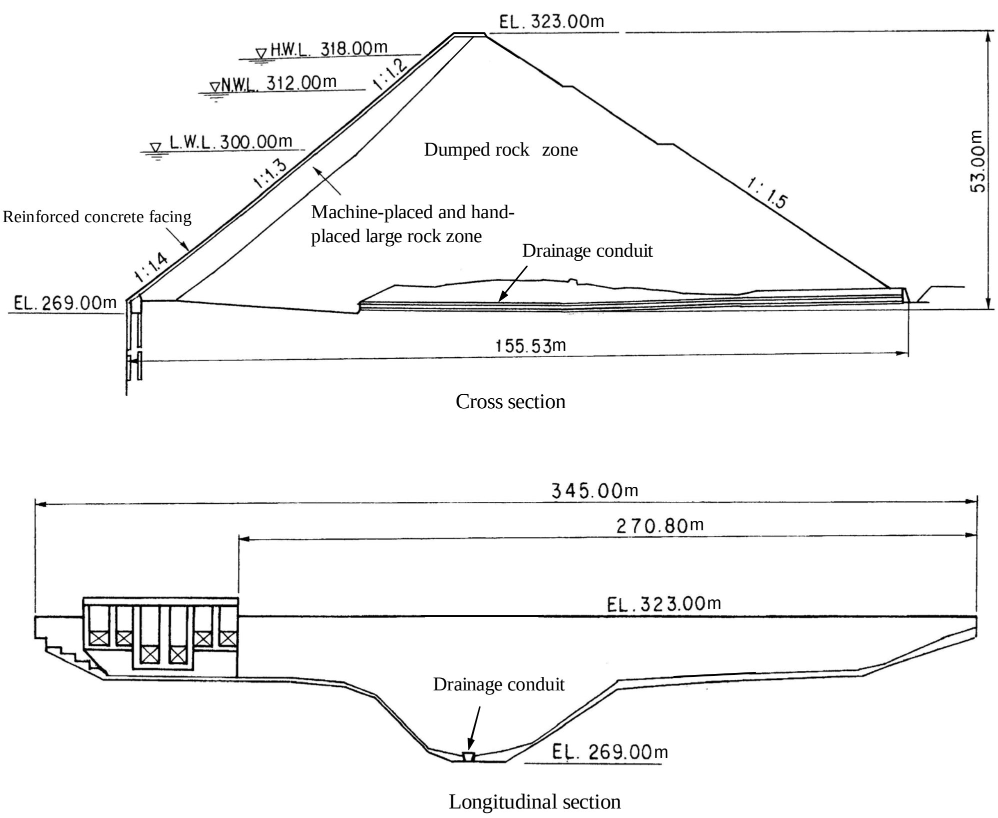

Fig. 3 Cross section and longitudinal section of Ishibuchi Dam

railing and pavement on the shoulder of the slope at the crest. On the downstream slope surface of the dam, projections were observed on the rock materials at the protruding parts of the wave on the crest pavement shown in Photos. 4 and 5, but damage of this kind was limited to high elevations. This dam was constructed by the dumped rock construction method as shown in Photo. 6 taken during construction. The piers for the railroad from where trucks dropped rock materials were left buried in the dam body. It is hypothesized that the whole dam body settled due to the earthquake, while the areas near the buried piers only settled a little. The maximum differential settlement is supposed to be about 50cm.

Leakage through the upstream concrete face and the shallow foundation, which is measured at the downstream slope toe, has increased since the occurrence of the earthquake. However, its amount was below the maximum amount which had ever been observed at the dam and has performed a stable behavior with a dependence on the reservoir level. Turbid leakage water was also observed after the earthquake, but it returned to normal after a few days.

A seismometer installed on the top of the downstream slope (elevation of the crest) recorded the maximum acceleration of 1,461 gal in the stream direction and 2,070 gal in the vertical direction, but this record might include

Photo.1 Concrete faced upstream slope on which no damage was found (Ishibuchi Dam) (Photographed by Public Works Research Institute (PWRI) on June 15, 2008)

Photo.2 Overview of the crest and downstream slope (Ishibuchi Dam) (Photographed by PWRI on June 15, 2008)

Photo.3 Cracks and waving of the crest pavement (Ishibuchi Dam) (Photographed by PWRI on June 15, 2008)

Photo.4 Gaps between the railing and pavement on the crest (Ishibuchi Dam) (Photographed by PWRI on June 15, 2008)

Photo.5 Projection of the riprap rocks around the top of the downstream slope (Ishibuchi Dam) (Photographed by PWRI on June 15, 2008)

Photo.6 Ishibuchi Dam under construction by the dumped rock method in 1950's (The piers of tramway were buried.) (Courtesy by Kitakami River Integrated Dam Management Office, MLIT)

local shaking of the large size rock on which the seismometer was installed, so further analysis is necessary.

Based on the results of emergency investigation, it was decided that no serious problems threatened the safety of the dam, but careful monitoring has been continued and the technical committee has been established to make a detailed survey to prepare for restoration of the dam.

4.2 Aratozawa Dam

Aratozawa Dam is an earth core rockfill dam (ECRD) with a dam height of 74.4m completed in 1998. It was constructed by Tohoku Regional Agricultural Administration Office, Ministry of Agriculture, Forestry and Fisheries (MAFF) and is managed by Miyagi Prefecture.

Photo.7 Huge landslides around the reservoir of Aratozawa Dam (Photographed by PWRI on June 15, 2008)

Huge landslides occurred around the reservoir on the left bank upstream from the dam. The largest landslide was 1.3km long, 0.8km wide, and approximately 67 million m^3 in volume as shown in Photo. 7 of an aerial photograph. Approximately 1.5 million m^3 of this landslide soil flowed into the reservoir. This corresponds to about 10% of the reservoir capacity of 14.13 million m^3.

Maximum settlement of about 20cm was measured at the upstream slope shoulder of the dam crest. The surveying target was installed on the rock zone surface. Because the pipe of a crossarm gauge protruded about 40cm shown in Photo. 8, it is hypothesized that the large settlement occurred at the core zone in the center of the crest rather than at the rock zone. Regardless of the large settlement, no conspicuous cracks were found on the crest pavement surface shown in Photo. 9. In addition, no deformation of the riprap on the upstream

Photo.8 The pipe of a crossarm gauge protruded, as a result of the settlement of the dam body (Aratozawa Dam) (Photographed by PWRI on June 16, 2008)

Photo.9 Few cracks in the crest pavement in spite of the dam body settlement (Aratozawa Dam) (Photographed by PWRI on June 16, 2008)

and downstream surfaces was found.
In the inspection gallery beneath the impervious core zone, a small amount of leakage was discovered through fine cracks in its ceiling and from the boundary between the upstream side wall and invert. And small openings caused by the earthquake were observed at the joints of blocks of the gallery.

The measured leakage through the dam body and shallow foundation increased immediately after the earthquake, but it was steadily declining by the time of our survey on June 16, 2008.

A seismometer installed in the dam foundation recorded earthquake motion dominant in the high frequency domain and maximum acceleration of about 1g in the stream direction. At the crest, a maximum acceleration of 525gal was recorded in the stream direction.

Based on the results of emergency investigation, it was judged that no serious problems threatened the safety of the dam at the time of our investigation. MAFF has established a technical committee and started a detailed survey to prepare for restoration of the dam.

4.3 Minase Dam
Minase Dam is a CFRD with a dam height of 66.5m completed in 1963. The surface concrete facing had already been repaired with asphalt paving for the appropriate watertightness. It was constructed by MILT (then Ministry of Construction (MOC)) and is managed by Akita Prefecture.

No cracks were confirmed on the pavement at the crest. Crest settlement of about maximum 14cm was observed, and at the connection of the spillway and the rockfill dam body, a level difference of about 15cm formed shown in Photo. 10. No deformation was confirmed on the upstream facing and the downstream rock slope surface.

The amount of leakage through the upstream concrete face and shallow foundation increased until 210L/min on the day after the earthquake, but after then it decreased with falling the reservoir level.

At the time of the investigation, it was decided that its condition was not in a state that would immediately threaten the safety of the dam.

4.4 Kamiohsawa Dam
Kamiohsawa Dam is an earthfill dam with a dam height of 19m completed in 2003. It was constructed and is managed by Miyagi Prefecture.

A few cracks with maximum width of 10mm occurred on the crest pavement. The L-shaped curbstones on the crest were pushed up at one place. Maximum settlement of 14.4cm was observed at the dam crest, but this is hypothesized to be largely an impact of foundation settlement whose maximum value is 14.8cm.

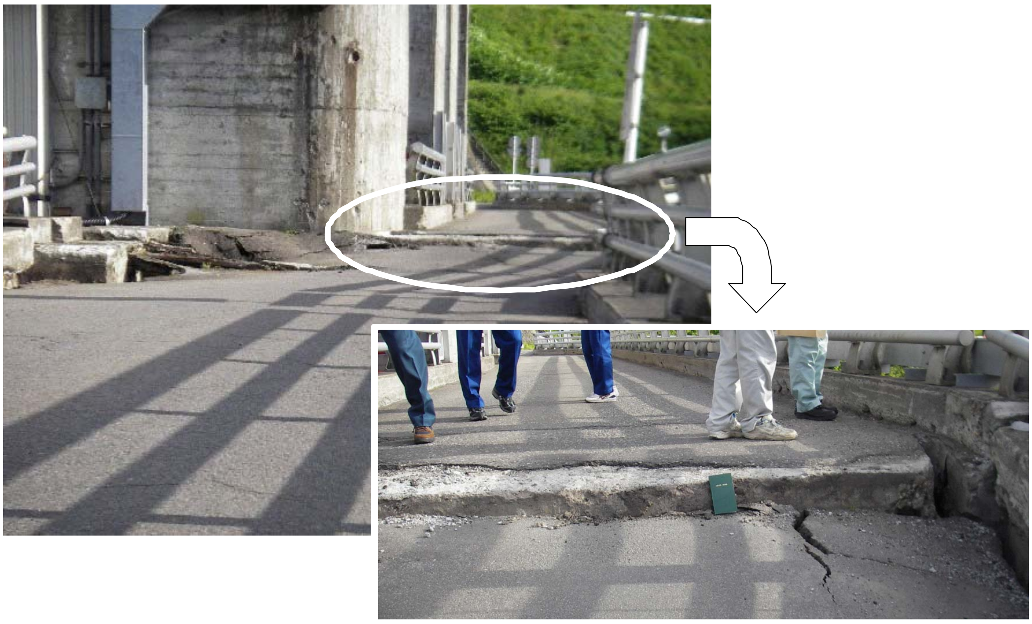

Photo.10 Level difference occurred at the connection of the spillway concrete and the rockfill dam body as a result of the settlement of the dam body (Minase Dam) (Photographed by PWRI on June 15, 2008)

Leakage increased by about 10L/min from 27.27L/min before the earthquake to a maximum of 39.34L/min after the earthquake, but it had stabilized by the time of our survey on June 15, 2008.

It was judged that the no conditions which could threaten the safety of the dam existed.

4.5 Koda Dam

Koda Dam is an ECRD with a dam height of 43.5m completed in 2005. It was constructed by Tohoku Regional Agricultural Administration Office, MAFF and is managed by Miyagi Prefecture.

The settlement at the crest was a maximum of 3.8cm and the horizontal displacement in the stream direction was a maximum of 5 to 6cm, but the horizontal displacement in the dam axis direction was a little large at a maximum of about 13cm. And the curbstones on the crest were partially damaged by compression as shown in Photo. 11. No conspicuous cracks were, however, found on the crest pavement. And the riprap on the upstream and downstream sides was free of any deformation.

Photo.11 The damaged curbstone on the crest shoulder (Koda Dam) (Photographed by PWRI on June 16, 2008)

Leakage doubled from 90.8L/min before the earthquake to a maximum of 194.4L/min. after the earthquake, but at the time of our survey on June 16, 2008, it was gradually decreasing. The turbidity of the leakage rose after the earthquake, but was tending to decline by the time of our survey.

It was judged that there were no conditions which could threaten the safety of the dam.

5. CONCLUSIONS

The Iwate-Miyagi Nairiku Earthquake of 2008 did not cause any damage to dams which were severe enough to possibly threaten their safety. This verifies the high level of seismic resistance of the dams.

Based on the results of the emergency inspections of the dams by the site officers immediately after the earthquake, dam engineering experts carried out site investigation at the five dams where damage had been found. According to the preliminary investigation, no problems severe enough to threaten the structural safety of any of the five dams were found. At present, repair works for damaged dams have already been started or finished based on the results of detailed inspections and surveys.

In Japan, dam sites are selected after a detailed geological survey. The dams are designed by performing careful structural analyses based on the design criteria, and are constructed under strict management with high quality materials. These careful survey, design and construction efforts help to ensure the safety of the dams. However, dams are large, important structures which must not fail. This earthquake caused the most severe damage to dams of any earthquake which has occurred in Japan in recent years. In the seismic acceleration observed at the dams, although the high frequency range was dominant, the maximum acceleration level was the highest ever recorded. Based on these facts, in the future, we plan to perform detailed surveys of the effect of this earthquake to dams and reflect the findings in development of future seismic research and technology for dams.

6. ACKNOWLEDGEMENTS

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