ICOLD 75th Annual Meeting
Saint Petersburg, Russia, June 24-29, 2007

*Symposium: «Dam Safety Management. Role of State, Private Companies and Public in Designing, Constructing and Operating of Large Dams»*

# Comprehensive Inspections and Evaluations of Existing Dams and Special Inspections for Dam Safety after Earthquakes in Japan

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## Introduction

Surveillance of dams in Japan is classified into First, Second and Third periods based on years since the first reservoir filling and the dam behavior stabilize. The regular inspections for aging and deterioration of the existing dams as well as special inspections for dam safety immediately after earthquakes are important for dam safety management on the Third period.

The Japan Dam Engineering Center (JDEC) has performed the comprehensive inspections and evaluations of the existing dams in order to maintain the functions and ensure the safety at 135 dams. Where a problem is identified, JDEC provides advice on identifying the problems and determining the repairs.

As a country with a seismically active, Japan also has standards regarding special inspections for the dam safety after earthquake. The dam operators must conduct the special inspections immediately after an earthquake in accordance with the standards, and that repairs of the dams and appurtenant works are carried out where necessary.

This paper reports on comprehensive inspections and evaluations of the existing dams and special inspections for dam safety after earthquakes as part of the dam safety management in Japan.

## Periods of dam surveillance and monitoring intervals in Japan

Regular inspection of dams has been carried out by the operating personnel of each dam in accordance with guidelines issued by the Ministry of Land, Infrastructure and Transport (MLIT) and Japanese National Committee on Large Dam. Table 1 shows the minimum required measurements for each type of dam. Surveillances of dams are classified into First, Seconds and Third periods according to the years since the first reservoir filling and the dam behavior stabilize. Table 2 shows the monitoring intervals for the various measurement items in each period of surveillance.

First period is the test reservoir filling, which provides the dam owner with the first genuine opportunity to evaluate the safety of the dam in operation. The safety for the problem during construction is confirmed at the First period, and repaired if necessary. Measurements often include monitoring equipment for stress and strain to accommodate future advances in dam design. The measurement observations obtained at the test reservoir filling are adopted as the safety standards for the dam. The results of the test filling are used to identify surveillance items of important for the Second period.

Second period lasts from the end of First period until the dam body behavior stabilizes. The second period takes a minimum of approximately three years. During Second period, the dam owners may need to perform additional repairs and modifications in order to resolve problems identified during First period. The gauge embedded in the dam body is aging, and the measurements of gauges are ended during Second period. It is thus important to complete an analysis of dam body behavior based on measurement results at this period. Also, the dam owners will need to determine the location and frequency of water seepage and deformation measurements to be undertaken during Third period.

Third period is characterized by stability, where dam body behavior follows a similar trend year after year, and also by the gradual aging of the dams and appurtenant works. The list of measurement items in Table 1 is narrowed down to the minimum essential items only. Visual inspection for signs of aging takes on greater importance. Dam owners conduct visual inspections for increased seepage from aging sluice gates, evidence of new cracks, and mud flow through drilling holes on foundation.

**Table 1 Dam types and measurements**

| Type of dam | | Dam height | Measurements |
|---|---|---|---|
| Concrete gravity | | Not higher than 50 m | Leakage, Uplift |
| | | Higher than 50m | Leakage, Uplift<br>Deformation |
| Concrete arch | | Not higher than 30 m | Leakage, Uplift |
| | | Higher than 30m | Leakage, Uplift<br>Deformation |
| Embankment | Homogeneous | Any | Leakage, Deformation<br>Saturation line |
| | Zoned | Any | Leakage, Deformation |

**Table 2 Periods of surveillance and monitoring intervals**

| Period of Surveillance | Type of dam | Intervals of monitoring with the type of measurements | | | |
|---|---|---|---|---|---|
| | | Leakage | Uplift | Deformation | Inspection patrol |
| First period (First reservoir filling) | Concrete | a day | a day | a day | a day |
| | Embankment | a day | | a week | a day |
| Second period (Minimum three years after first period) | Concrete | a week | a week | a week | a week |
| | Embankment | a week | | a month | a week |
| Third period (After finishing the second period) | Concrete | a month | a month | a month | a month |
| | Embankment | a month | | three months | a month |

Second period is defined as the period from the end of First period until such time as the dam behavior stabilizes

**Dam safety management in Third period**

Dam safety management in Third period revolves around regular inspections of routine for aging and deterioration of dams and special inspections for dam safety after earthquakes. In accordance with the measurement items and frequencies listed in Tables 1 and 2 respectively, the operators inspect dams that are owned by MLIT regularly. Dam operators are also required to conduct the systematic regular inspections (normally once every three years, or once every five years for small dams). Meanwhile, JDEC performs the comprehensive inspections and evaluations of the existing dams in order to maintain the functions and ensure the safety of the dam.

MLIT has decreed that special inspections be carried out immediately after an earthquake in order to confirm the seismic resistance of the dam. If seismic strong motion exceeds the prescribed threshold for a given dam site, the dam operator must perform a special inspection consisting of a primary inspection and a secondary inspection. The special inspection is designed to confirm the safety status of the dam. Any damage identified in the inspection must be repaired immediately.

**Comprehensive inspections and evaluations of the existing dams**

JDEC has thus far conducted 135 comprehensive inspections and evaluations of the existing dams to maintain the functions and insure the safety. The comprehensive inspections and evaluations of the existing dams are based on a facility inspections focused on safety and a function inspection that evaluated the suitability of the flood control. Figure 1 shows the number of MLIT dams subjected to comprehensive inspections and evaluations against the age in years since completion. Dams aged 20 to 30 years are given the highest priority for inspection. Normally around five dams are inspected per year.

Table 3 shows the main considerations in dam comprehensive inspections, including concrete aging and cracking in the surface of dam body, and sluice gate operation and water seepage. After conducting a dam comprehensive inspection, JDEC provides an overall evaluation of dam performance, along with recommendations such as modifications to facilities and operational improvements. The dam owners then prepare detailed action plans based on the recommendations. For instance, a comprehensive inspection of the 52-year-old Sabagawa dam (gravity dam, height 54 m, completed 1955) found advanced deterioration in the crest gate lifting mechanisms and the gate stop seals. The gates were reconditioned as shown in Picture 1, and the gate height was increased to accommodate outlet discharge.

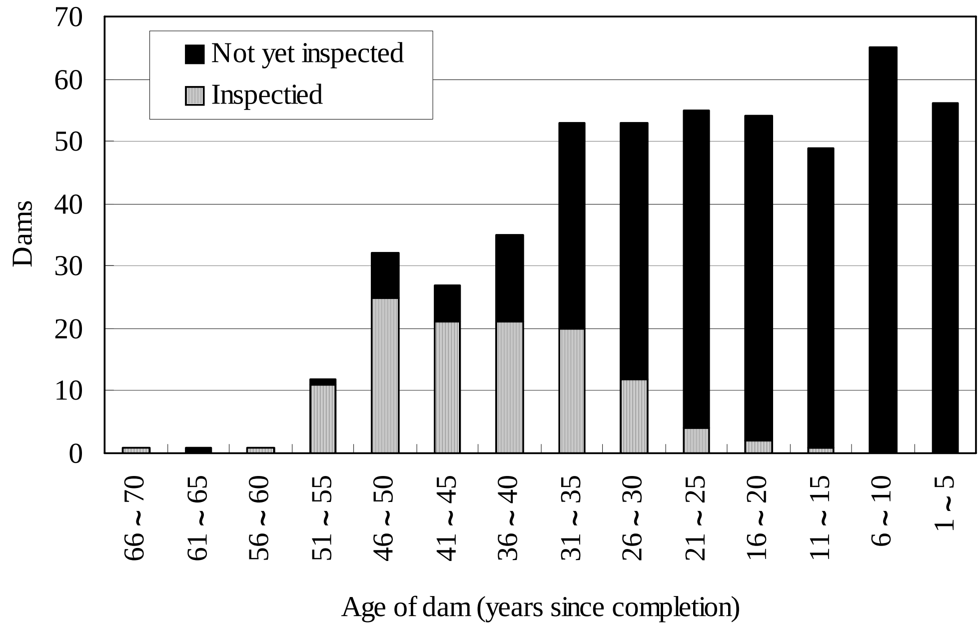


**Figure 1 Dams of comprehensive inspections and evaluations by JDEC and the age of dams**

JDEC conducted follow-up surveys at the 110 dams of inspections and evaluations to assess the response to the comprehensive evaluations. Figure 2 shows the results. Of the 108 dams issued with improvement recommendations, 97% subsequently implemented the recommendations. The implementation rate was 73% of the 692 recommendations. Recommendations based on on-site investigations accounted for the majority (nearly 70%); of these, 33% were concerning the dam and foundations, while a further 47% were concerning the gates. In this way, the comprehensive inspections and evaluations of the existing dams by JDEC play an important role in promoting the upgrading and maintaining of existing dam structures.

**Table 3 Main considerations in comprehensive inspections and evaluations**

| | |
|---|---|
| Dams and foundations | • Concrete degradation and exfoliation<br>• Seepage through joints<br>• Cracks in surface of dam body<br>• Corrosion of steel reinforcement<br>• Gaps and offset in surface containment plates<br>• Scouring and other damage on energy dissipaters<br>• Seepage through dam body (particularly edge abutments) |
| Outlets | • Insufficient gate lift affecting abnormal flood discharge<br>• Damaged gate skin plates<br>• No roof on machinery control room<br>• Rusting gates, seepage through packing, surface damage to cables, exfoliation of paint coating<br>• Cracking due to age in gate lifting platform<br>• Faulty gate machinery/electrical equipment (such as lifting machinery and control panels)<br>• Faulty water utilization valves |
| Management facilities | • Roadway of dam top in poor condition requiring immediate repairs<br>• Safety concerns due to lack of instrumentation for measuring uplift, displacement and seismographs |
| Other | • Rate of sedimentation is 2 – 3 times faster than initially expected<br>• Water quality in reservoir exceeds standards (e.g. SS, COD)<br>• Insufficient crest height in current design standards (Design flood standard different) |

**Picture 1　Sabagawa dam (reconditioned gates)**

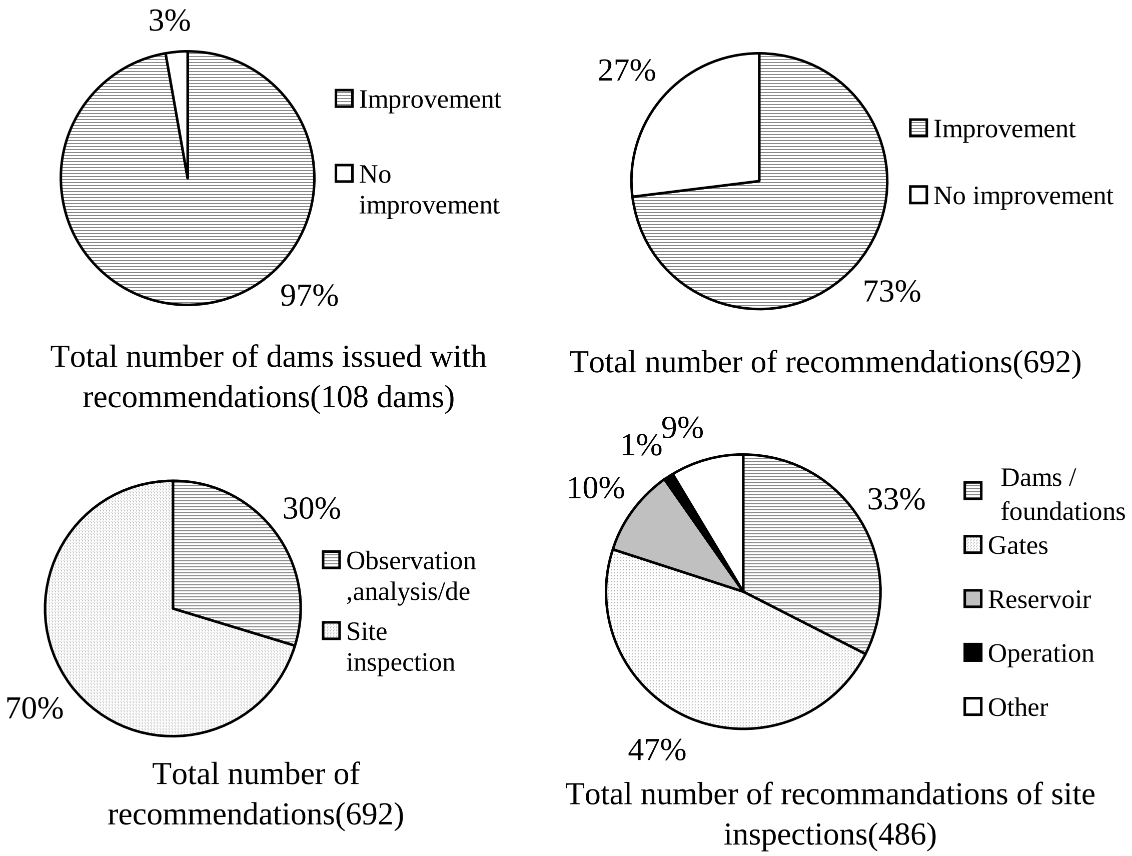


**Figure 2　Recommendations of comprehensive inspections and evaluations by JDEC**

## Special inspections for dam safety after earthquakes

Figure 3 shows the procedure for special inspections for dam safety after earthquakes. Seismographs are being installed at dams throughout Japan as a means of determining when such inspections are required. In the event of an earthquake in the vicinity of a dam with a peak acceleration of at least 25 gal on the Japanese scale (as recorded by the seismograph in the dam foundations for dam safety) or a maximum seismic intensity of at least four (as proclaimed by the Bureau of Meteorology), the dam operator must be required to conduct immediately a special inspection for dam safety. The special inspection consists of a visual primary inspection for damage, to be conducted within 3 hours of the earthquake, followed by a more detailed secondary inspection involving further visual inspection and taking measurements, to be conducted within 24 hours.

| Earthquake occurs |
|---|

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| | |
|---|---|
| Threshold for special inspection | Peak acceleration of at least 25 gal (as recorded by the seismograph on the dam foundations) or a maximum seismic intensity of at least four (as proclaimed by the Bureau of Meteorology) in the vicinity of the dam |

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| | | |
|---|---|---|
| Special inspection | Primary (to be conducted within three hours) | Visual inspection<br>Inspection items: dam body and abutments, ground, outlet works, telecommunications equipment |

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| | | |
|---|---|---|
| Special inspection | Secondary (to be conducted within 24 hours) | Detailed visual inspection plus measurement<br>Inspection items: all items from primary inspection plus measurement items (incuding seepage and deformation), reservoir surrounds and discharge warning equipment |

**Figure 3 Procedure for special inspections for dam safety after earthquake**

Table 4 summarizes the results of special inspections for dam safety performed in recent years in Japan. In the 2000 Tottori-Ken Seibu Earthquake, peak acceleration of 531 gal was recorded by seismograph in the inspection gallery on the Gasho dam. However, the earthquake did not damage the safety of the dam. Other earthquakes have caused damage to sections of the dams and appurtenant works, but none have had any lasting effect on the overall functions of the dam.

**Table 4 Results of recent special inspections**

| Date | | Name | M | Depth (km) | Maximum seismic intensity | Special inspection | Peak acceleration | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Number of Dams | Dam | (gal) |
| 2000.10.6 | 13:30 | Tottori-ken Seibu earthquake | 7.3 | 10 | 6+ | 180 | Gasho dam | 531 |
| 2003.5.26 | 18:24 | Miyagi-oki earthquake | 7.1 | 72 | 6- | 154 | Tase dam | 232 |
| 2003.9.26 | 4:50 | Tokachi-oki earthquake | 8.0 | 45 | 6- | 74 | Kuttari dam | 113 |
| 2004.10.23 | 17:56 | Niigata-ken Chuetsu earthquake | 6.8 | 13 | 7 | 114 | Kawanishi dam | 558 |

In the 2003 Tokachi-oki earthquake, the Sahoro dam — a concrete gravity dam of height 46.6 m, completed in 1984 — recorded a peak acceleration of 84 gal and experienced a sharp increase in seepage directly afterwards. Figure 4 shows total seepage over time since the completion of the dam. The quantity of seepage was much during the test reservoir filling but declined steadily thereafter to an average of 10 l/min in the period directly prior to the earthquake.

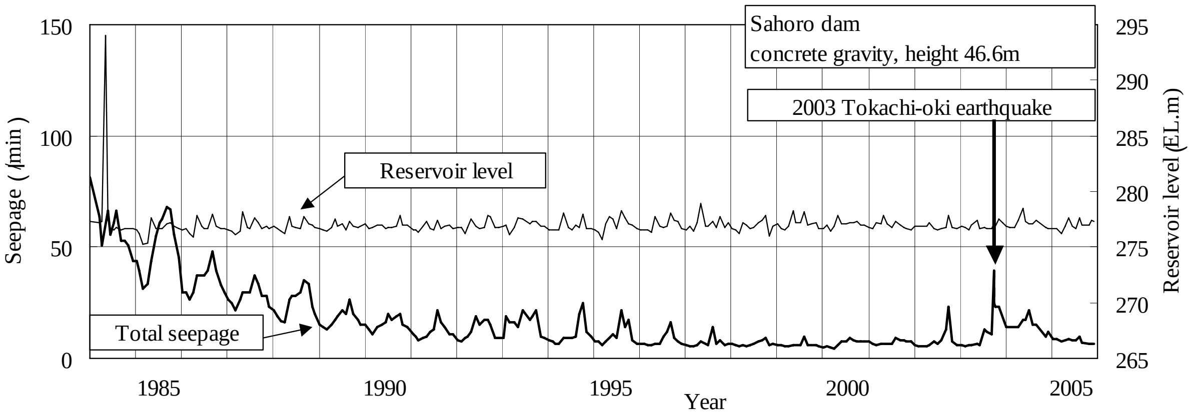


**Figure 4 Increase in seepage at Sahoro dam after the Tokachi-oki Earthquake**

Figure 5 shows the correlation between the reservoir level and the seepage rate. The seepage increased sharply after the earthquake, with the reservoir level in the range EL 276.5 – 277.0 m. The quantity of seepage was actually higher during the test reservoir filling when the reservoir level was at a similar height, mainly due to seepage through joints and foundation drilling holes. Over time, these escape paths normally block up with rubbish and suspended matter such as free lime, and the rate of seepage declines. The strong ground motion loosened the blockage materials, causing an increase in seepage, but this is thought to be only temporary, and seepage levels are expected to return to normal. Provided that the seepage rate after an earthquake is less than the rate during the test reservoir filling, it can be safely concluded that the earthquake has not created any new seepage paths.

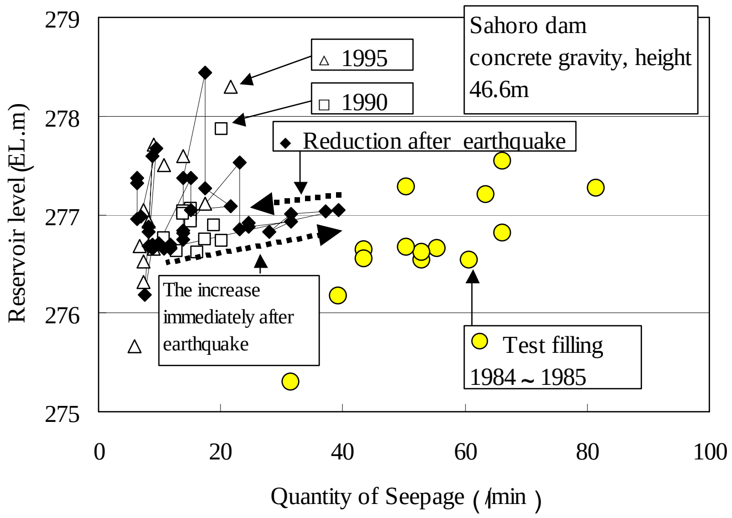


**Figure 5 Correlation between reservoir level and seepage (Increase of seepage after Tokachi-oki earthquake)**

Figure 6 shows the effect of the 2003 Tokachi-oki earthquake on uplift at Samani dam (a concrete gravity dam of height 44 m completed in 1974). Uplift is defined as the water level as determined by the measuring equipment, divided by the converted water head value, which eliminates the effect of changes in the reservoir level. During the test reservoir filling, burdon pressure gauges 17 and 18 recorded high uplift values of around 0.3, but these had low to around 0.08 directly before the earthquake. After the earthquake, the uplift values increased immediately their former levels, suggesting that the uplift paths had returned to the condition during the first reservoir filling within a narrow range. Uplift has declined thereafter, suggesting gradual progress towards stabilization.

Special inspections for dam safety after earthquakes often reveal sharp increases in seepage and uplift values. The dam operator can readily determine whether these increases represent a significant change in the dam structure, simply by comparing them to the corresponding values at the test filling stage. If the post-earthquake values are lower than the test filling values, this indicates that the earthquake has not created new seepage path; if the values are higher, however, the possibility of new seepage path means that a more detailed inspection and evaluation will be required. The dam behavior must be supervised carefully when the seepage and uplift value increase gradually. It is important that dam operators arrange in advance the data of the test reservoir filling, so that in the event of an earthquake, comparisons can be made with the data of the special inspection, and the safety of dams can be evaluation.

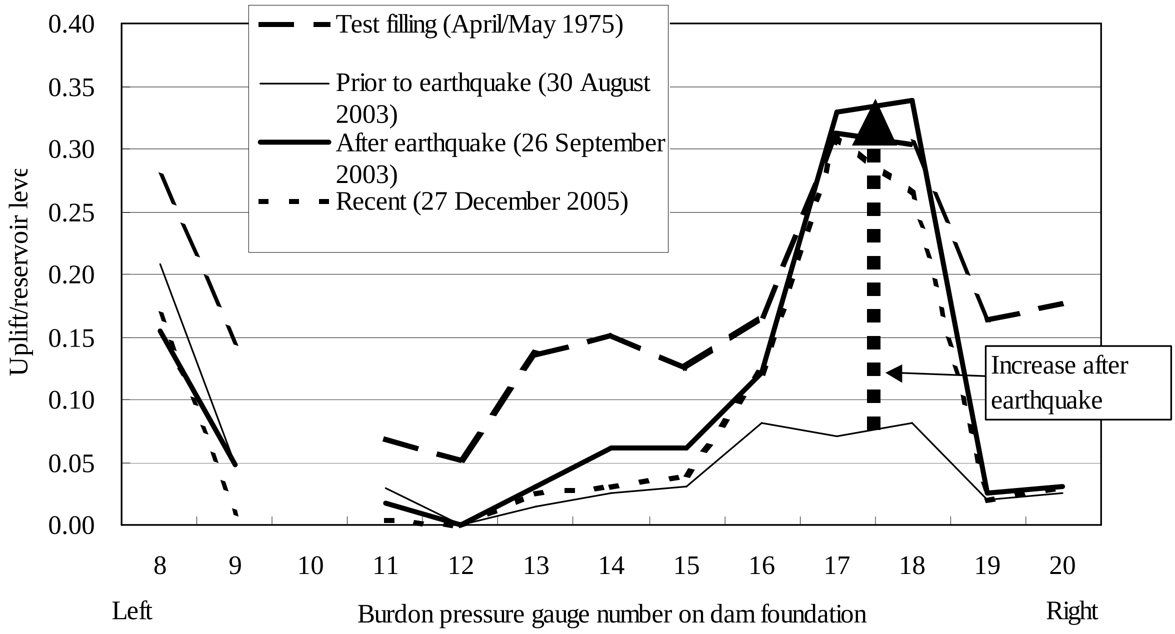


**Figure 6 Uplift/water pressure converted reservoir level at Samani dam (Increase of rate after Tokachi-oki earthquake)**

## Conclusions

This paper has discussed dam safety management of Third period in Japan, particularly with respect to the comprehensive inspections and evaluations of aging dams and special inspections for dam safety after earthquakes. Japan has an increasing number of dams that are still in operation over some 50 years after completion, so it is important to conduct intentionally the dam comprehensive inspections and evaluations in order to maintain the functions and ensure the safety of dams. Similarly, it is important that the dam operators arrange in advance the data of the test reservoir filling for comparison purposes in the event that a special inspection becomes necessary. Every dam operator should produce an earthquake inspection manual and ensure that personnel are familiar with the emergency response procedures.

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