Damage to Dams due to Three Large Earthquakes Occurred in 2003, in Japan

by

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ABSTRACT
In 2003, three comparatively large earthquakes occurred in Japan. They were Miyagi-oki earthquake of Japan Meteorological Agency magnitude (Mj) 7.1 on May 26, 2003, Miyagi-hokubu earthquake of Mj 6.4 on July 26, 2003 and Tokachi-oki earthquake of Mj 8.0 on September 26, 2003. The National Institute for Land and Infrastructure Management (NILIM) and the Public Works Research Institute (PWRI) dispatched joint teams to conduct field surveys of the dams. This paper reports the outlines of the damages to the dams due to the earthquakes and the acceleration data observed at dam sites.

KEYWORDS: Damage to Dam, Large Earthquake, Field Survey, Special Inspection

1. INTRODUCTION

The outlines of the damages by the three earthquakes are summarized in Table 1.

Miyagi-oki earthquake is the magnitude 7.1 earthquake that occurred at about 6:24 p.m. on May 26, 2003 injured 174 people, damaged 2,428 houses and caused damage of more than 17.4 billion yen (according to the report by the Fire and Disaster Management Agency, as of November 21, 2003 [1]).

Miyagi-hokubu earthquake is the magnitude 6.4 earthquake that occurred at about 7:13 a.m. on July 26, 2003 injured 677 people, damaged 16,061 houses and caused damage of more than 32.0 billion yen (according to the report by the Fire and Disaster Management Agency, as of March 30, 2004 [2]).

Tokachi-oki earthquake is the magnitude 8.0 earthquake that occurred at about 4:50 a.m. on September 26, 2003 injured 849 people, damaged 2,073 houses and caused damage of more than 25.8 billion yen (according to the report by the Fire and Disaster Management Agency, as of March 31, 2004 [3]).

Four research institutes under the jurisdiction of the Ministry of Land, Infrastructure and Transport surveyed earthquake damages to civil engineering structures, buildings, port and harbor structures. The NILIM and the PWRI dispatched joint teams to conduct field surveys of the dams. This paper describes the damages to dams due to the three earthquakes.

2. MIYAGI-OKI EARTHQUAKE ON MAY 26, 2003

2.1 Outline of Earthquake

The hypocenter of this earthquake was at a depth of 72km at north latitude 38°49.0' and east longitude 141°39.2'. During this earthquake, seismic intensity of 6-lower was recorded in northern Miyagi Prefecture and southern Iwate Prefecture, seismic intensity of 5-upper to 5-lower was recorded over a wide area of Tohoku, and seismic intensity of 4 was recorded from Hokkaido to the Kanto region. It is considered that this earthquake was occurred in the Pacific Plate which subducts under the Continental Plate. The 1978 Miyagi-oki earthquake (M=7.4) occurred near the boundary of the two plates and its epicenter was about 80km south south-east of that of this earthquake (Figures 1 and 2). It is assumed that the anticipated Miyagi-oki Earthquake that is

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expected to occur periodically and extremely likely to occur soon will be an earthquake occurring near the plate boundary. But the hypocenter depth and occurrence mechanism of the anticipated Miyagi-oki Earthquake were different from those of this earthquake. So it has been concluded that the earthquake on May 26, 2003 was a different earthquake from the anticipated Miyagi-oki Earthquake.

2.2 Outlines of Dam Damages and Field Survey

In Japan, the owner of the dam ought to make special inspections of the dam, in the case the peak acceleration at the dam site is greater than 25 gal or the Japanese Seismic Intensity in the area is greater than 4. The special safety inspection includes a primary inspection that is a visual inspection immediately after the earthquake and a secondary inspection that is a detailed visual inspection accompanied by analyzing the data measured by instruments. The results should be reported to the Ministry of Land, Infrastructure, and Transport (MLIT).

It was reported that the special post-earthquake inspection conducted by dam management offices found damages such as cracking of the balconies of the crest of concrete gravity dams and cracking at the crests of earthfill dams, and increases in leakage (seepage). The NLIM and the PWRI dispatched joint survey teams to conduct a field survey of the dams. The surveys confirmed that the above damages reported after the special inspections were slight and no damages were found at most of the dams [4][5].

Post-earthquake field surveys were performed at a total of 23 dams in the two prefectures of Iwate and Miyagi, from June 4 to 6 and June 11 to 13 of 2003. Figure 3 shows the surveyed dams and their positional relationship with the epicenter. The object of the survey was to check damages to dams, to confirm the situation of collection of earthquake motion records and obtain these records, and to check to clarify if values measured by instruments before and after the earthquake had changed, and to check the tendency of changes in the case that those values had changed.

2.3 Results of Field Survey

The damages that the special inspection and the field survey confirmed at the Hinata Dam, the Tase Dam and the Ishibudhi Dam are described below in detail.

2.3.1 Hinata Dam

At the Hinata Dam, a concrete gravity dam with a height of 56.5m, completed in 1997 (Figure 4), the maximum accelerations of 228 gal (stream direction) and 1,111 gal (stream direction) were recorded in the dam foundation and at the crest respectively. The epicentral distance was 54.5km.

There were fine cracks in five of seven overhangs on the upstream side of the piers of the crest bridge as shown in Photograph 1. And the joints on the crest balustrade and the overhanging part at the same location were opened between 1.0 and 2.5cm as shown in Photograph 2. But these damages did not extend to the dam body section and did not reduce safety.

2.3.2 Tase Dam

At the Tase Dam, a concrete gravity dam with a height of 81.5m, completed in 1954 (Figure 5), the maximum accelerations of 232 gal (stream direction) and 1,024 gal (stream direction) were recorded in the dam foundation and at the crest respectively. The Tase Dam is the highest dam among the dams where maximum acceleration higher than 200gal was recorded in the foundation during the earthquake. The epicentral distance was 72.7km.

The earthquake damaged crest lighting fixtures and formed fine cracks from the downstream side of the dam body at the entrance to the inspection gallery (Photographs 3 and 4), but these did not reach the dam body section, and so they did not affect the safety of the dam body. Water leaked from displaced packing of an air bleed valve that is a low capacity valve newly installed as part of a facility improvement project that started in 1994 and was completed in 1998, but it had already been repaired by the time the survey team arrived.

In addition, the earthquake caused the temporary increase of the water leakage and a little turbidity in leaked water, but by 4 or 5 hours after the earthquake, the water leakage had returned to its original level and the turbidity had disappeared.

2.3.3 Ishibuchi Dam

At the Ishibuchi Dam, a concrete face rockfill dam (CFRD) constructed first in Japan, with a height of 53.0m, completed in 1953 (Figure 6), the maximum accelerations of 147 gal (stream direction) and 267.6 gal (stream direction) were recorded in the dam foundation and at the crest respectively. The epicentral distance was 84.9km.

Compaction of rockfill materials was not performed by the large construction machine and this dam has many joints in concrete slab. This dam is namely the old type CFRD. So, much leakage (seepage) has been observed at this dam since the beginning of operating the dam reservoir.

The deformation was not confirmed in the special safety inspection after the earthquake. But, the value of water leakage (seepage) measured at the river bed section increased about twenty percent from 2,880 l/min before the earthquake to about 3,500 l/min after the earthquake, then the amount of leakage stabilized in the situation where it increased. In addition, the turbidity of leakage (seepage) measured at the river bed section was confirmed immediately after the earthquake, but the turbidity disappeared 4 hours after the earthquake.

2.4 Earthquake Motions Observed at Dams

During the earthquake, stream-direction horizontal acceleration of 200gal or more in dam foundations was observed at five dams, and 1,000gal or more at dam crests was observed at 4 dams. Figure 7 shows the attenuation of the maximum acceleration (the largest value among two horizontal directions) observed in the dam foundation (bottom inspection galleries of concrete dams or of embankment dams). In the figures, the attenuation equation after Tamura et al. (1979) [6] for maximum acceleration in bedrock under a magnitude 7.1 earthquake that corresponds to the scale of the earthquake was also drawn. This figure shows that the attenuation of the maximum acceleration in the dam site bedrock caused by the earthquake can be generally approximated by the estimation equation after Tamura et al.

3. MIYAGI-HOKUBU EARTHQUAKE ON JULY 26, 2003

3.1 Outline of Earthquake

The hypocenter of this earthquake was at a depth of 12.9km at north latitude 38.4° and east longitude 141.2°. In the north Miyagi prefecture, three earthquakes (the foreshock, the main shock and the aftershock) which brought more than seismic intensity of 6-lower occurred on July 26, 2003. It is the first in the history of observation of the Meteorological Agency to have recorded more than seismic intensity of 6 three times in one day.

3.2 Outlines of Dam Damages and Field Survey

The temporary increase of water leakage and the turbidity of leakage immediately after the earthquake were observed at some dams that were severely shaken. The Miyagi-oki Earthquake of May 26, 2003 caused, in addition to temporary increases of the quantity of water leakage (seepage) at some dams, slight damages including cracking of the crest balcony of concrete gravity dams, cracking at the crest of earthfill dams and damage to lighting at the crest of dams. But even slight damage was not confirmed after this earthquake [7]. Therefore, it can be concluded that the impact of this earthquake on dams was smaller than that of the earthquake of May 26.

The special inspections were conducted at 59 dams immediately after the earthquake. No damages including slight deformations were reported at all dams. But the NLIM and the PWRI dispatched joint field survey teams to investigate the details concerning changes in the quantity of water leakage or seepage by the earthquake and the situation of the installation of seismographs at dams where relatively high acceleration records were obtained, and to check the subsequent situation at dams where deformations had been confirmed after the previous earthquake of May 26. The field surveys were performed at a total of 7 dams from August 4 to 5 of 2003. The locations of the surveyed dams are shown in Figure 8. The surveyed dams were those where maximum acceleration of 100gal or more was recorded at the crest of dam, and where a field survey was not conducted after the earthquake of May 26, or where some kind of damage such as the increase of the quantity of leakage was reported.

3.3 Earthquake Motions Observed at Dams

Figure 9 shows the attenuation of the maximum acceleration (the largest value among two horizontal directions) observed in the dam foundation (bottom inspection galleries of concrete dams and of embankment dams). In the figures, the attenuation equation after Tamura et al. (1979) for maximum acceleration in bedrock under a magnitude 6.4 earthquake that corresponds to the scale of the earthquake was also drawn. This figure shows that the values the maximum accelerations in the dam site bedrock caused by the earthquake are smaller than the values by the estimation equation after Tamura et al.

4. TOKACHI-OKI EARTHQUAKE ON SEPTEMBER 26, 2003

4.1 Outline of Earthquake

This hypocenter of the earthquake was at a depth of 42km at north latitude 41°46’ and east longitude 144°04’. It is considered that this earthquake occurred in the boundary of the Pacific Plate and the plate of land is interplate earthquake.

4.2 Outlines of Dam Damages and Field Survey

It was reported that the special post-earthquake inspection conducted by dam operation offices found shallow cracking in the dam axis direction at the crest of the Takami Dam, a rockfill dam, the deformation of the protective rock layer on the earth blankets on the surface of natural slope around the reservoir of the Makubetsu Dam, an earthfill dam, and the temporary increase of water leakage (seepage) at some dams. The NLIM and the PWRI dispatched joint survey teams that performed field surveys to find out whether or not damages occurred and to survey changes in the quantity of deformation or water leakage (seepage) caused by the earthquake. The surveys confirmed that all the damages reported by the special inspections are slight and that there was no damage at most dams [8].

Post-earthquake field surveys were performed at a total of 16 dams in Hokkaido from October 1 to 3 of 2003. Figure 10 shows the dams surveyed and their positional relationship with the epicenter. The object of the survey was the same as that of the Miyagi-oki earthquake.

4.3 Results of Field Survey

The damages that the special inspection and the field survey confirmed at the Takami Dam and the Makubetsu Dam are described below in detail.

4.3.1 Takami Dam

At the Takami Dam, a rockfill dam with a height of 120m, completed in 1983 (Figure 11), the maximum accelerations of 57.8 gal (dam axis direction) and 325.3 gal (stream direction) were recorded in the dam foundation and at the crest respectively. The epicentral distance was 140.4km.

The special inspection after the earthquake found longitudinal cracks parallel to the dam axis at the crest of the dam (Photograph 5). The cracks were up to 160m long in the dam axis direction. The maximum width of the cracks at the surface was 50mm. Accordingly, on the same day, Hokkaido Prefecture that is the dam manager excavated an exploratory pit at the locations of the widest crack to measure the depth of the crack (Photograph 6 and Figure 12). The results confirmed that the cracks remained within the crest protective layer with a thickness of about 90cm without reaching the core zone. The excavated pit was filled in immediately after the survey, and to prevent seepage by rainfall from expanding the cracks to the core, the entire cracked area was covered with impervious sheets (Photograph 7).

On October 20, a follow-up survey of the crack depth at the crest of the Takami Dam was carried out. The results confirmed that as in the case of the previous survey, none of the cracks extended beyond the protective layer. Accordingly, after October 21, the locations of the cracks inside the protective layer were repaired by backfilling them with identical material (Photograph 8). During the backfilling, density measurements inside the protective layer were done to control compaction so that the density would be the same as that before damage.

4.3.2 Makubetsu Dam

At the Makubetsu Dam, an earthfill dam with a height of 26.9m, completed in 2004 (Figure 13), the maximum accelerations of 173.1 gal (dam axis direction) and 251.6 gal (stream direction) were recorded in the dam foundation and at the crest respectively. The epicentral distance was 140.6km.

The sliding of the protective rock layer on the earth blanket placed on the left and right bank slopes of just upstream of the dam body occurred at two locations on the left bank (length (1) 20m, (2) 23m in Figure 13) and two locations on the right bank (length (3) 80m, (4) 30m in Figure 13). The topmost end of the sliding was directly above the water level during the earthquake. The location of the maximum sliding is near the spillway on the right bank side, and the maximum settlement of approximately 90cm was confirmed by the shape of the slope, and a level difference of about 40cm was formed at the top edge of the deformation (Photographs 9 and 10).

After the earthquake, the dam manager performed an excavation survey, confirming that the sliding was limited to the protective rock layer (approximately 2m) and did not extend to the interior of the earth blanket. And the part of the protective rock layer, that became thinner because of the sliding, was thickened by placing more rock materials to temporarily repair the sliding.

The pore water pressure inside the dam body rose slightly at almost all parts of the upstream side zone, and it had almost peaked at the time of the survey. The values later by a regular inspection were stabilized, and almost no abrupt change was found. The seepage was increased slightly due to the earthquake, but it stabilized later.

The dam body displacement in the upstream-downstream direction near the center of the crest is approximately 2cm on the upstream side and the settlement is about 3cm.

4.4 Earthquake Motions Observed at Dams

Figure 14 shows the attenuation of the maximum acceleration (the largest value among two horizontal directions) observed in the dam foundation (bottom inspection galleries of concrete dams and of embankment dams). In the figures, the attenuation equation after Tamura et al. (1979) for maximum acceleration in bedrock under a magnitude 8.0 earthquake that corresponds to the scale of the earthquake was also drawn. This figure shows that the attenuation of the maximum acceleration in the dam site bedrock caused by the earthquake can be approximated by the estimation equation after Tamura et al.

5. CONCLUSIONS

Great earthquake motions by three large earthquakes occurred in 2003 in Japan were observed at many dam sites. Regardless of these high levels of earthquake motions, none of these dams suffered damages severe enough to threaten their safety. Although this is presumed to be an effect of the properties of the earthquake motions in the bedrock generated by these earthquakes, it does remind us of the high earthquake resistance of dams. Further studies of the more detailed properties of earthquake motions must be carried out in order to reflect these findings in earthquake motion research and the seismic resistance design and safety management of dams.

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Table 1 Outline of Damage

	Miyagi-oki Earthquake on May 26, 2003	Miyagi-hokubu Earthquake on July 26, 2003	Tokachi-oki Earthquake on September 26, 2003
Japan Meteorological Agency magnitude	7.1	6.4	8.0
Injured People (persons)	174	677	849
Damaged Homes (houses)	2,428	16,061	2,073
Total Damage Amount (yen)	17.4 billion	32.0 billion	25.8 billion

According to the report by the Fire and Disaster Management Agency

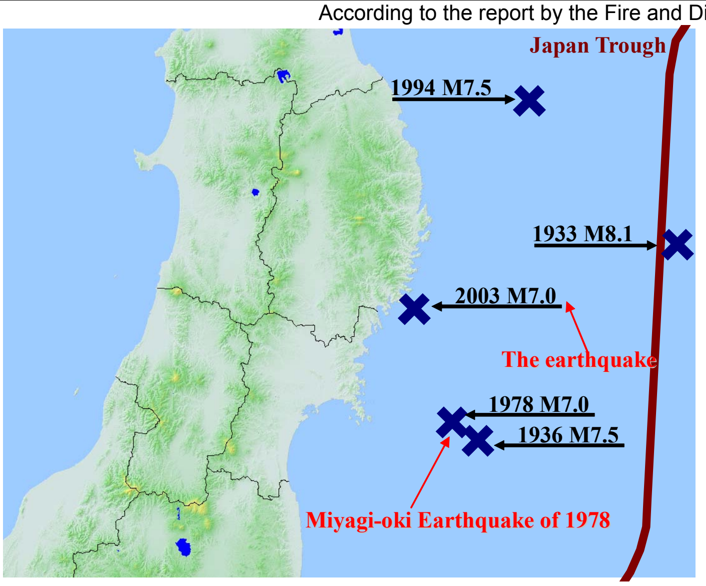


Figure 1 Locations / Profiles of Nearby Earthquakes

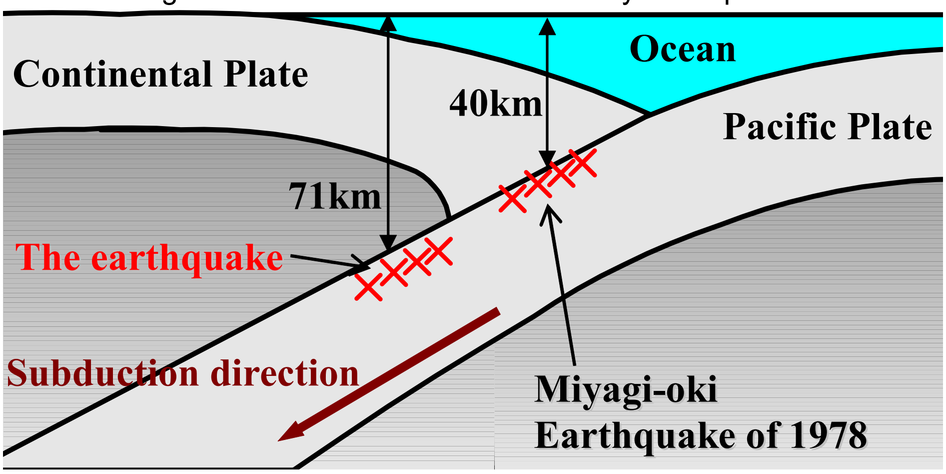
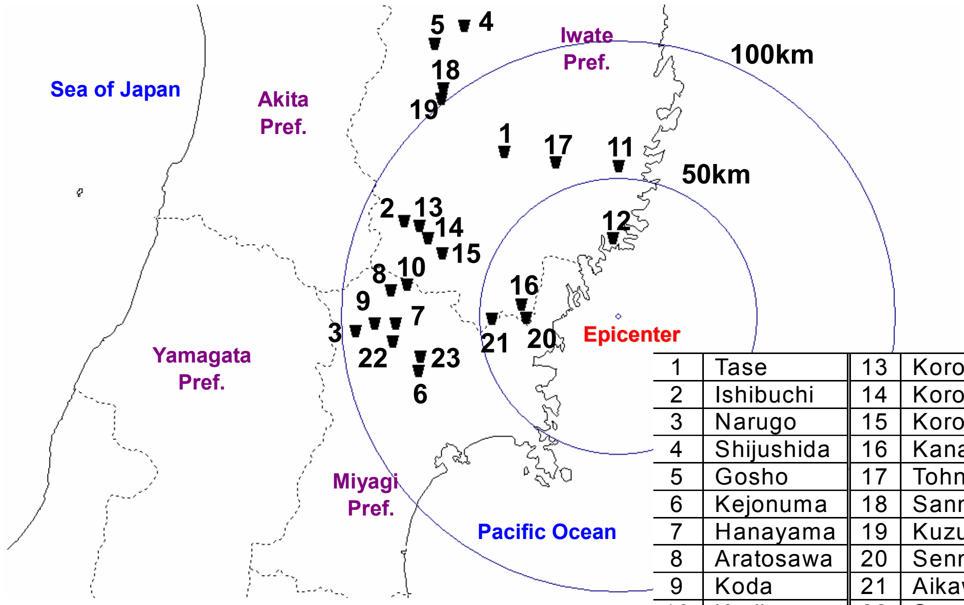


Figure 2 Schematic Diagram of Region around Epicenters



1	Tase	13	Koromogawa1
2	Ishibuchi	14	Koromogawa4
3	Narugo	15	Koromogawa5
4	Shijushida	16	Kanagoesawa
5	Gosho	17	Tohno
6	Kejonuma	18	Sannoukai
7	Hanayama	19	Kuzumaru
8	Aratosawa	20	Senmatsu
9	Koda	21	Aikawa
10	Kurikoma	22	Sugo
11	Hinata	23	Syukunosawa
12	Ryorigawa		

Figure 3 Surveyed Dams and Positional Relationship with Epicenter of Miyagi-oki Earthquake

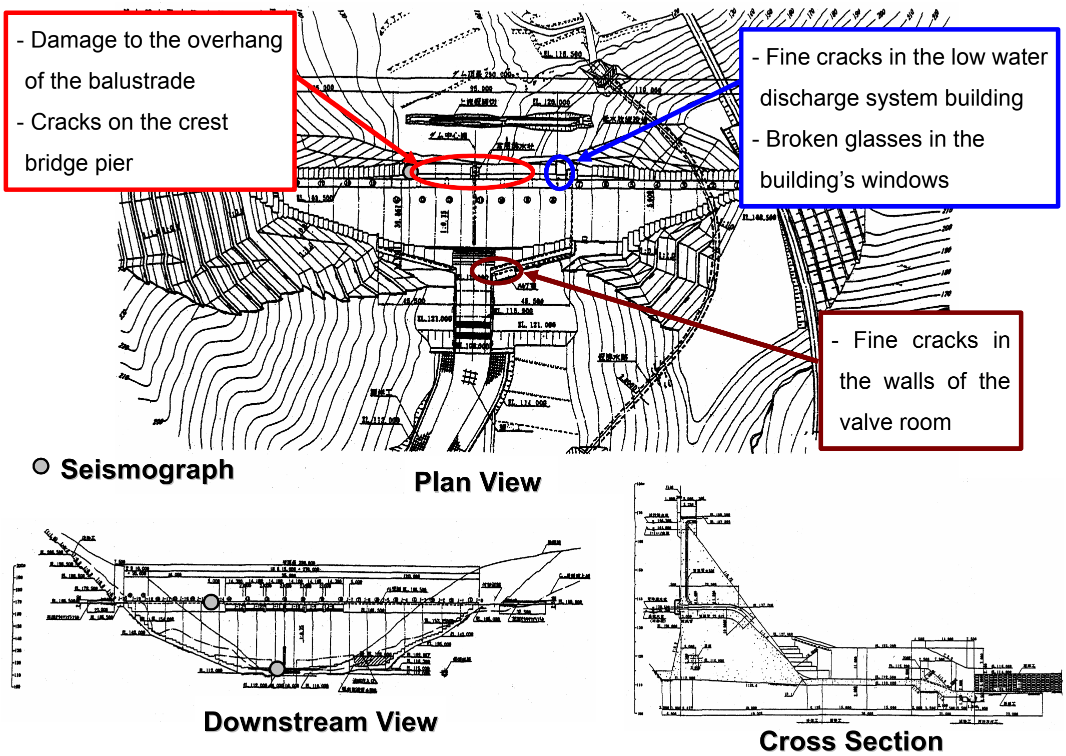


Figure 4 Hinata Dam

Photograph 1 Crack on Crest Bridge Pier (Hinata Dam; White line touched up shows location of crack.)

Photograph 2 Opening of Joints on Balustrade (Hinata Dam)

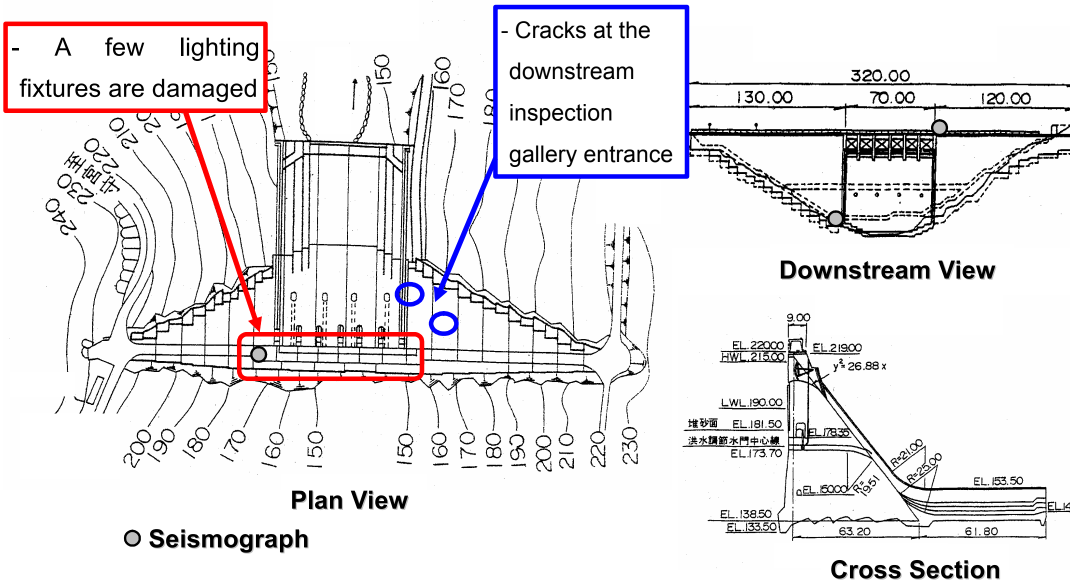
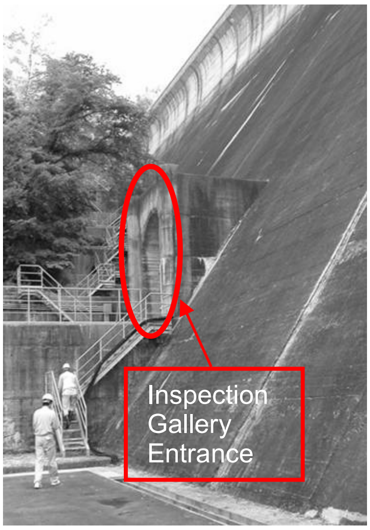
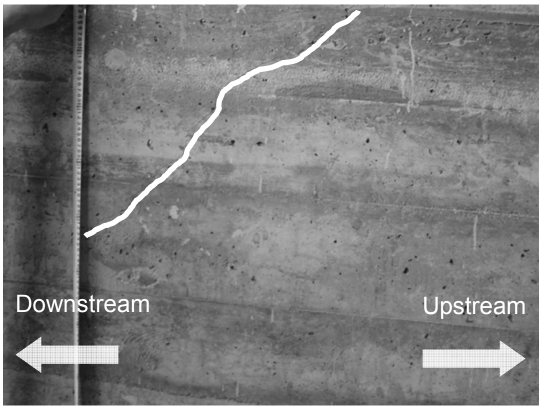


Figure 5 Tase Dam



Photograph 3 Inspection Gallery Entrance on Right Bank Abutment (Tase Dam)



Photograph 4 Cracking at Entrance to Inspection Gallery on Downstream Side
(Tase Dam; White line touched up shows location of crack.)

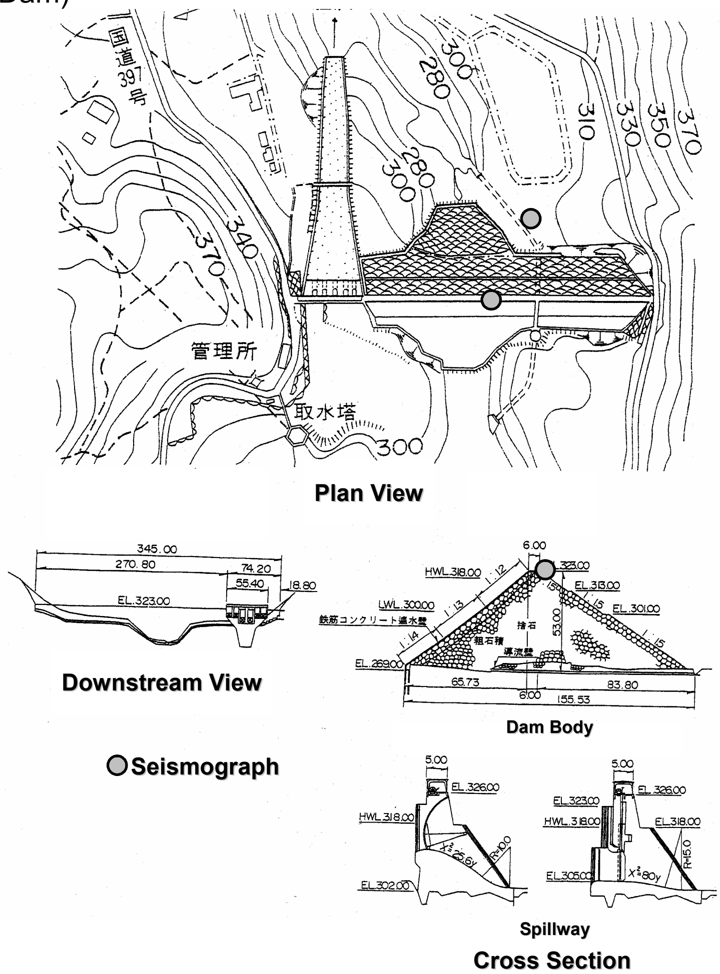


Figure 6 Ishibuchi Dam

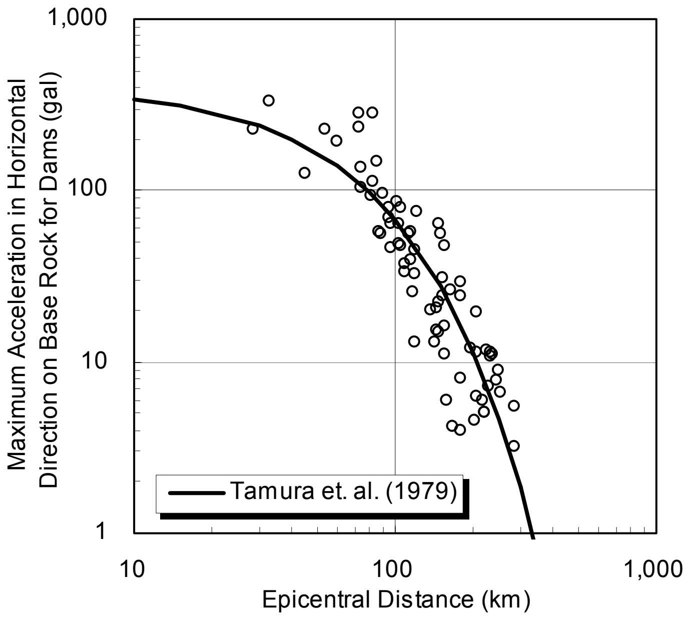


Figure 7 Attenuation of Maximum Acceleration in Dam Foundation Bedrock (Miyagi-oki Earthquake)

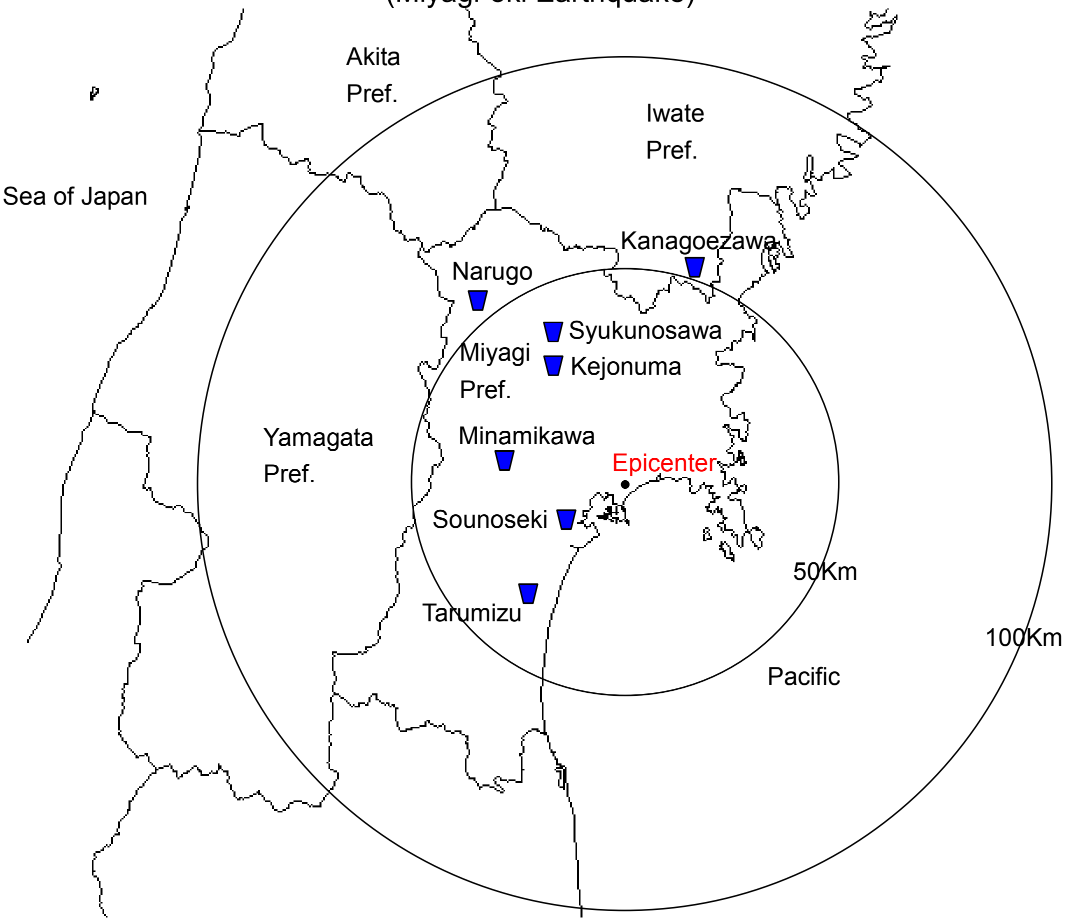


Figure 8 Surveyed Dams and Positional Relationship with Epicenter of Miyagi-hokubu Earthquake

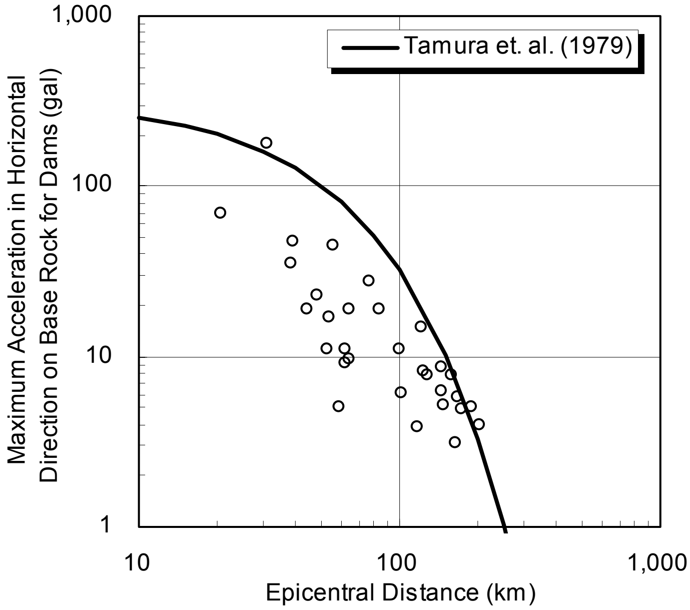
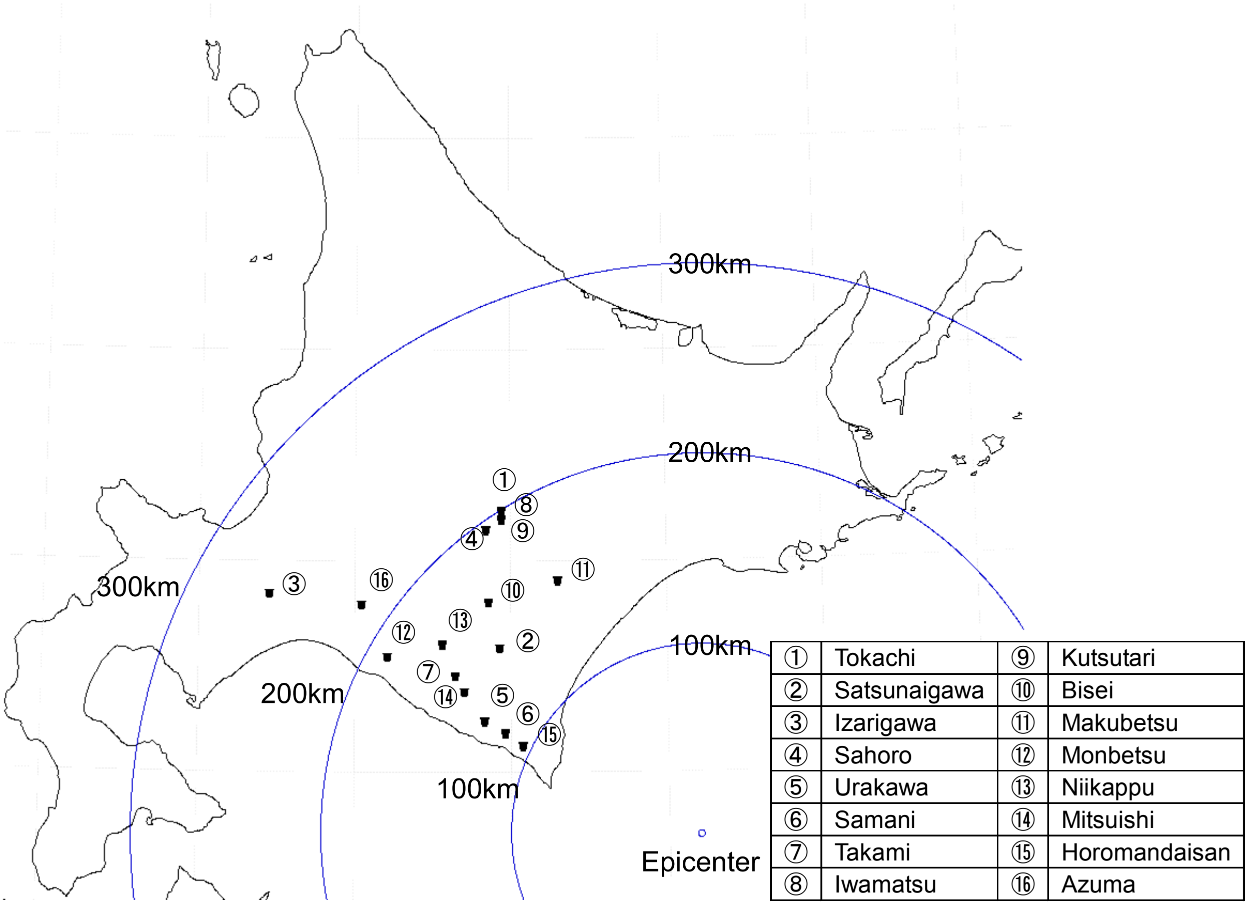


Figure 9 Attenuation of Maximum Acceleration in Dam Foundation Bedrock
(Miyagi-hokubu Earthquake)



①	Tokachi	⑨	Kutsutari
②	Satsunaigawa	⑩	Bisei
③	Izarigawa	⑪	Makubetsu
④	Sahoro	⑫	Monbetsu
⑤	Urakawa	⑬	Niikappu
⑥	Samani	⑭	Mitsuishi
⑦	Takami	⑮	Horomandaisan
⑧	Iwamatsu	⑯	Azuma

Figure 10 Surveyed Dams and Positional Relationship with Epicenter of Tokachi-oki Earthquake

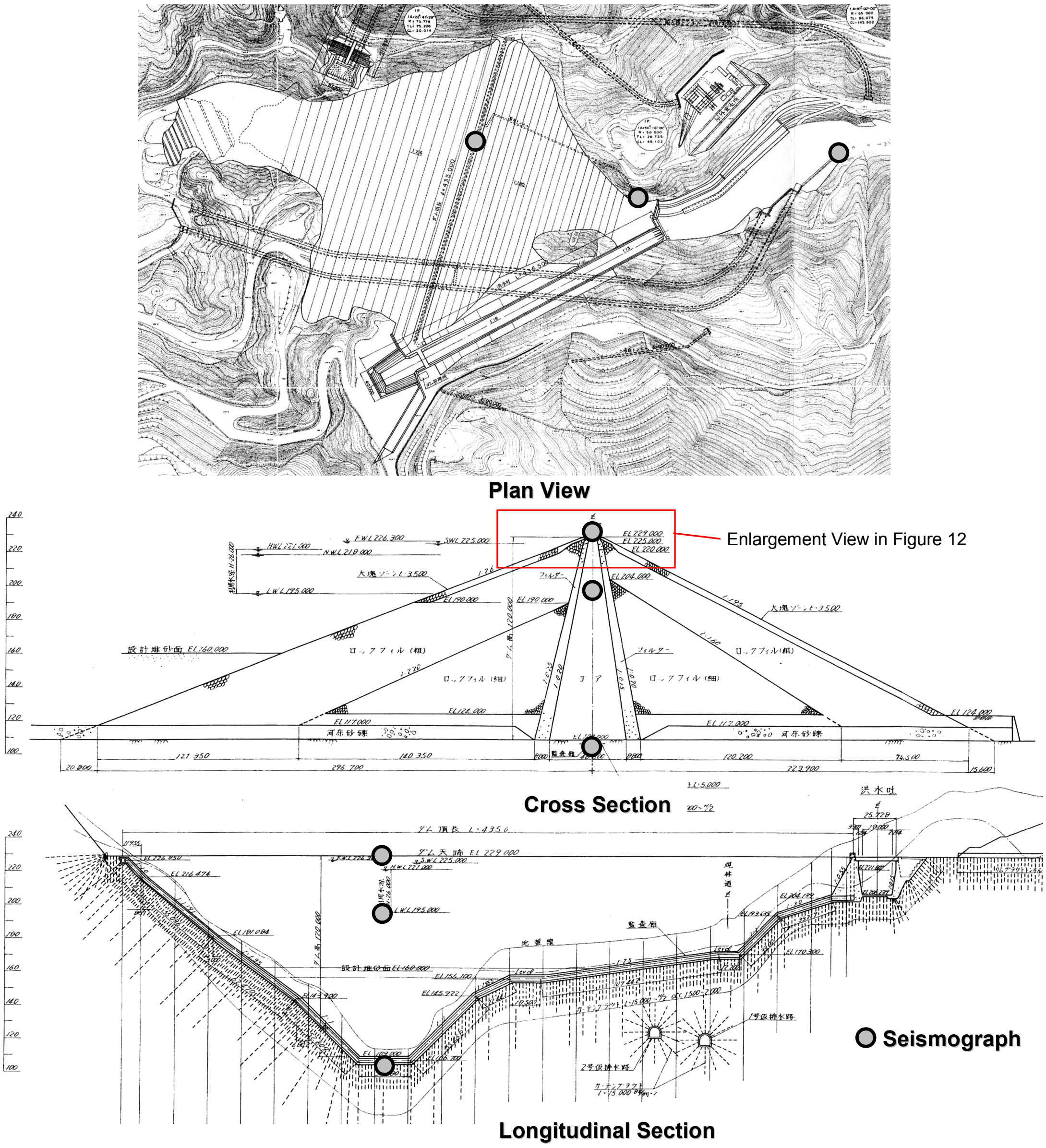


Figure 11 Takami Dam

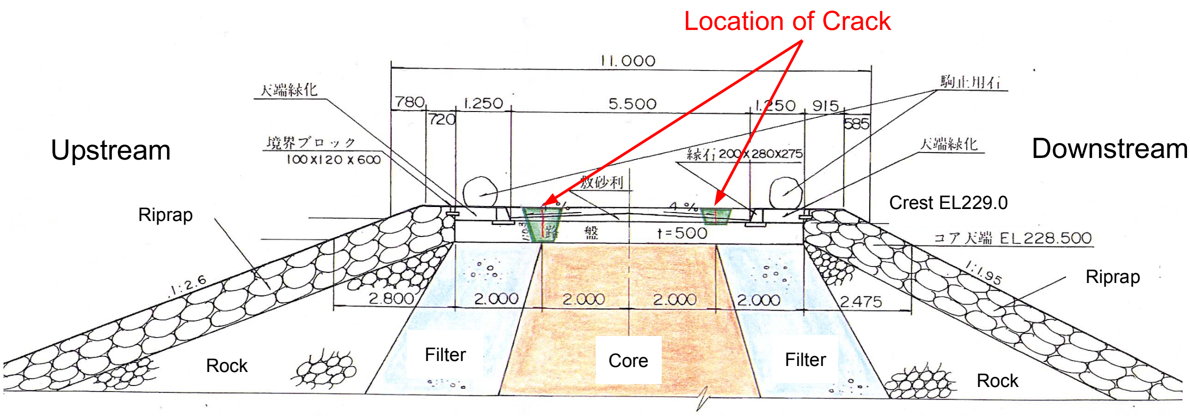


Figure 12 Cross Section near Crest of Takami Dam

Photograph 5 Crack at Crest of Dam
(Takami Dam)

Photograph 6 Survey of Crack Depth by
Exploratory Pit (Takami Dam)

Photograph 7 Protection of Cracks at Crest
(Takami Dam)

Photograph 8 Repair Work of Crack Locations
(View of Excavation) (Takami Dam)

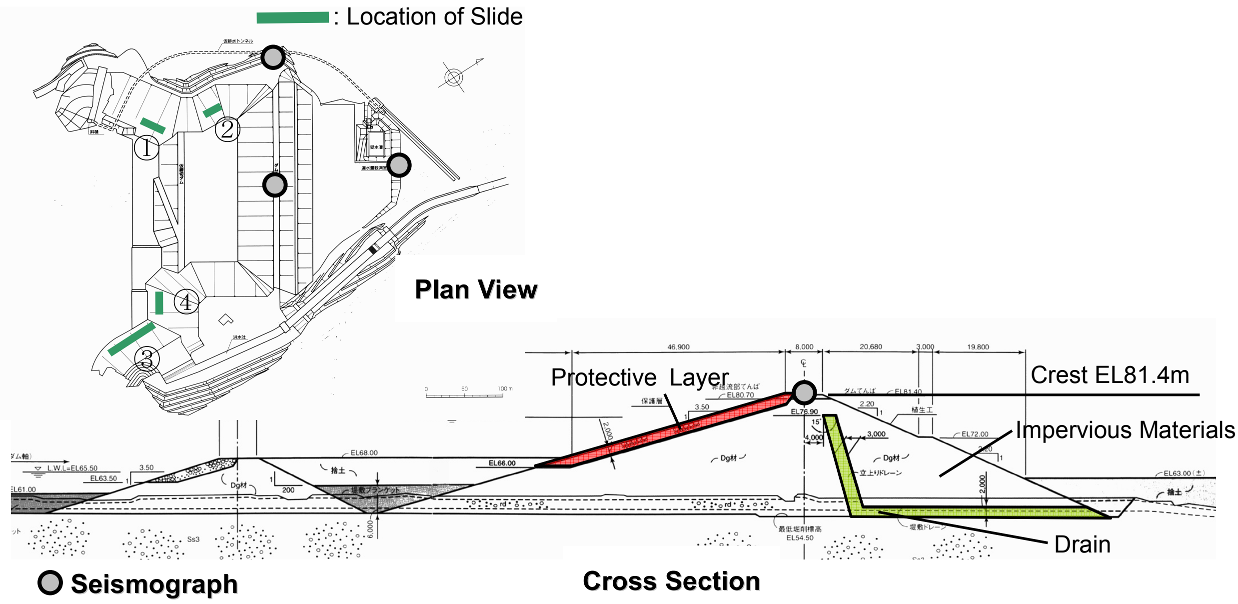


Figure 13 Makubetsu Dam

Photograph 9 Sliding of Protective Rock Layer of Makubetsu Dam

Photograph 10 Sliding of Protective Rock Layer of Makubetsu Dam (Enlargement)

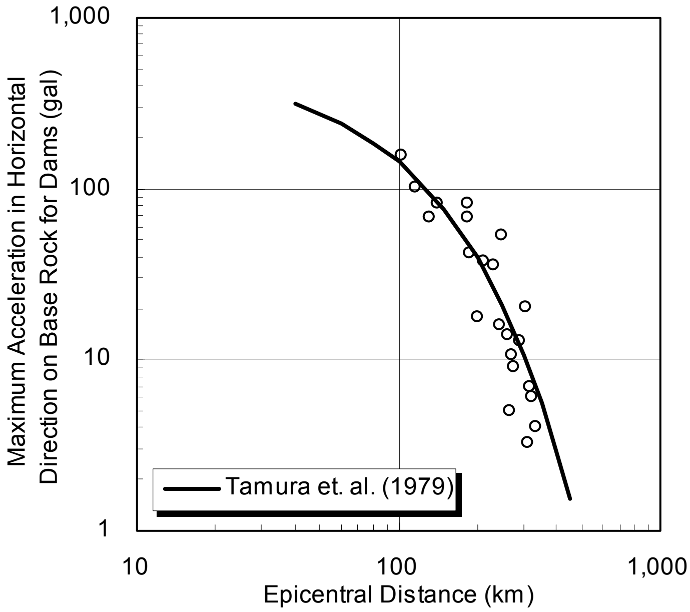


Figure 14 Attenuation of Maximum Acceleration in Dam Foundation Bedrock (Tokachi-oki Earthquake)