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

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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

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 (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) 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. 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. 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

<table>
<thead>
<tr>
<th>Name of earthquake</th>
<th>The Western Tottori Prefecture Earthquake in 2000</th>
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<tbody>
<tr>
<td>Time of occurrence</td>
<td>1:30 p.m. on October 6, 2000</td>
</tr>
<tr>
<td>Epicenter</td>
<td>35°16.5' north latitude 133°21.0' east longitude</td>
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<tr>
<td>Focal depth</td>
<td>11.3 km</td>
</tr>
<tr>
<td>JMA Magnitude</td>
<td>7.3</td>
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</table>
### Table 2 (1) Specifications and Outline of Damage of the Investigated Small Earth Dams for Irrigation

<table>
<thead>
<tr>
<th>#</th>
<th>Name of Earth Dams</th>
<th>Location</th>
<th>Distance from Source Fault (km)</th>
<th>Bedrock geology</th>
<th>Topography</th>
<th>Dam height (m)</th>
<th>Dam length (m)</th>
<th>Crest width (m)</th>
<th>Upstream slope gradient</th>
<th>Downstream slope gradient</th>
<th>Dam body material</th>
<th>Direction of the dam axis (right abutment)</th>
<th>Year constructed</th>
<th>State of damage</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Kinusako Saihaku</td>
<td>Town</td>
<td>0.2</td>
<td>Miocene Volcanic rocks</td>
<td>Mountainous</td>
<td>15</td>
<td>65</td>
<td>4</td>
<td>1:2.4</td>
<td>1:2.4</td>
<td>Red clay</td>
<td>N66°W</td>
<td>Around 1910</td>
<td>- Lateral cracking on upstream slope on the left and right abutments</td>
</tr>
<tr>
<td>2</td>
<td>Tsibakitani Saihaku</td>
<td>Town</td>
<td>0.3</td>
<td>Alluvial layer and Miocene volcanic rocks</td>
<td>Mountainous</td>
<td>15.2</td>
<td>76.2</td>
<td>5.8</td>
<td>1:2.6</td>
<td>1:2.1</td>
<td>N86°E</td>
<td>1885</td>
<td>- Two longitudinal cracks on the center of the dam crest and on the shoulder of the upstream slope</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Natsuyake Saihaku</td>
<td>Town</td>
<td>1.7</td>
<td>Alluvial layer</td>
<td>Hilly</td>
<td>50</td>
<td>4</td>
<td>1:1.7</td>
<td>1:2.1</td>
<td>N88°W</td>
<td>Red clay</td>
<td>- 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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Saigatoge Saihaku</td>
<td>Town</td>
<td>1.7</td>
<td>Miocene Volcanic rocks</td>
<td>Mountainous</td>
<td>4.5</td>
<td>2.8</td>
<td>1:1.6</td>
<td>1:2.0</td>
<td>Decomposed weathered granite</td>
<td>N66°W</td>
<td>- Longitudinal cracks with length of 16 cm on shoulder of the upstream slope at the crest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Sagesatani Saihaku</td>
<td>Town</td>
<td>0.9</td>
<td>Late Mesozoic rocks</td>
<td>Hilly</td>
<td>6</td>
<td>21</td>
<td>2.5</td>
<td>1:2.0</td>
<td>S26°E</td>
<td>- 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.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Yomegoroshi Saihaku</td>
<td>Town</td>
<td>0.9</td>
<td>Late Mesozoic rocks</td>
<td>Hilly</td>
<td>18</td>
<td>65</td>
<td>1:1.2</td>
<td>1:2.0</td>
<td>N85°E</td>
<td>1926</td>
<td>- No damage caused by the earthquake was found.</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>Ohsako Saihaku</td>
<td>Town</td>
<td>0.8</td>
<td>Late Mesozoic rocks</td>
<td>Mountainous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Slide of 7 m long of the road on the reservoir bank</td>
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<td>8</td>
<td>Kamakura No.1</td>
<td>Hino Town</td>
<td>0.4</td>
<td>Alluvial layer and Late Mesozoic rocks</td>
<td>Mountainous</td>
<td>3</td>
<td>100</td>
<td>4.6</td>
<td>1:1.7</td>
<td>N0°</td>
<td>- 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</td>
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<td>9</td>
<td>Kamakura No.2</td>
<td>Hino Town</td>
<td>0.4</td>
<td>Late Mesozoic rocks</td>
<td>Mountainous</td>
<td>4</td>
<td>50</td>
<td>2.5</td>
<td>1:1.7</td>
<td>N18°W</td>
<td>- No damage caused by the earthquake was found.</td>
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<tr>
<td>#</td>
<td>Name of Earth Dam</td>
<td>Location</td>
<td>Distance from Source Fault (km)</td>
<td>Bedrock geology</td>
<td>Topography</td>
<td>Dam height (m)</td>
<td>Dam length (m)</td>
<td>Crest width (m)</td>
<td>Upstream slope gradient</td>
<td>Downstream slope gradient</td>
<td>Dam body material</td>
<td>Direction of the dam axis (right abutment)</td>
<td>Year constructed</td>
<td>State of damage</td>
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<td>10</td>
<td>Odazu</td>
<td>Hino Town</td>
<td>2.3</td>
<td>Diluvial talus deposit layer</td>
<td>Mountainous</td>
<td>4</td>
<td>1.2</td>
<td></td>
<td></td>
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<td></td>
<td>S52°W</td>
<td></td>
<td>- Cracking of concrete of the spillway channel wall</td>
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<td>Yoshi</td>
<td>Hino Town</td>
<td>2.1</td>
<td>Diluvial talus deposit layer</td>
<td>Mountainous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S20°E</td>
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<td>- Longitudinal crack with a length of 15 m on the shoulder of the upstream slope of the dam crest</td>
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<td>Toge</td>
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<td>Late Mesozoic rocks</td>
<td>Mountainous</td>
<td>55</td>
<td>1:1.7</td>
<td>1:1.5</td>
<td></td>
<td></td>
<td></td>
<td>N75°E</td>
<td></td>
<td>- 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</td>
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<td>13</td>
<td>Iwaya</td>
<td>Hino Town</td>
<td>2.4</td>
<td>Diluvial talus deposit layer and Late Mesozoic rocks</td>
<td>Mountainous</td>
<td>40</td>
<td>3.5</td>
<td>1:2.2</td>
<td></td>
<td></td>
<td></td>
<td>S88°W</td>
<td></td>
<td>- Cracking of the concrete of the spillway channel and cracking of the asphalt on the reservoir bank road</td>
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<td>14</td>
<td>Kanayatani</td>
<td>Mizokuchi Town</td>
<td>14.1</td>
<td>Diluvial volcanic rocks</td>
<td>Flat land</td>
<td>40x50x40</td>
<td>4</td>
<td>1:1.6</td>
<td>1:1.4</td>
<td>Decomposed weathered granite</td>
<td></td>
<td>N8°E</td>
<td></td>
<td>- 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</td>
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<td>Late Mesozoic rocks</td>
<td>Hilly</td>
<td>11</td>
<td>55</td>
<td>3</td>
<td>1:1.7</td>
<td>1:2.1</td>
<td></td>
<td>N12°E</td>
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<td>- An 8 m long slip down of the reservoir cliff</td>
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<td>12.3</td>
<td>Alluvial layer and Late Mesozoic rocks</td>
<td>Hilly</td>
<td>65</td>
<td>3</td>
<td>Almost vertical because of erosion</td>
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<td></td>
<td>N10°W</td>
<td></td>
<td>- Longitudinal cracking on the shoulder of the upstream slope at the crest</td>
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<td>Choryuji</td>
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<td>7.6</td>
<td>Late Mesozoic rocks</td>
<td>Mountainous</td>
<td>8</td>
<td>18</td>
<td>3.5</td>
<td>1:1.7</td>
<td>1:1.6</td>
<td></td>
<td>S45°W</td>
<td></td>
<td>- 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</td>
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<tr>
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<td>Tomue-shin</td>
<td>Mizokuchi Town</td>
<td>14</td>
<td>Diluvial volcanic rocks</td>
<td>Hilly</td>
<td>4</td>
<td>40</td>
<td>3.5</td>
<td>1:1.4</td>
<td></td>
<td></td>
<td>N8°W</td>
<td></td>
<td>- 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.)</td>
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</table>
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)
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)

Figure 5: Downstream View and Cross Section of the Kasho Dam and Locations of Seismographs
Figure 6 Earthquake Records at the Kasho Dam
Figure 7 Acceleration Response Spectra at Lower Inspection Gallery of the Kasho Dam