Effects of the Mid Niigata Prefecture Earthquake in 2004 on dams

by

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ABSTRUCT

Due to the Mid Niigata Prefecture Earthquake that occurred in October 2004, several embankment dams and other off-stream impounding facilities for irrigation and power generation located near hypocenter of the earthquake were suffered some changes in condition or damage such as cracks on their dam bodies.

In this paper, results of site investigations on the changes in condition or damage found at dams and regulating reservoirs after the earthquake are reported. The records of strong earthquake motion observed at the dam sites near hypocenter of the earthquake are also indicated and discussed.

KEYWORDS：the Mid Niigata Prefecture Earthquake in 2004, dam, site investigations, earthquake motion

1. INTRODUCTION

Just after the main shock of the Mid Niigata Prefecture Earthquake that occurred at 17:56 JST on October 23, 2004, management office conducted emergency inspections. As a result, although many dams showed no changes in condition or damage, six facilities located in the area of Ojiya City, Tokamachi City and Kawanishi Town showed changes in conditions (see Table .1). The National Institute for Land and Infrastructure Management (NILIM) and the Public Works Research Institute (PWRI) dispatched investigation team to detect changes in condition, details of changes, and the amounts of changes in deformation and leakage/seepage caused by the earthquake. The investigations at several dams revealed changes in the conditions, such as cracks. In order to ensure the safety of dam bodies, therefore, reservoir water level was lowered at some facilities.

2. OUTLINE OF THE SITE INVESTIGATIONS

Fig. 1 shows the locations of the investigated dams, which are shown in Table 2, and the epicenter. The main purposes of the investigations were to verify the occurrence or nonoccurrence of earthquake-induced changes in the conditions of the dams in detail, collect earthquake motion records, investigate dam deformation and changes in leakage/seepage rates, and identify the tendencies of such changes, if any. This report focuses on the earthquake-induced changes and damage to the regulating reservoirs for power generation of East Japan Railway Company (JR East) and the embankment dams built for irrigation purposes that have been suffered relatively large changes in condition. The report also deals with the recorded earthquake motions at dam sites located near the hypocenter of the earthquake.

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3. INVESTIGATION RESULTS AND DISCUSSION

3.1 Investigation Results

3.1.1 Regulating Reservoirs for Power Generation

At JR East's Shinanogawa Power Station, water diverted by Miyanaka Diversion Dam built on the main stream of the Shinano River is sent to three regulating reservoirs, which are Asagawara, Shin-Yamamoto and Yamamoto Regulating Reservoirs. Stored water in these reservoirs is used to generate the power plants to supply electric power for the operation of Joetsu Line and other trains in the Kanto region including the Tokyo Metropolitan Area. Fig. 2 shows the layout of the main facilities related to the Shinanogawa Power Station.

(1) Asagawara Regulating Reservoir

Fig. 3 shows a plan and a typical cross section of the Asagawara Regulating Reservoir.

At this reservoir, a number of cracks parallel with the embankment axis have been found at the crest of the dam body. Cracks are staggered and are more or less continuous, and the crack occurred area extends almost over the entire length (292 m) of the embankment. These cracks have caused stepping so that the reservoir side of the embankment has subsided (see Photos 1 and 2). The total difference in elevation at the cracks is up to about 70 cm, and the maximum crack width of a single crack is about 40 cm. Elevation differences at the cracks and the magnitudes of crack openings are larger in the middle section of the embankment and smaller in the sections closer to both abutments, where dam height is smaller.

Surveying performed by management office to investigate the deformation of the dam revealed that the earthquake did not cause significant settlement in the area downstream (opposite side of the reservoir) of the crest cracks, and the survey results indicated the possibility of settlement to the upstream side (reservoir side). Since, however, the control points for monitoring might have moved due to the earthquake, more detailed investigation is necessary.

Neither the upstream face nor the downstream face shows any earthquake-induced changes such as bulging or cracking. Since, however, reservoir sedimentation has already reached the riprap zone, the condition below the sediment level on the upstream side cannot be observed.

After the investigation conducted on October 25, the cracked areas were covered with vinyl sheeting, as a temporary measure, to prevent further progress of anomalous conditions caused by seepage of rainwater into the cracks (see Photo 3).

It has been reported that JR East, managing the reservoir, will investigate and analyze the extent of the crack zone and the mechanisms of the earthquake-induced changes and conduct repairs accordingly.

Crest cracks parallel with the dam axis occurred at Makio Dam [2] during the Western Nagano Prefecture Earthquake in 1984 and at Takami Dam [3] during the Tokachi-oki Earthquake in 2003. Crack depth surveys showed that those cracks occurred only in the protective surface layers and did not reach the impervious core zones. So, after confirming these results, the protective layers were repaired. At these dams, there were open crest cracks caused by strong motions in the upstream–downstream direction, but vertical displacement (stepping) as extensive as the one observed at the embankment of the Asagawara Regulating Reservoir was not observed. The fact that vertical displacements of up to 70 cm have occurred on the surface indicates that the cracked area inside the embankment could be considerably deep. Detailed information can only be obtained from the results of detailed survey investigations to be conducted by JR East, but extensive repairs might be necessary depending on the degree of impervious core damage. Currently, a committee on detailed investigations of the embankment damage of the three regulating reservoirs and countermeasures for rehabilitation is in session.

The earthquake occurred while water was being conveyed to the reservoir, and the conveyance of water was stopped when the earthquake occurred. Because of stoppage of power supply, however, the gate for emergency discharge of drawdown from reservoir could not be opened immediately. As a result, the water remaining in the water tunnel flowed into the reservoir so that the reservoir water level became high temporarily (see Photo 4). It has been reported that generators were then brought in to open the gate for discharge, and the reservoir was emptied in about one day, and in view of the damage conditions and the water storage conditions, evacuation requests for adjacent areas were issued immediately. This case makes us recognize anew the importance of providing dams with drawdown facilities and non-utility generation facilities.

With respect to seepage, neither changes in seepage rates nor turbidity caused by the earthquake have not been reported, but because of the repeated aftershocks, continuous seepage rate measurement has not been conducted for ensuring the safety of inspectors.

Visual inspection did not reveal major damage to intake facilities.

(2) Shin-Yamamoto Regulating Reservoir

Fig. 4 shows a plan and a typical cross section of the Shin-Yamamoto Regulating Reservoir.

Many cracks running across the reservoir to the outside were found on the asphalt pavement at the crest of the embankment. The maximum crack opening width was 2–3 cm.

There was also an area where the crest pavement is noticeably inclined toward the reservoir (see Photo 5).

There was also a 100-meter-long crack along the embankment axis at about one meter below the outside edge of the embankment crest, and it seemed that the embankment above the fracture had subsided partially(see Photo 6).

The riprap zone on the reservoir side slope has been stepping (see Photo 7). Although the depth of the fault is unknown, slip may have occurred. Overturned boulders indicating the possibility of sand boiling were found in the lower-elevation area in the riprap zone.

From these results, it can be inferred that the earthquake caused settlements of up to several tens of centimeters in the area near the shoulder of the reservoir-side (upstream) slope where the largest amount of crest settlement were observed. The deformation occurred possibly in such a manner that the crest region leaned in the direction to the reservoir side. Such deformation agrees with the results of a study [4] on the type of damage caused by a large earthquake to a rockfill dam with an impervious core, conducted through centrifuge model testing and elastoplastic analysis performed by the effective stress method. The facts, however, will be revealed by detailed investigations to be conducted by management office.

The mid-elevation region of the outside slope has a scarp zone that is thought to be the head of a sliding block and a bulging zone that is thought to be the toe of the sliding block (see Photo 8). This region measures about 5 m in the direction of the embankment cross section by several tens of meters in the embankment axis direction. From the fact that the trench at the toe of the embankment slope was not moved, it can be inferred that the slip occurred only in a relatively small mid-slope region, but more detailed investigation is necessary.

The dam structure is a relatively new rockfill dam with center core completed in 1990, so the dam is instrumented with various sensors and instruments for the purpose of monitoring including embedded instruments, such as piezometers, earth pressure cells and differential settlement gauges, and a total of six seismographs (four at the crest and two at the toe of the downstream slope). The results of behavior analyses being performed by the management office on the basis of the results of seepage rate and external displacement measurements, and also measured values obtained from the embedded instruments are being awaited. Trenching and boring surveys are being conducted at the damage locations so as to determine the extent of damage and make appropriate repairs.

It has been reported that as in the case of the Asagawara Regulating Reservoir, while water was being conveyed to the Shin-Yamamoto Regulating Reservoir, the earthquake struck. Although the water conveyance was stopped when the earthquake occurred, the gate for emergency discharge of drawdown could not be opened because of stoppage of power supply, and the water remaining in the water tunnel flowed into the reservoir and the reservoir water level temporarily became high. Then, generators were brought in to operate the gate, and the reservoir was emptied in about one day.

(3) Yamamoto Regulating Reservoir

Fig. 5 shows a plan and a typical cross section of the Yamamoto Regulating Reservoir.

It was found that slip had occurred in the riprap zone of the reservoir-side slope, causing a vertical displacement of up to about 50 cm (see Photo 9). The slip zone measures about 10 m in the direction parallel to the embankment axis direction and about 5 m in the slope direction.

The settlement of the backfill behind the retaining wall around the water pool, which is an intake structure, was particularly large (see Photo 10). Small crest cracks were found along the joint between the backfill and the crest of embankment.

The embankment was surveyed just after the earthquake. Though the embankment seemed to te settled, because the control points for monitoring may have been moved as in the cases of the other regulating reservoirs, their locations need to be verified.

The seeping water became turbid after the earthquake. After reservoir operation is resumed, therefore, it is necessary to carefully monitor seepage.

As in the cases of the other regulating reservoirs, water was being conveyed to the reservoir when the earthquake occurred, so the water conveyance was stopped immediately after the earthquake struck. However, the gate could not be opened because of stoppage of power supply, the water remaining in the water tunnel flowed into the reservoir and the reservoir water level became temporarily high. Then, generators were brought in to operate the gate, and the reservoir was emptied in about one day.

Because slip occurred in the penstock area and on the downstream slope and because part of the fill near the intake settled, the management office investigates the intake structure immediately upstream to check whether any anomalous conditions have occurred. The earthquake damage to the tunnels for water conveyance to the regulating reservoir and generators at the Ojiya Power Plant, except one tunnel for water conveyance which has been found to be leaking, seems to be minor from the result of external inspections, but these facilities will be inspected in detail through water testing.

3.1.2 Earthfill Dams for Irrigation [5]

(1) Chofukuji Dam

Fig. 6 shows a plan and a typical cross section of Chofukuji Dam.

Cracks running in the upstream–downstream direction were found at the right- and left-abutments. The maximum crack opening width was about 5 cm (see Photo 11). Exploratory excavation will be conducted to collect information such as crack depth.

At the upstream and downstream slopes, faulting occurred between the spillway and the upstream fill on the left bank. The displacement due to faulting was about 7 cm (see Photo 12). Though it was difficult to inspect the upstream slope because it was covered with facing blocks, visual observation did not reveal any major local changes in the condition of the upstream slope.

When the earthquake occurred, the reservoir was empty.

The seepage rates before the earthquake were 58.0 L/min through the dam body and 2.4 L/min through the abutment. The seepage rates immediately after the earthquake (18:00, October 23) were 88.0 L/min through the dam body and 2.4 L/min through the abutment, and the seepage rates two hours after the earthquake were 125.9 L/min through the dam body and 3.7 L/min through the abutment. At 9:00 on October 28, seepage rates of 109.8 L/min through the dam body and 1.9 L/min through the abutment were recorded, but since then seepage decreased and the turbidity disappeared.

(2) Tsuboyama Dam

Fig. 7 shows a plan and a typical cross section of Tsuboyama Dam.

Five or so cracks running in the upstream–downstream direction were found on the crest pavement surface.

On the upstream and downstream slopes, faulting occurred between the spillway and the fill on the right bank. The vertical displacement was about 7 cm (see Photo 13). Earthquake-induced changes, such as slip and collapse-causing cracks, were found at three locations on the downstream slope (see Photo 14).

When the earthquake occurred, the reservoir was empty.

Before the earthquake, the seepage rates were 24.2 L/min through the dam body and 0 L/min through the abutment. The seepage rates immediately after the earthquake (18:00, October

23) were 21.7 L/min through the dam body and 0 L/min through the abutment. At 12:00 on October 25, the seepage rates through the dam body and through the abutment were 32.5 L/min and 0 L/min, respectively. At 9:00 on October 30, the seepage rates through the dam body and through the abutment were 25.5 L/min and 0 L/min, showing little earthquake-induced change and no turbidity.

The seismograph has not been installed at the dam.

(3) Kawanishi Dam

Fig. 8 shows a plan and a typical cross section of Kawanishi Dam.

Four cracks running in the upstream–downstream direction have been found in the right- and left-bank areas of the crest pavement. Survey results indicate that the crest has settled by 31–276 mm. Since, however, the control points for monitoring might have been moved, displacements in the vertical and horizontal directions need to be verified.

The region from the mid-elevation level to the toe of the upstream slope had been settled. Near the toe of the slope, there were some areas that had moved horizontally in the upstream direction. The earthquake-induced changes, such as subsidence with vertical displacements of about 30 cm, in the conditions of facing blocks on the left-bank region of the dam were particularly noticeable (see Photos 15 and 16). The facing blocks will be removed to investigate the changes in the internal conditions.

On the downstream side, one-block of the concrete sidewall of the tailrace connected from the end of the spillway was found to have disintegrated along the horizontal construction joint and collapsed. The management office building had been damaged to the extent so that it was not possible to enter it.

The seepage water became turbid after the earthquake. Subsequent investigation revealed that the water pipes running along the tailrace had been damaged so that the water leaking from the spillways entered the pipes. As of this writing (May 1, 2005), therefore, it is not possible to obtain accurate data on post-quake seepage rates.

Seismographs were installed at three locations, that is, at the midpoint of the crest, in the left-bank ground, and at the toe of the downstream slope), and a maximum acceleration of 558 gal was recorded at the toe of the downstream slope.

3.2 Ground Motions Observed at Dams

(1) Attenuation Characteristics of Peak Ground Acceleration (PGA)

Horizontal PGAs recorded by accelerometers installed at the locations corresponding to dam foundation rock (hereafter referred to simply as "dam foundations") during the main shock of the Mid Niigata Prefecture Earthquake are shown in Table 3.

Fig. 9 shows the relationship of the PGA at the foundation to the distance from the epicenter to the dam site for both the horizontal component (the value in the upstream–downstream direction or the value in the dam axis direction, whichever is greater) and the vertical component.

In Fig. 9, the horizontal component graph also shows estimated values for the Mid Niigata Prefecture Earthquake calculated using Tamura, Okamoto and Kato's attenuation formula [6] and Matsumoto et al.'s attenuation formula [7] (equivalent to the average μ of peak accelerations and the sum of the average μ and standard deviation σ) based on many records of PGA observed at the dam rock foundations.

With respect to the transverse axis (distance) of graph, however, the former formula is based on the epicentral distance, and the latter formula is based on the shortest distance from the fault plane (or, if the fault plane is not known, the distance from hypocenter of the earthquake). The estimates shown in Fig. 9 are based on not only observation data but also the shortest distance from the estimated fault plane [8] of the earthquake.

As shown in Fig. 9, the observation data are mostly enveloped by the range of estimates given by the existing three formulas. Near earthquake source of the earthquake, however, there are dams where measured values exceeding the values given by the existing formulas were obtained. One of the reasons for this result might be that the Mid Niigata Prefecture Earthquake was a reverse-fault earthquake. In Fig. 9, therefore, the observation data for the dams that are thought to be located near hypocenter of the earthquake (the shortest distance from the focal fault plane is within 50 km) and that are located on the hanging-wall side or somewhere on a line extending from the fault are shown with black circles (●), and the other data are shown with white circles (○).

These data indicate that higher accelerations were recorded at the dams located on the hanging-wall side or on a line extending from the fault near hypocenter of the earthquake than at the other dams. It may be concluded, therefore, that in the case of a reverse-fault earthquake like the Mid Niigata Prefecture Earthquake, the intensity of ground motion at a dam site is dependent not only on the distance from the focus of the earthquake but also on the location relative to the focal fault plane.

(2) Acceleration Time-history at Dam Foundation

Fig. 10 shows the acceleration time-history waveforms during the main shock at the foundations of Shirokawa Dam (distance to focal fault plane: about 14 km), Gejogawa Dam (about 28 km) and Sabaishigawa Dam (about 21 km), all of which are among the dams at which acceleration were recorded during the main shock. One characteristic of the Mid Niigata Prefecture Earthquake is that at some dams, higher accelerations were recorded during aftershocks than during the main shock. At Shirokawa Dam and Sabaishigawa Dam, accelerations higher than those recorded during the main shock were recorded during the greatest aftershock (18:34, October 23). Fig. 11 shows the acceleration time-history during the greatest aftershock.

Shirokawa Dam and Sabaishigawa Dam are located on the hanging-wall side of the focal fault, while Gejogawa Dam is located roughly on a line extending from the fault.

(3) Acceleration Response Spectrum

Fig. 12 shows acceleration response spectra determined from the acceleration time-history waveforms shown in Figs. 10 and 11. For comparison, Fig. 12 also shows the acceleration response spectra measured at dam foundations near the hypocenter during the 1995 Hyogo-ken Nanbu Earthquake [9] , which was an earthquake caused by active fault, and the 2003 Tokachi-oki Earthquake [3], which was a plate boundary earthquake.

4. CONCLUSIONS

The damage caused by the Mid Niigata Prefecture Earthquake to adjacent dams or regulating reservoirs turned out to be relatively heavy. Unfortunately, earthquake observation records were not obtained at most of the affected dams. As can be inferred from the records obtained at Shirokawa Dam, Sabaishigawa Dam, however, the dams located on the hanging-wall side of the focal fault should have been subjected to considerably strong motions. The management office of each dam will conduct investigations to collect detailed information on the earthquake-induced changes in condition and damage so as to decide on restoration methods to be adopted. These investigations can also be expected to yield invaluable information about the seismic performance of dams against strong ground motions, such as "Level 2" earthquake motions, that are maximum ground motions recorded at the past, or expected in future at dam site. Very little information is available about seepage through dams or embankments while water is stored either because reservoirs were almost empty when the earthquake occurred or because the reservoir water level was lowered after the earthquake promptly. In order to resume the operation of these facilities, it is necessary to pay careful attention to seepage as well as the conditions of repaired areas of the facilities and external deformation.

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Table 1 Results of emergency inspections conducted after the main shock [1]

Classification		No. of dams inspected	Reported earthquake-induced changes
Managed by MLIT	MLIT project	10	None
	Subsidized project	30	None
Japan Water Agency		3	None
Water utilization facilities		71	Three irrigation dams (Kawanishi, Chofukuji and Tsuboyama) owned by Niigata Prefectural Government
Total		114	

※ Earthquake-induced changes in the conditions of three more off-stream storage facilities (Asagawara Regulating Reservoir, Shin-Yamamoto Regulating Reservoir and Yamamoto Regulating Reservoir owned by JR East) have been reported.

Table 2 Investigated Dams

Name	Manager	Type	Dam height (m)	Year completed
Asagawara Regulating Reservoir	JR East	Earthfill dam with an impervious core	37	1945
Shin-Yamamoto Regulating Reservoir	JR East	Rockfill dam with an impervious core	44.5	1990
Yamamoto Regulating Reservoir	JR East	Earthfill dam with an impervious core	27.22	1954
Sabaishigawa Dam	Niigata Pref. (Dept. of Public Works)	Concrete gravity dam	37	1973
Kakizakigawa Dam	Niigata Pref. (Dept. of Public Works)	Earth-core rockfill dam	54	2003
Chofukuji Dam	Niigata Pref. (Dept.of Agricultural Land)	Earthfill dam with an impervious core	27.2	2000
Tsuboyama Dam	Niigata Pref. (Dept. of Agricultural Land)	Earthfill dam with an impervious core	20.5	1997
Kawanishi Dam	Niigata Pref. (Dept. of Agricultural Land)	Earthfill dam with an impervious core	43	1978
Hirokami Dam	Niigata Pref. (Dept. of Public Works)	Concrete gravity dam	83	Under construction
Naramata Dam	Japan Water Agency	Earth-core rockfill dam	158	1991
Myoken Weir	Hokuriku Regional Development Bureau, MLIT	Movable weir	13.815※	1990

※ Height from the upper surface of the upstream apron (mean sea level of Tokyo Bay + 32.430 m) to the top of the weir post (mean sea level of Tokyo Bay + 46.215 m)

Table 3 Peak accelerations observed at dam foundation and crest

(main shock; horizontal component measured at foundation of more than 50 gal)

Name of dams	Type	Manager	Peak Acceleration of main shock (gal)					
			Foundation			Crest		
			Upstream-downstream	Dam axis	Vertical	Upstream-downstream	Dam axis	Vertical
Kawanishi[5]	Earthfill dam	Niigata Pref.(Dept.of Agricultural Land)	558	444	406	582	518	430
Shirokawa	Concrete gravity dam	Niigata Pref.(Dept.of Pablic Works)	162	92	48	182	110	74
Gejogawa	Concrete gravity dam	Niigata Pref.(Dept.of Pablic Works)	120	101	80	215	118	66
Sabaishigawa	Concrete gravity dam	Niigata Pref.(Dept.of Pablic Works)	105	85	67	131	189	81
Kariyatagawa	Concrete gravity dam	Niigata Pref.(Dept.of Pablic Works)	62	78	66	455	404	107
Sagurigawa	Rockfill dam	Hokuriku Regional Development Bureau	46	74	32	146	164	112
Kasabori	Concrete gravity dam	Niigata Pref.(Dept.of Pablic Works)	56	62	39	448	261	235
Otani	Rockfill dam	Niigata Pref.(Dept.of Pablic Works)	62	53	44	195	205	140
Yagisawa	Concrete arch dam	Japan Water Agency	55	46	37	425	97	119

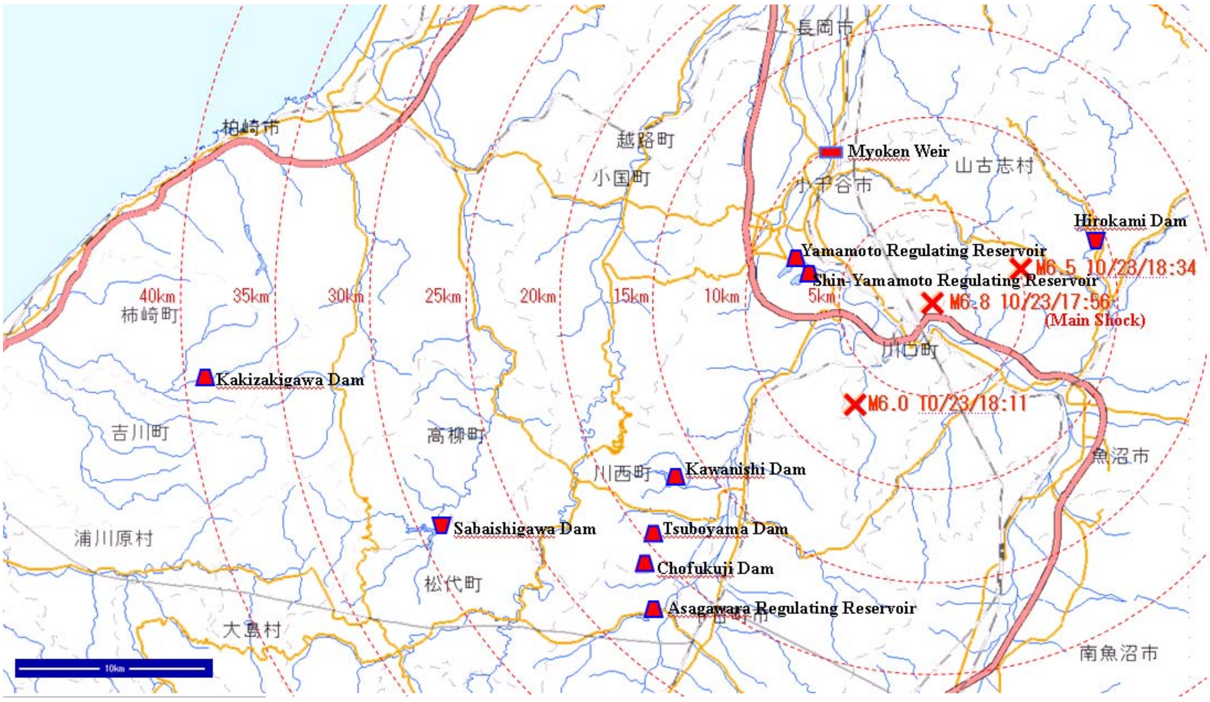


Fig .1　Locations of the investigated dams and the epicenters

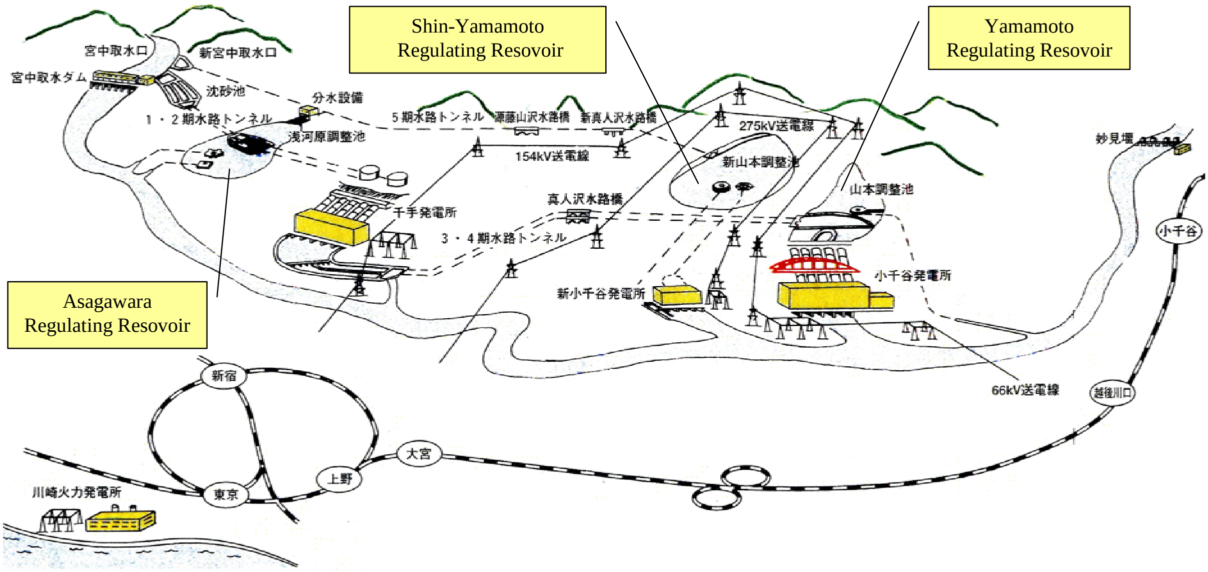
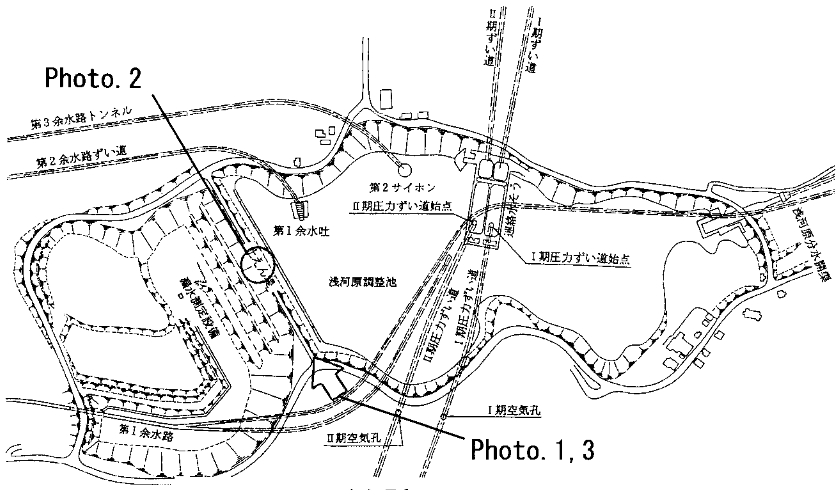
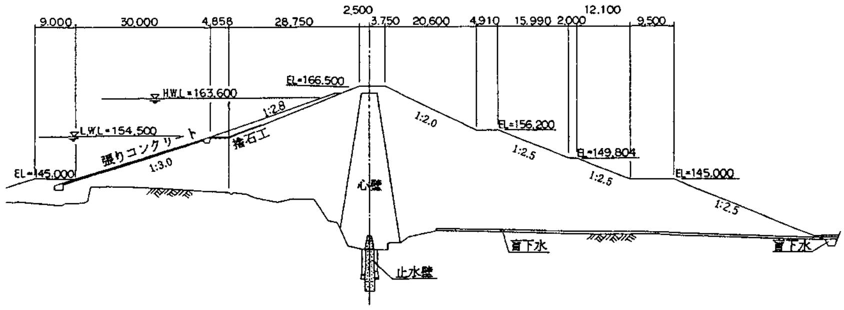


Fig .2　Locations of the principal facilities of the Shinanogawa Power Station

(courtesy of East Japan Railway Company)

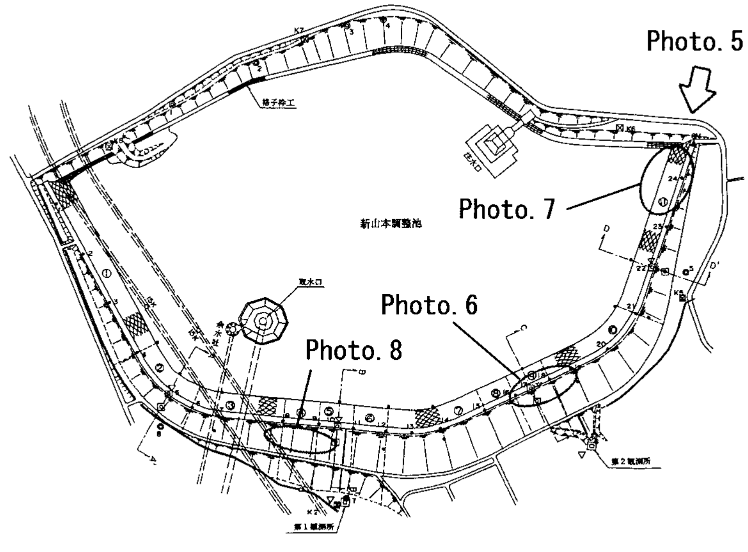


(a) Plan

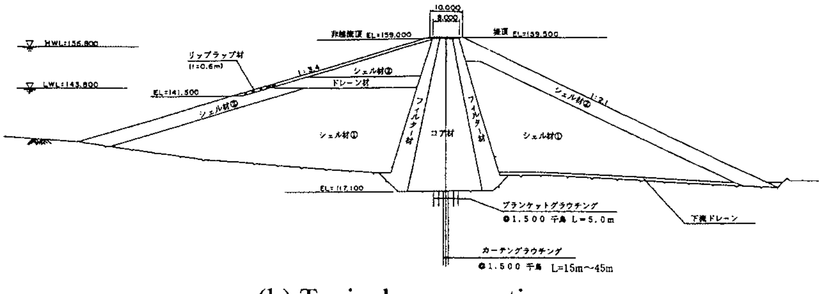


(b) Typical cross section

Fig. 3 Structure of Asagawara Regulating Reservoir (courtesy of East Japan Railway Company)

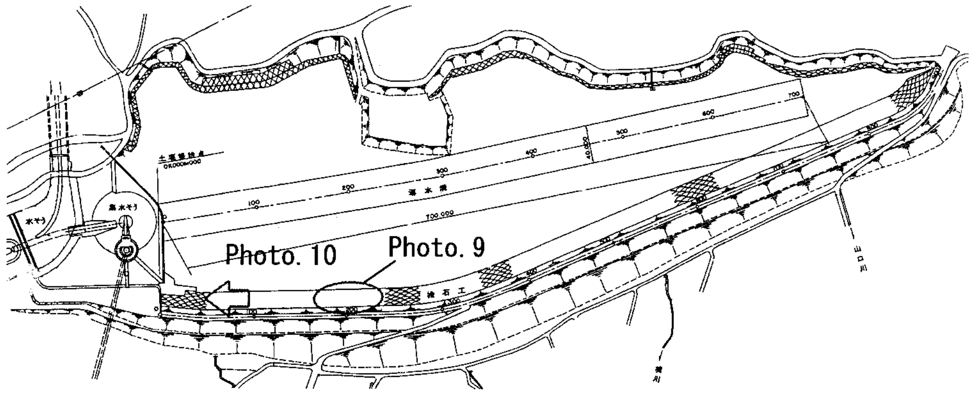


(a) Plan

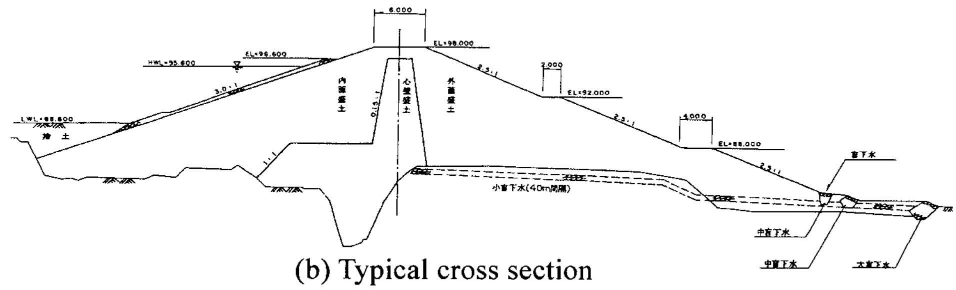


(b) Typical cross section

Fig. 4 Structure of Shin-Yamamoto Regulating Reservoir (courtesy of East Japan Railway Company)

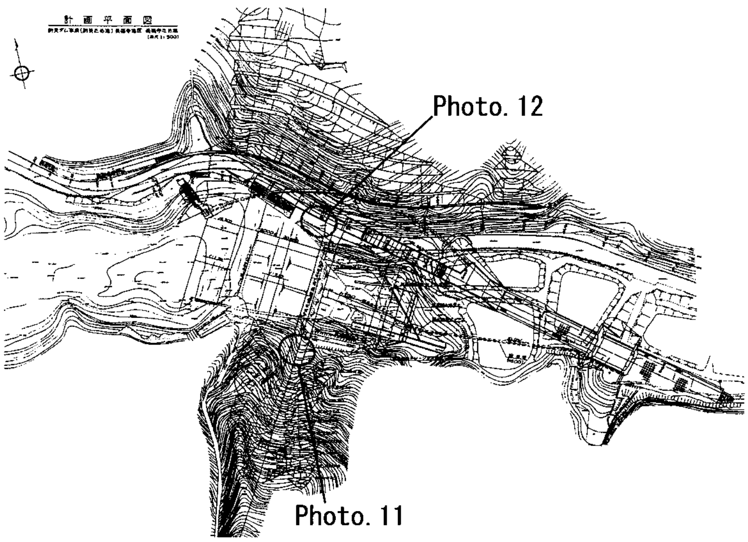


(a) Plan

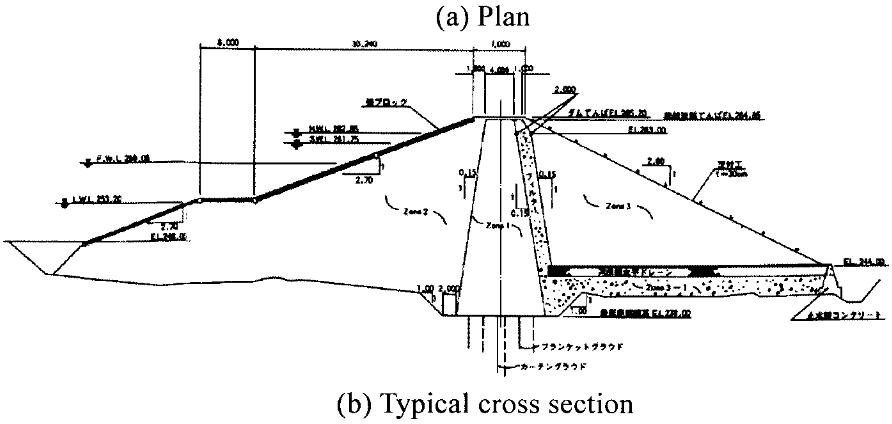


(b) Typical cross section

Fig. 5 Structure of Yamamoto Regulating Reservoir (courtesy of East Japan Railway Company)



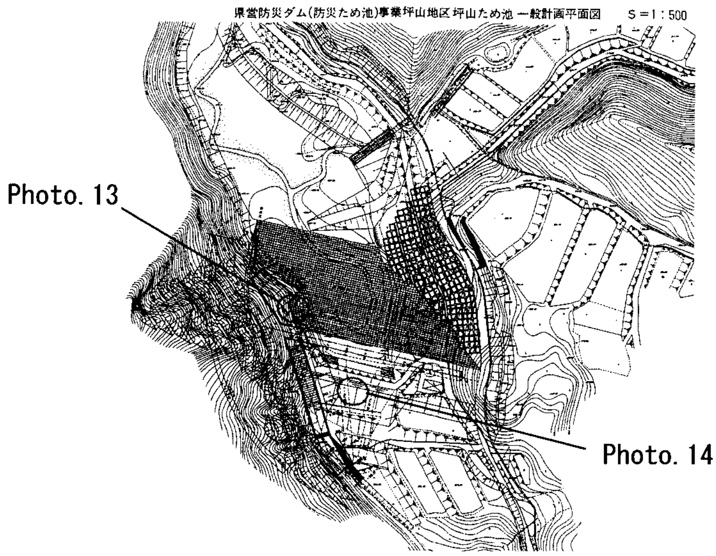
(a) Plan



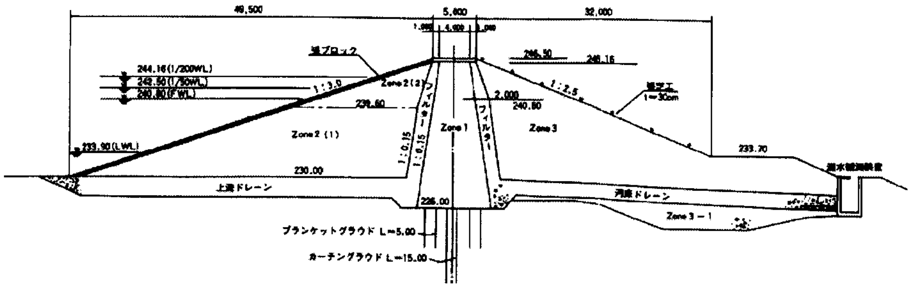
(b) Typical cross section

Fig. 6 Structure of Chofukuji Dam

(courtesy of Agricultural Promotion Division, Regional Development Bureau, Tokamachi Municipal Government)



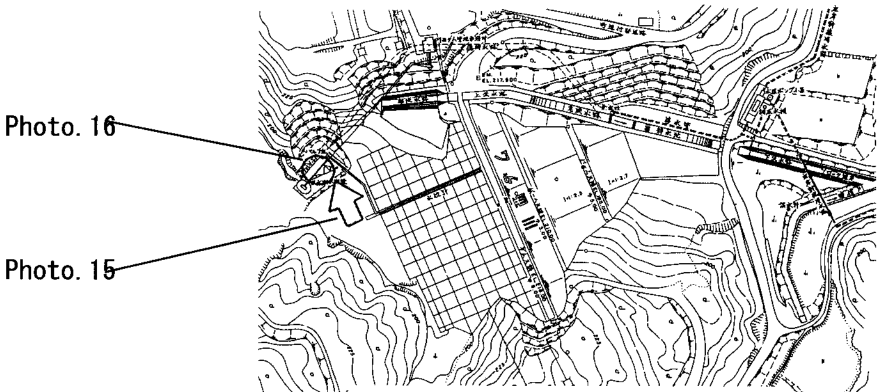
(a) Plan



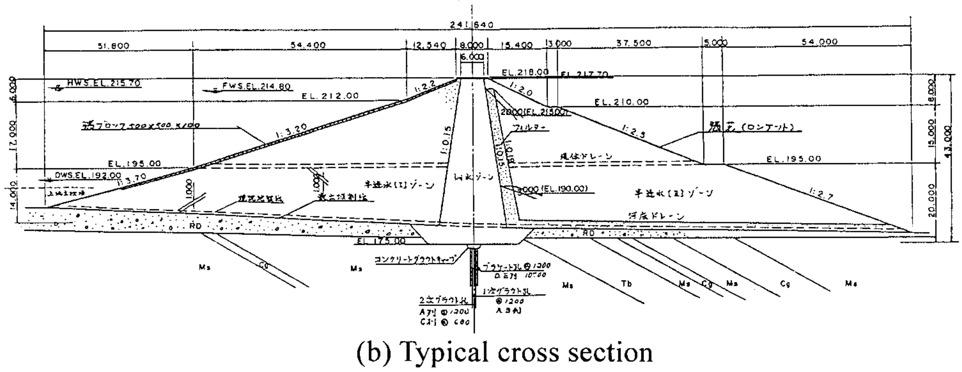
(b) Typical cross section

Fig. 7 Structure of Tsuboyama Dam

(courtesy of Agricultural Promotion Division, Regional Development Bureau, Tokamachi Municipal Government)



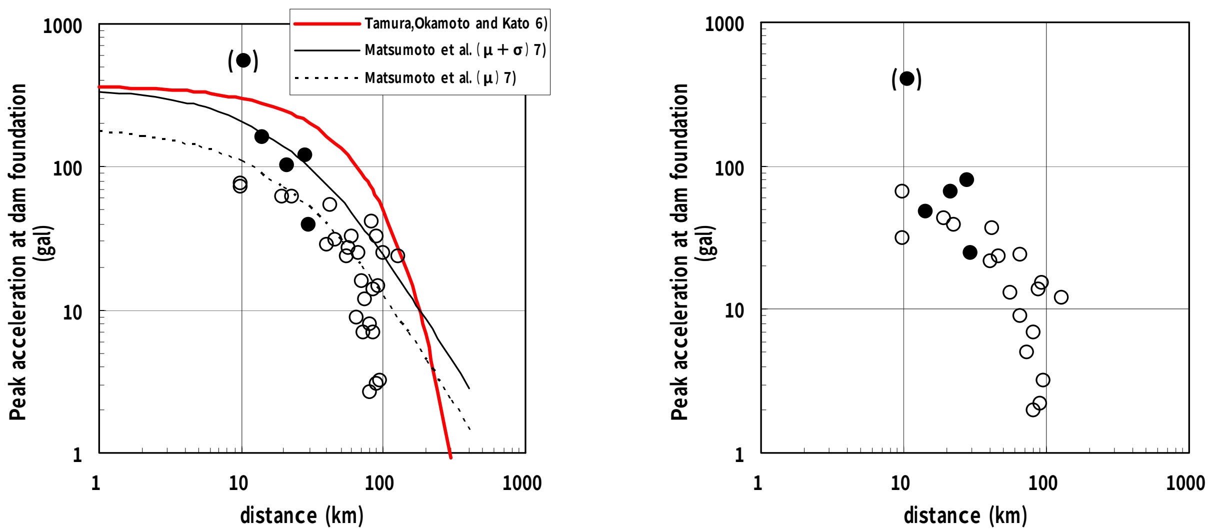
(a) Plan



(b) Typical cross section

Fig. 8 Structure of Kawanishi Dam

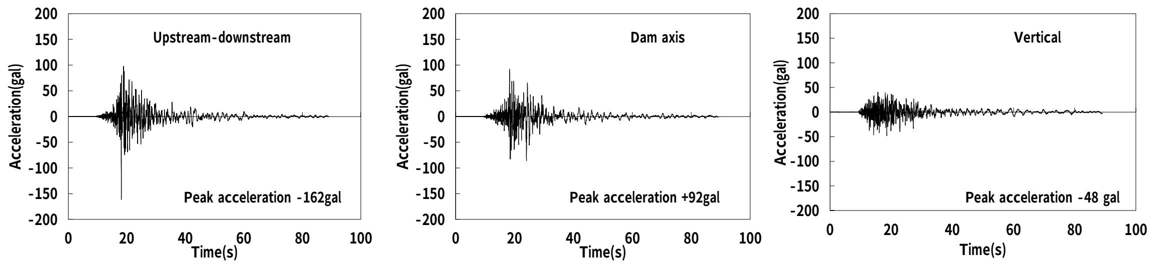
(courtesy of Agricultural Promotion Division, Regional Development Bureau, Tokamachi Municipal Government)



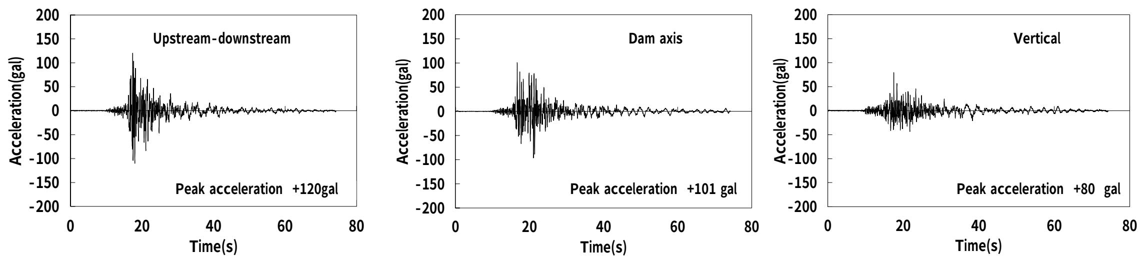
(a) horizontal component (b) Vertical component

Fig. 9 Relationship between peak acceleration and epicentral distance (main shock, at dam foundation)

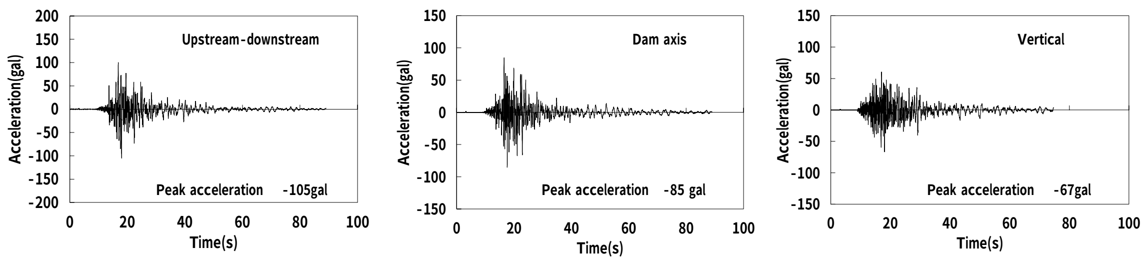
Note: A black circle (●) represents a measurement taken in the ground at the toe of the downstream slope of the dam.[5)]



(a) Shirokawa Dam

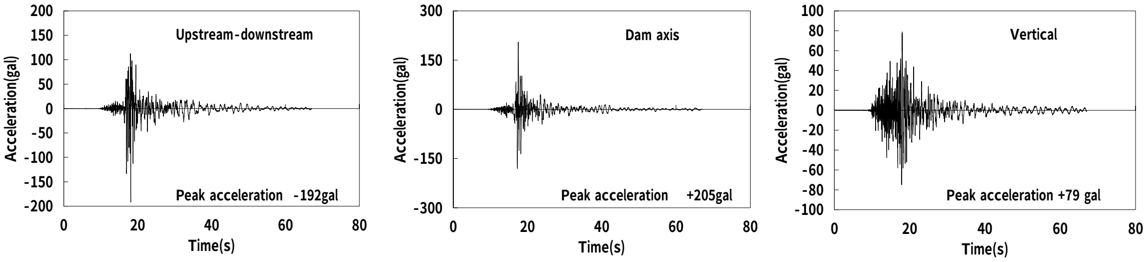


(b) Gejokawa Dam

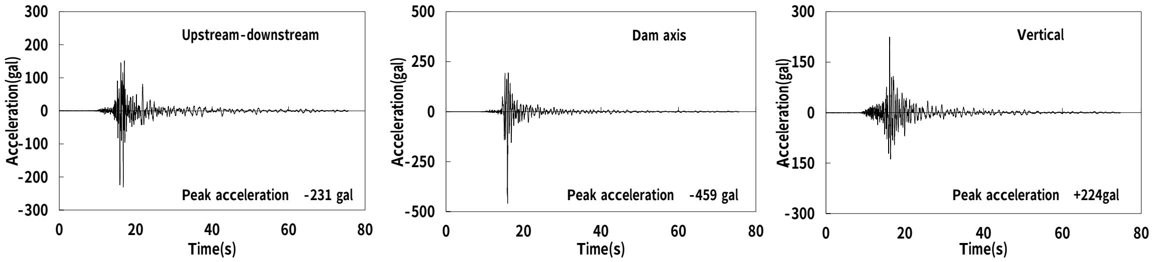


(c) Sabaishigawa Dam

Fig. 10 Acceleration time-history waveform (main shock, at dam foundation)

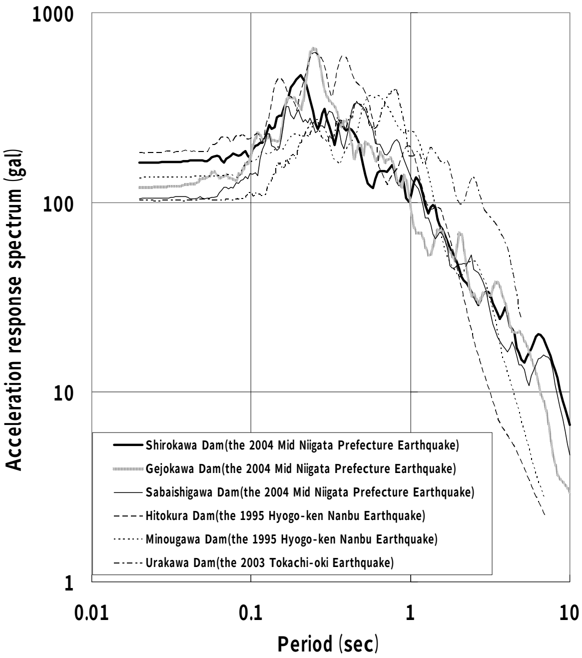


(a) Shirokawa Dam

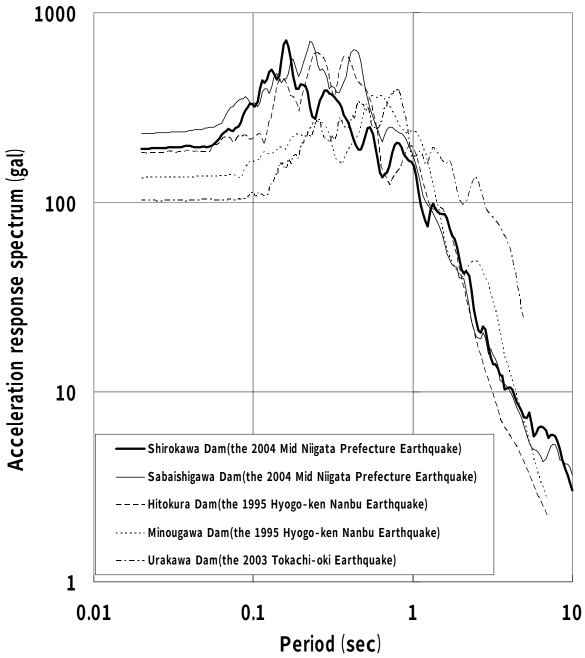


(b) Sabaishigawa Dam

Fig. 11 Acceleration time-history waveform (strongest aftershock, at dam foundation)



(a) Main shock



(b) Strongest aftershock

Fig. 12 Acceleration response spectrum
(component in the upstream–downstream direction; damping ratio=5%)

Photo .1 Close view of crest cracks (Asagawara Regulating Reservoir)

Photo .2 Stepping caused by crest cracking (Asagawara Regulating Reservoir)

Photo .3 Vinyl sheeting to protect cracked crest (Asagawara Regulating Reservoir)

Photo .4 Water level rise after earthquake (photo by Hokuriku Regional Development Bureau) (Asagawara Regulating Reservoir)

Photo .5 Inclination of crest pavement (Shin-Yamamoto Regulating Reservoir)

Photo .6 Outer slope cave-in and cracking (Shin-Yamamoto Regulating Reservoir)

Photo .7 Stepping of riprap surface of reservoir-side slope (Shin-Yamamoto Regulating Reservoir)

Photo .8 Bulging of outer slope surface (Shin-Yamamoto Regulating Reservoir)

Photo .9 Slip of reservoir side slope (Yamamoto Regulating Reservoir)

Photo .10 Ground deformation near the intake facilities (Yamamoto Regulating Reservoir)

Photo .11 Transverse crack at the crest of the dam (Chofukuji Dam)

Photo .12 Settlement of surfacing blocks relative to spillway (Chofukuji Dam)

Photo .13 Settlement of surfacing blocks relative to spillway (Tsuboyama Dam)

Photo .14 Crack on downstream slope (Tsuboyama Dam)

Photo .15 Earthquake-induced changes on upstream slope (Kawanishi Dam)

Photo .16 Earthquake-induced changes on left-bank upstream slope, viewed from the toe of the upstream slope (Kawanishi Dam)