Behavior of Dams due to The Western Tottori Prefecture Earthquake in 2000

By

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ABSTRACT

The Western Tottori Prefecture Earthquake of October 6, 2000 caused strong earthquake motion over a wide area. Immediately after the earthquake, dam management personnel carried out special safety inspections of dam facilities in the region. Research engineers of the Public Works Research Institute performed field investigation of dams near the epicenter and gathered the earthquake observation data of these dams. The results of the special safety inspections by the dam site offices and field investigation by the PWRI have confirmed that no damage harming dam safety occurred.

KEY WORDS: Western Tottori Prefecture Earthquake, Dam, Special Safety Inspection, Acceleration Records

1. INTRODUCTION

Immediately after the Western Tottori Prefecture Earthquake in 2000, dam management personnel carried out special safety inspections of dam facilities in the region shaken strongly. Research Engineers of the PWRI performed field investigation of dams near the epicenter and gathered the earthquake observation data of these dams. This report summarizes the performance of the dams during the earthquake.

2. SPECIFICATIONS OF EARTHQUAKE

The specifications of the earthquake published by the Japan Meteorological Agency are summarized in Table 1

This earthquake caused strong shaking in the Chugoku, Kinki, and Shikoku regions in Japan. It recorded a seismic intensity of 6 (strong) in Sakaiminato City and Hino Town in Tottori Prefecture, 6 (weak) in Saihaku Town, Aimi Town, Kishimoto Town, Yodoe Town, Mizokuchi Town, and Hiezu Village in Tottori Prefecture, and 5 (strong) in Yonago City in Tottori Prefecture, in Yasugi City, Nita Town, and Shinji Town in Shimane Prefecture, in Niimi City and Tetta Town in Okayama Prefecture, and in Tonosho Town in Kagawa Prefecture.

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3. SPECIAL SAFETY INSPECTIONS OF DAMS AFTER EARTHQUAKE

Immediately after the earthquake, the site offices of the dams performed special safety inspections within the river reaches administered under the River Act. The inspections were conducted at dams which recorded an acceleration of 25 gal or greater by seismometers and dams where the nearest station of the Japan Meteorological Agency recorded a seismic intensity of 4 or greater. The special safety inspection included a primary inspection that was a visual inspection immediately after the earthquake and a secondary inspection that was a detailed visual inspection accompanied by analyzing the data measured by instruments.

A total of 180 dams were included in the special safety inspections: 119 dams in the region of the Chugoku Regional Construction Bureau, 31 dams in the region of the Shikoku Regional Construction Bureau, and 30 dams in the region of the Kinki Regional Construction Bureau. The special safety inspections by dam site offices did not result in any reports of damage that could threaten the safety of a dam. But the slight damages were reported from the Kasho Dam managed by Tottori Prefecture (a concrete gravity dam with a height of 46.4 m, completed in 1989) and the Sugesawa Dam managed by the Ministry of Land, Infrastructure and Transport (main dam: a concrete gravity dam with a height of 73.5 m, saddle dam: concrete face rockfill dam with a height of 17.0 m, completed in 1968). Figure 1 shows the locations of the epicenter and the two dams.

1) Damages to the Kasho Dam

- Cracking of the walls and the foundation of the guard gate house
- Sliding of the mountain-side slope of the road on the right bank
- Settlement of pavement around the dam management office building

2) Damages to the Sugesawa Dam

- Cracking of the walls and the floor of the guard gate house
- Chipped concrete on the downstream surface of the dam body (length of about 1 m and width of about 0.3 m)
- Partial rupture of the foundation work of the mooring facility
- V-shaped crack on the ground around the garage on the right bank downstream from the dam (length of about 100 m)
- Cracking of the wall of the garage shed on the right bank downstream from the dam
- V-shaped cracking on the left bank slope upstream from the dam
- Cracking of the surface of the wall of the dam management office building on the right bank

4. FIELD INVESTIGATION

(1) Dams

We, research engineers of the PWRI, performed a field investigation of dams near the epicenter. The followings are a summary of the results of the investigation.

At the Kasho Dam (Photograph 1), the earthquake caused peak accelerations at the lower inspection gallery of 529 gal (north/south direction), 531 gal (east/west direction), and 485 gal (vertical direction). At the elevator tower at the crest elevation (Photograph 2), the peak accelerations were 2,051 gal (north/south direction), 1,406 gal (east/west direction), and 884 gal (vertical direction). The stream direction is 20 degrees east from north. At this dam, the wall (Photograph 3) and the foundation of the guard gate house that was a cantilever structure projecting upstream from the dam crest were cracked. But the drainage from the foundation, dam body leakage, and displacement of the dam body had stabilized so that there were no problems threatening the dam's safety. The water level in the reservoir dropped abruptly by 6 cm immediately after the earthquake. The level measurement, conducted at a later time, revealed that the upper end of the reservoir subsided about 20 cm as compared with the dam by the quake. It would be a possible reason for the dropping of water level of the reservoir.

The repairing works are planned to come into force shortly by Tottori Prefecture.

At the Sugesawa Dam (Photograph 4), in the lower inspection gallery of the dam, the peak accelerations were 158 gal (downstream/upstream direction), 126 gal (right bank/left bank direction), and 109 gal (vertical direction). On the walls and the floor of the guard gate house that is a cantilever structure projecting upstream from the dam crest (Photograph 5), there were cracks that appeared to be extensions of the transversal joints of the dam (Photograph 6), and concrete on the dam's downstream surface was partially chipped (Photograph 7), but the no trouble of dam body was observed. Although the drainage from the foundation increased slightly immediately after the earthquake, it later stabilized. Near the dam and in the natural ground surrounding the reservoir, ground deformation caused cracking (Photograph 8). The Chugoku Regional Construction Bureau has been monitoring the situation and counter-measures will be conducted by the end of this year.

The Uh Dam (Photograph 9) is a regulating reservoir for the Ohmiya Dam that is for power generation and owned by the Chugoku Electric Power Co. and located upstream from the Sugesawa Dam. This dam is a concrete gravity dam with a height of 14 m and a crest length of 34 m. Figure 2 shows its standard cross section. It is located about 1 kilometer from the fault estimated by the Geographical Survey Institute, Japan[1)] (hereafter called the "earthquake source fault"). During the earthquake, its reservoir water level was about 2 m below the full water level. The Hino Observation Station of the Digital Strong-Motion Seismograph Network (KiK-net) [2)] owned by the National Research Institute for Earth Science and Disaster Prevention is located 20 m from the Uh Dam. At this location, seismographs installed at the surface (S wave velocity of 210 m/s) and the underground (100 m below the surface, S-wave velocity of 790 m/s) recorded earthquake motion with a peak accelerations (combination of 3 constituents) of 1,135 gal and 607 gal respectively. Although the dam was subjected to this strong earthquake motion, the only damage to the dam was cracking with a width of 1 to 2 cm on the spillway channel near the foot of the downstream slope (Photographs 10). The embankment along the lakeside had slips caused small cracks. In addition, because of damage to the water supply facilities for power generation, after the earthquake, the water supply from the Ohmiya Dam to the Uh Dam was shut off and discharged into the reservoir of the Sugesawa Dam.

(2) Small earth dams for irrigation

It was reported that this earthquake damaged about 40 small earth dams for irrigation in Tottori Prefecture. Thirty-six of these small earth dams were in Saihaku Town, Hino Town and Mizokuchi Town that are close to the epicenter. Main damage of about half of them was damage to inclined sluiceways, bottom sluiceways and spillways.

We performed a field investigation of 18 small earth dams that were assumed to have suffered relatively serious damage or were located extremely close to the epicenter. Figure 3 shows the locations of the investigated dams, and Table 2 shows their specifications and outlines of their damage. For example, Photograph 12 shows sliding of the upstream slope of the Kanayatani Dam in Mizokuchi Town. Almost all the damage to the dam bodies was longitudinal cracking at the crest or settlement of blocks on their upstream slopes. At three dams among them, the reservoir water level was reduced considering the safety of dams.

The above earthquake damages are much less serious than the damages to earth dams due to the Kobe Earthquake (the Hyogoken-Nambu Earthquake) in 1995 [3]. We estimated that one of main reasons for this is the stiffer foundation of the dams. Many of the earth dams close to the earthquake source fault were located in mountainous and hilly area, but few of them were bank on alluvium such as that on Awaji Island or the basin of the Kakogawa River where the Kobe Earthquake damaged many small earth dams.

5. EARTHQUAKE ACCELERATION

(1) Attenuation of peak acceleration of dam sites

Figure 4 shows the attenuation by distance from the earthquake source fault of the peak horizontal acceleration measured at dam foundations (at the lower inspection gallery in a concrete dam or at the inspection gallery beneath an embankment dam). Where, the peak horizontal acceleration indicates composing the two horizontal components. The figure also shows the composite of peak horizontal accelerations recorded under the ground at a depth of 100 m at the Hino Observation Station and Hakuta Observation Station of the KiK-net[2]. The S-wave velocities at the two underground observation sites were 790 m/s and 2,800 m/s respectively. They are hard enough to become the foundation for a dam, although it differs according to the type and scale of a dam.

(2) Records at the Kasho Dam

Figure 5 shows the locations of seismographs installed in the Kasho Dam, and Figure 6 shows the time history of the acceleration measured at the lower inspection gallery and the crest of the Kasho Dam. In addition, Figure 7 shows the acceleration response spectra recorded at the inspection galley in case damping ratio is 5%. The response spectrum with a frequency of 0.1 seconds or less dominates in the east/west component that has the greatest response.

6. SUMMARY

The results of the special safety inspections by the dam site offices and the field investigation by the PWRI have confirmed that no damage harming dam safety occurred. But at dams where the some troubles were happened in the dam body, related facilities of dam, or the ground around the reservoir, and at dams where the foundation drainage, dam body leakage, or uplift pressure increased, it will be necessary to observe their behavior very carefully during the reservoir water level rising in the future. At the Kasho Dam, large earthquake acceleration was recorded. Its earthquake records should be analyzed to study the relationship of the earthquake motion generated by the Western Tottori Prefecture Earthquake with the behavior of the dams.

REFERENCES

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2) Web page of the KiK Network of the National Research Institute for Earth Science and Disaster Prevention, http://www.kik.bosai.go.jp/kik/.

3) Tomoya IWASHITA, Norihisa MATSUMOTO, Akira NAKAMURA, Hitoshi YOSHIDA and Shinji YOKOYAMA: "Factor Analysis of Damage to Small Earth Dams due to the 1995 Hyogoken-Nambu Earthquake", Proc. of the Fourth International Conference on Case Histories in Geotechnical Engineering, Paper No.3.07, pp.579-586, Univ. of Missouri-Rolla, 1998.

Table 1 Specifications of the Western Tottori Prefecture Earthquake (Published by the Japan Meteorological Agency)

Name of earthquake	The Western Tottori Prefecture Earthquake in 2000
Time of occurrence	1:30 p.m. on October 6, 2000
Epicenter	35°16.5'north latitude 133°21.0' east longitude
Focal depth	11.3 km
JMA Magnitude	7.3

Table 2 (1) Specifications and Outline of Damage of the Investigated Small Earth Dams for Irrigation

#	Name of Earth Dams	Location	Distance from Source Fault (km)	Bedrock geology	Topography	Dam height (m)	Dam length (m)	Crest width (m)	Upstream slope gradient	Downstream slope gradient	Dam body material	Direction of the dam axis (right abutment)	Year con-structed	State of damage
1	Kinusako	Saihaku Town	0.2	Miocene Volcanic rocks	Mountainous	15	65	4	1:2.4	1:2.4	Red clay	N66°W	Around 1910	- Lateral cracking on upstream slope on the left and right abutments
2	Tsubakitani	Saihaku Town	0.3	Alluvial layer and Miocene volcanic rocks	Mountainous	15.2	76.2	5.8	1:2.6	1:2.1		N86°E	1885	- Two longitudinal cracks on the center of the dam crest and on the shoulder of the upstream slope
3	Natsuyake	Saihaku Town	1.7	Alluvial layer	Hilly		50	4	1:1.7	1:2.1	Red clay	S88°W		- As a result of upstream slope surface concrete block settlement of 10 cm and bulging on the downstream side, pushing out of top concrete blocks on the retaining wall at the slope toe
4	Saigatoge	Saihaku Town	1.7	Miocene Volcanic rocks	Mountainous	4.5		2.8	1:1.6	1:2.0	Decomposed weathered granite	N66°W		- Longitudinal cracks with length of 16 cm on shoulder of the upstream slope at the crest
5	Sugegatani	Saihaku Town	0.9	Late Mesozoic rocks	Hilly	6	21	2.5	1:2.0			S26°E		- Leaking from the boundary of the left abutment and toe of the slope of the dam body (it is not clear if the earthquake caused it.)
6	Yomegoroshi	Saihaku Town	0.9	Late Mesozoic rocks	Hilly	18	65		1:1.2	1:2.0		N85°E	1926	- No damage caused by the earthquake was found.
7	Ohsako	Saihaku Town	0.8	Late Mesozoic rocks	Mountainous									- Slide of 7 m long of the road on the reservoir bank
8	Kamakura No.1	Hino Town	0.4	Alluvial layer a and Late Mesozoic rocks	Mountainous	3	100	4.6	1:1.7			N0°		- Breaking of the concrete of the inclined sluiceway - Local cracking of the boundary between dam body and left abutment because of the dam crest settlement of 15 cm
9	Kamakura No.2	Hino Town	0.4	Late Mesozoic Rocks	Mountainous	4	50	2.5	1:1.7			N18°W		- No damage caused by the earthquake was found.

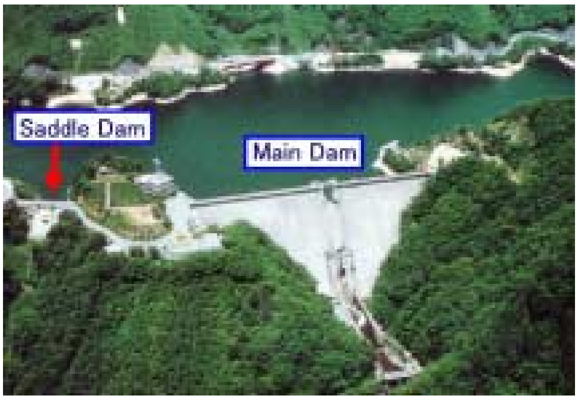
Table 2 (2) Specifications and Outline of Damage of the Investigated Small Earth Dams for Irrigation

#	Name of Earth Dam	Location	Distance from Source Fault (km)	Bedrock geology	Topography	Dam height (m)	Dam length (m)	Crest width (m)	Upstream slope gradient	Downstream slope gradient	Dam body material	Direction of the dam axis (right abutment)	Year con-structed	State of damage
10	Odazu	Hino Town	2.3	Diluvial talus deposit layer	Mountainous			4		1:1.2		S52°W		- Cracking of concrete of the spillway channel wall
11	Yoshi	Hino Town	2.1	Diluvial talus deposit layer	Mountainous							S20°E		- Longitudinal crack with a length of 15 m on the shoulder of the upstream slope of the dam crest
12	Toge	Hino Town	4.6	Late Mesozoic rocks	Mountainous		55	3	1:1.7	1:1.5		N75°E		- Longitudinal cracking with a length of 3 m on the shoulder of the upstream slope at the crest and cracking on the steps along the inclined sluiceway
13	Iwaya	Hino Town	2.4	Diluvial talus deposit layer and Late Mesozoic rocks	Mountainous		40	3.5	1:2.2			S88°W		- Cracking of the concrete of the spillway channel and cracking of the asphalt on the reservoir bank road
14	Kanayatani	Mizokuchi Town	14.1	Diluvial volcanic rocks	Flat land	4	40×50×40	2.2	1:1.6	1:1.4	Decomposed weathered granite	N8°E		- Longitudinal crack over the full length of the crest, collapse of concrete blocks, bulging of the upstream slope, and breakage of the inclined sluiceway caused by the slippage of the dam body towards the reservoir
15	Kumagayaue	Mizokuchi Town	7.4	Late Mesozoic rocks	Hilly	11	55	3	1:1.7	1:2.1		N12°E		- An 8 m long slip down of the reservoir cliff
16	Neubara	Mizokuchi Town	12.3	Alluvial layer and Late Mesozoic rocks	Hilly		65	3	Almost vertical because of erosion	1:1.6		N10°W		- Longitudinal cracking on the shoulder of the upstream slope at the crest
17	Choryuji	Mizokuchi Town	7.6	Late Mesozoic rocks	Mountainous	8	18	3.5	1:1.7	1:1.6		S45°W		- Two longitudinal cracks on the shoulder of the upstream slope at the crest, one longitudinal crack on the shoulder of the downstream slope, 4 cm settlement of concrete blocks on the upstream slope
18	Tomie-shin	Mizokuchi Town	14	Diluvial volcanic rocks	Hilly	4	40	3.5		1:1.4		N8°W		- Gap of 3 cm between the spillway channel wall and the dam body, and leaking from the toe of the downstream slope (It is not clear if it was caused by the earthquake.)

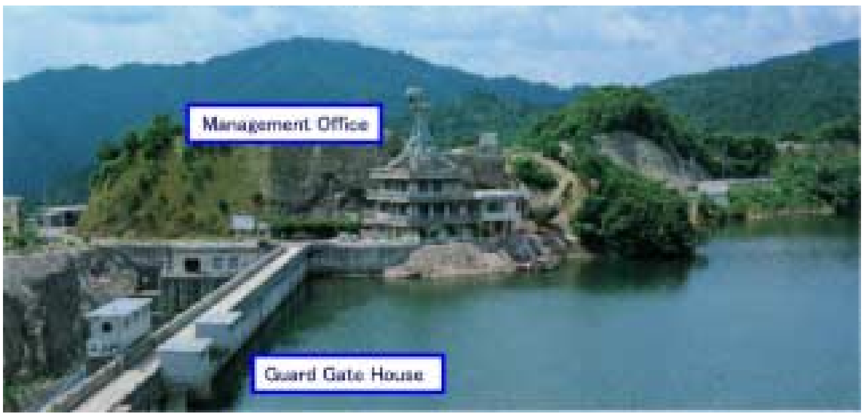
Photograph 1 View of the Kasho Dam

Photograph 2 Elevator Tower and Guard Gate House of the Kasho Dam

Photograph 3 An Example of Cracks on Wall of Guard Gate House of the Kasho Dam (exterior wall surface on the right bank side)



Photograph 4 View of the Sugesawa Dam



Photograph 5 Upstream Surface and Guard Gate House of the Sugesawa Dam

Photograph 6 Cracking on Wall of Guard Gate House of the Sugesawa Dam
(interior wall surface on the downstream side)

Photograph 7 Chipped Concrete on Downstream Surface of the Sugesawa Dam

Photograph 8 An Example of Cracks in Ground Near the Sugesawa Dam
(near the garage on the downstream right bank)

Photograph 9 Downstream View of the Uh Dam

Photograph 11 Cracking on the Spillway Channel Wall of the Uh Dam

Photograph 12 Damage to the Kanayatani Dam

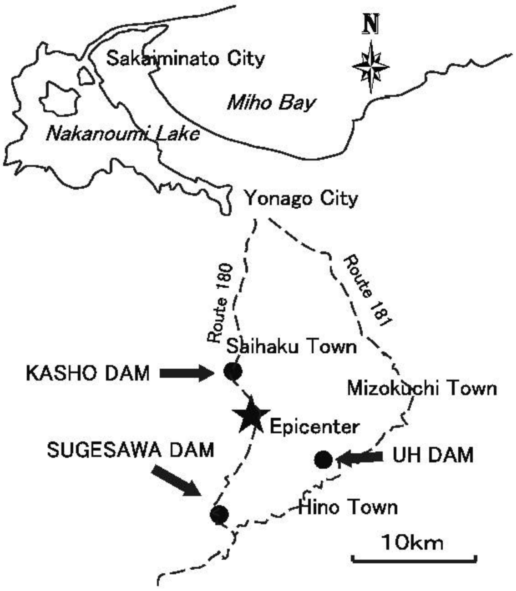


Figure 1 Locations of the Epicenter and the Dams Investigated by the PWRI

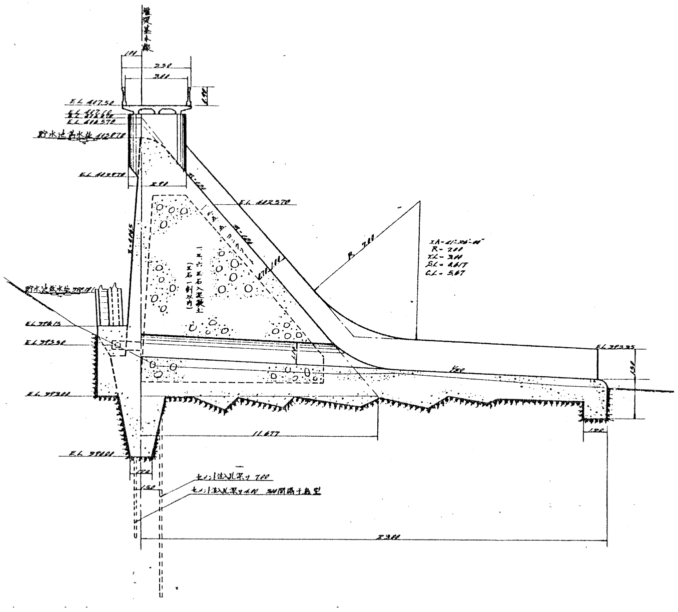


Figure 2 Cross Section of the Uh Dam

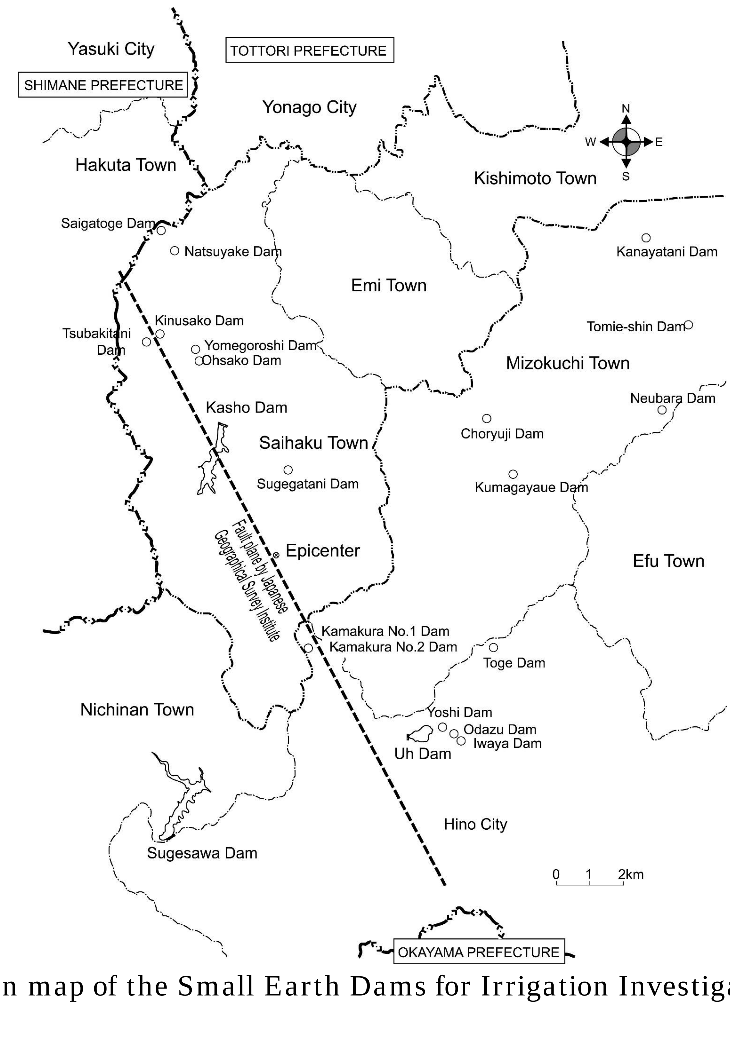


Figure 3 Location map of the Small Earth Dams for Irrigation Investigated by the PWRI

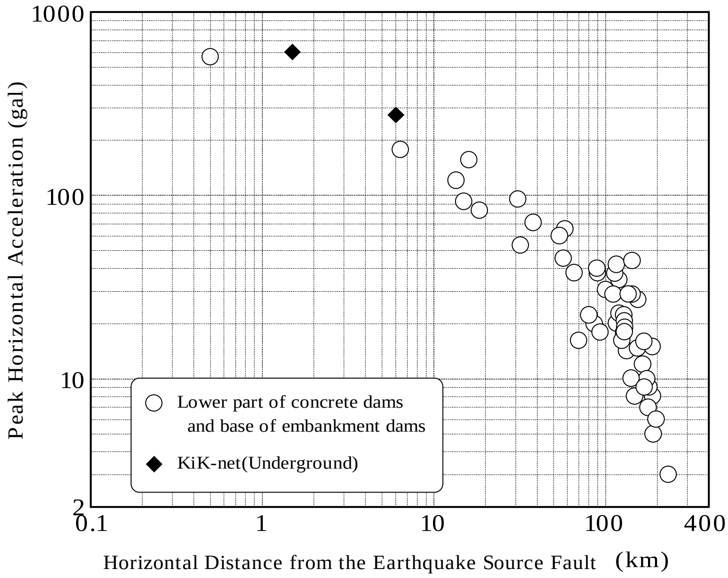
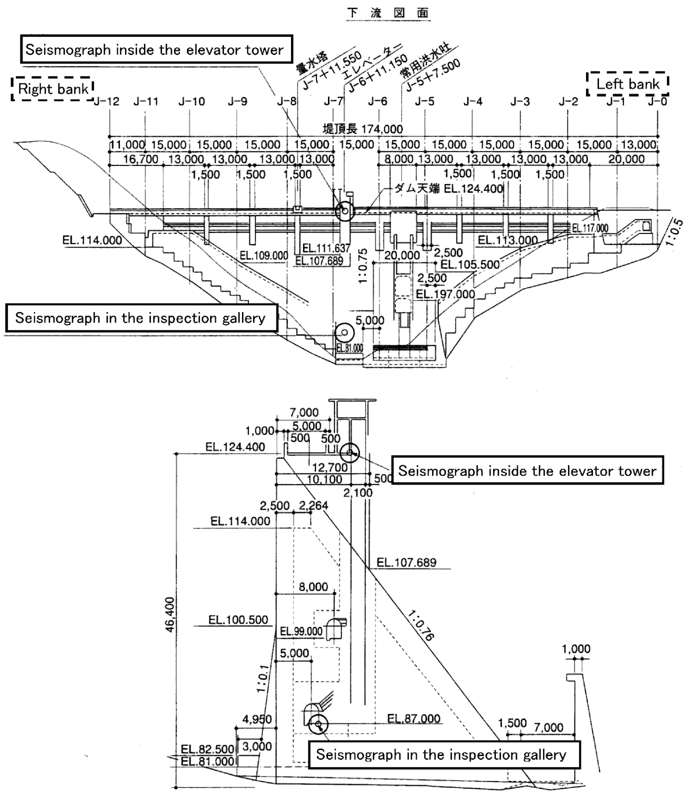
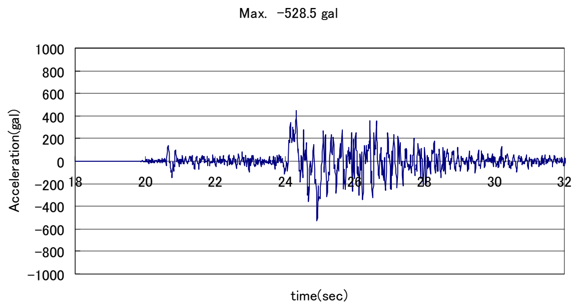


Figure 4 Attenuation of Peak Horizontal Acceleration Observed in Dam Foundations
(including data obtained at the lower inspection gallery in concrete dams
or at the inspection gallery beneath embankment dams)

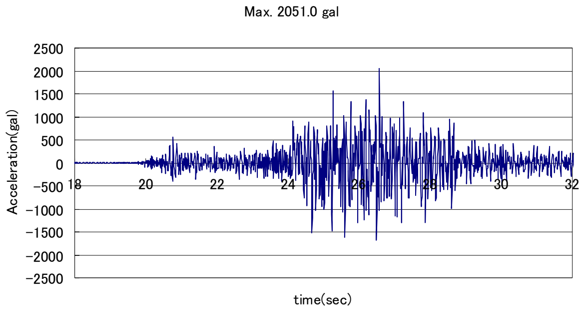


(unit: m)

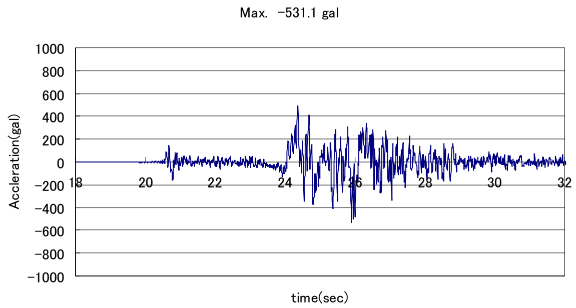
Figure 5 Downstream View and Cross Section of the Kasho Dam
and Locations of Seismographs



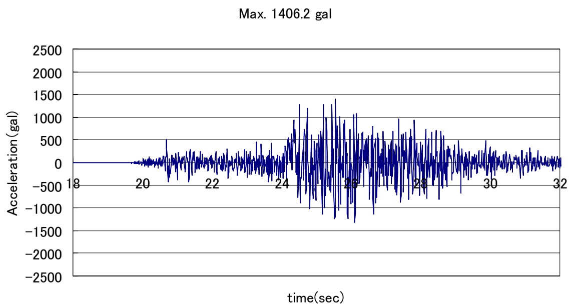
(a) North/south



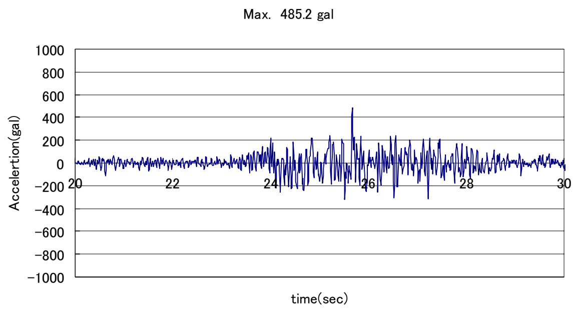
(a) North/south



(b) East/west

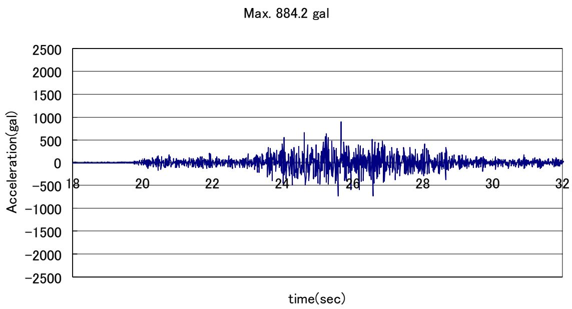


(b) East/west



(c) Up/down

(1) Lower Inspection Gallery



(c) Up/down

(2) Elevator Tower at Crest Elevation

Figure 6 Earthquake Records at the Kasho Dam

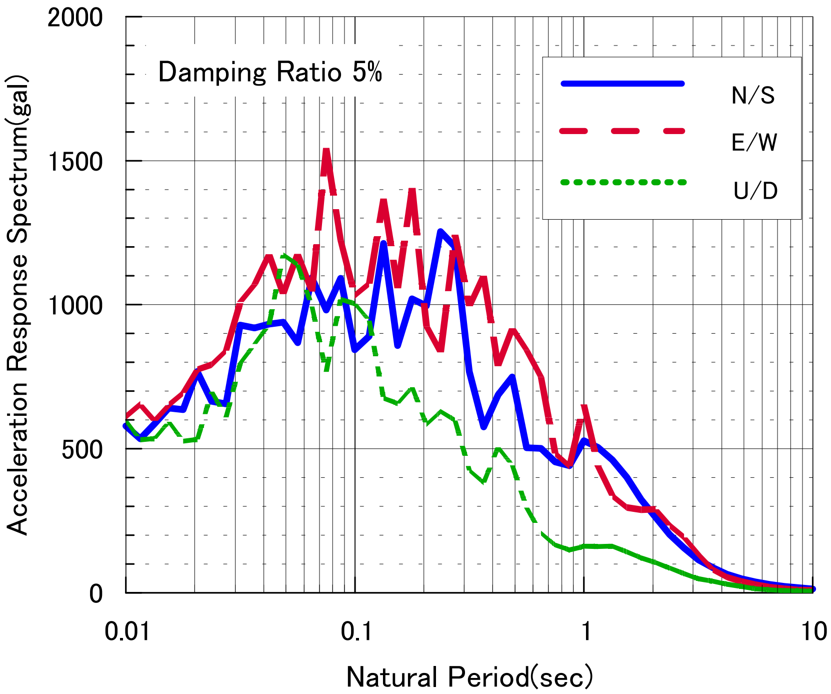


Figure 7 Acceleration Response Spectra at Lower Inspection Gallery of the Kasho Dam