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Study of Efficient Maintenance of Dams

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ABSTRACT:
The number of dams in Japan directly managed by Ministry of Land, Infrastructure, Transport and Tourism (hereinafter call MLIT) which have been in service for 50 years or longer will double from their present level in the next 10 years and increase 3.5 times in the next 20 years. To efficiently manage dams with limited maintenance budgets and personnel, maintenance costs and labor requirements must be reduced.
We performed a full inspection of a dam constructed 50 years ago, the Futase Dam on the Arakawa River of the Arakawa River Systems. Based on the results, we then performed case studies of efficient maintenance of the dam body.
As a result of the research, regarding efficient maintenance methods, a number of proposals were made from the perspectives of (1) ensuring reliability of measurement data, (2) monitoring deterioration, (3) preparing to large earthquakes, (4) and building and using databases.

Keywords: Bathtub curve, maintenance, deterioration, large earthquake

1. BACKGROUND OF THE STUDY AND OVERVIEW OF THE FUTASE DAM

The number of dams in Japan directly managed by MLIT which have been in service for 50 years or longer will double from their present level in the next 10 years and increase 3.5 times in the next 20 years. A dam body deteriorates as its period of service increases, so the maintenance cost increases with age. However, dam maintenance budgets and the number of maintenance personnel are both expected to continue to decrease in the future.

To efficiently manage dams with limited maintenance budgets and personnel, maintenance costs and labor requirements must be reduced. MLIT is therefore introducing service life extension guidelines for its facilities in order to lower the cost of renewing public capital, which is expected to increase in the future. This guideline stipulates a policy of emphasizing preventive maintenance to extend the period until renewal is necessary by selecting, and concentrating existing inspection and repair methods.

First, we performed a full inspection of a dam constructed 50 years ago, the Futase Dam on the Arakawa River of the Arakawa River System. Based on the results, we then performed case studies of efficient maintenance of the dam body .

Fig.1. shows a panoramic photograph of the dam. Table 1. provides an overview of the Futase Dam, which was used for the case study.

Fig.1. Panoramic view of the Futase Dam

Table 1. Overview of the Futase Dam

Dam (Reservoir name)	River System	River	Management Office	Location	Year completed	Manager
Futase Dam (Lake Chichibu)	Class A Rivers Arakawa River System	Arakawa River	Futase Dam Management Office	Otaki, Chichibu City, Saitama Pref.	1961	MLIT

Type	Arch gravity dam	Purpose	Flood Control , Irrigation , Hydropower
Dam height	95.0 (m)	Total reservoir capacity	26.9 million m^3
Crest length	288.5 (m)		
Dam body volume	356 thousand m^3	Effective reservoir capacity	21.8 million m^3
Catchment area	170.0 (km^2)	Flood control capacity	21.8 million m^3
Reservoir area	0.76 (km^2)	Water utilization capacity	20.0 million m^3 (Breakdown) Irrigation: 16 million m^3 Hydropower: 20 million m^3

2. EFFICIENT MAINTENANCE OF DAM BODY

2.1 Period of Service of the Dam and Management Priorities

Fig.2. shows a so-called “bath-tub curve” to explain the relationship between the malfunction rate of mechanical equipment and its period of service. Curve (1) in the figure represents malfunctions based on an early abnormality, curve (2) those caused by deterioration, and curve (3) those caused by large external force. The curve obtained by combining these three curves is shaped like a bath-tub, hence its name, and shows the relationship between malfunction rate and period of service of a dam body.

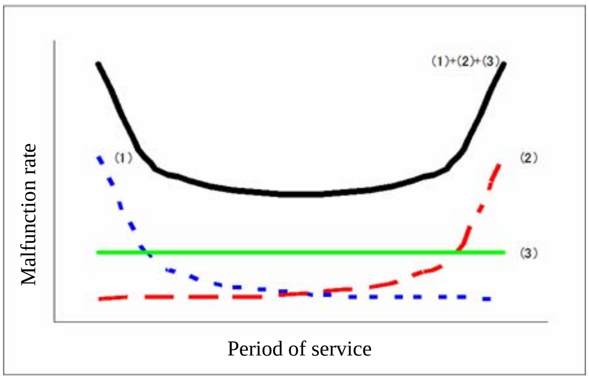

Fig.2. Bath-tub curve

(1) Early abnormalities
Early abnormalities, which are caused by faulty construction of the dam body or a defect in the foundation ground, are likely to be found during initial impounding, and so are less likely to occur as time passes. Therefore, this rate is shown by curve (1).

(2) Deterioration
Deterioration of dam body facilities causes curve (2), because the deterioration progresses as time passes. Generally, the concrete of a dam body neutralizes and slowly loses strength, and cracking of concrete is a problem at some dams. Lumps of concrete fell from the body of the one arch dam in 1999 (22 years after completion) and at the another arch dam (35 years). In response, a nationwide survey of cracking in dam body concrete was carried out, and the results clearly revealed such cracks at many dams. This highlights the importance of monitoring the cracking of concrete dams.

(3) Large external force (large earthquake)
The probability of some malfunction in a dam body caused by a large earthquake is a straight line (3) because it does not change over time.

Thus, the three causes of dam abnormalities are early abnormalities, deterioration, and large external force, and so management priorities must change according to the period of service of the dam. At newly constructed dams, the priority is on monitoring early abnormalities. But, at dams such as the Futase Dam which has been in service for about 50 years, priority is on monitoring deterioration and large external force.

In general, a dam which has been in service for 5 to 10 years or more since completion displays constant stable behavior over time related to the reservoir level or external air temperature. Therefore, patrols, inspections, and measurements of the dam body usually focus on particular locations only in order to roughly estimate the behavior of the dam body. Once early abnormalities have been monitored for 50 or more years for a dam since completion, it is necessary to shift the management priority to monitoring deterioration.

During the many large earthquakes that have struck Japan in recent years, strong earthquake motion has been observed at dams. Large dams or dams with large-capacity reservoirs located upstream from large cities are important structures, so it is necessary to quickly and accurately manage their safety in case of large external force (large earthquake).

At the Futase Dam, to monitor deterioration and to respond to large earthquakes, another priority is to reduce maintenance costs by reviewing, selecting, and centralizing past monitoring, inspection, and measurement methods.

2.2 Concept of the Efficient Management of Dams

(1) To efficiently maintain a dam body, the priority of future maintenance shifts to monitoring deterioration and responding to large-scale earthquakes.

(2) Monitoring of deterioration focuses on locations where the progress of deterioration must be watched carefully based on the results of comprehensive inspections. It is impossible to identify cracking of the downstream slope of the dam body by normal patrols and inspections, and so new measurement technologies are being studied. If a new method is found to be useful in terms of measurement precision or economic benefits, it will be actively introduced to lower maintenance costs.

(3) To respond to large earthquakes, safety management is performed in order to be able to immediately determine whether an earthquake has damaged a dam body and if it has, to identify the locations of damage. Foundation drainage holes are re-bored at one or more locations in each block of the dam body and used to manually measure leakage and uplift pressure about once a month.

(4) The measurement results are stored in a database, and then used to set safety management standard values and monitor changes in behavior over time. If the measured values show a tendency to rise or fall, the causes are assessed and appropriate measures are taken, such as making improvements or revisions according to circumstances.

2.3 Efficient Maintenance Methods at the Futase Dam

2.3.1. Ensuring reliability of measured data

Monitoring of a dam to evaluate its safety is premised on the reliability of the measured data. Fig.3. shows the layout of the measuring instruments at the Futase Dam. Overall inspections have shown that to ensure data reliability, the following factors must be measured.

[1] Leakage

Total leakage by the left and right bank is measured at a triangular weir in the deepest part of the inspection gallery (9BL). A view of the weir is shown in Fig.3.: material adhered to it might prevent accurate measurements.

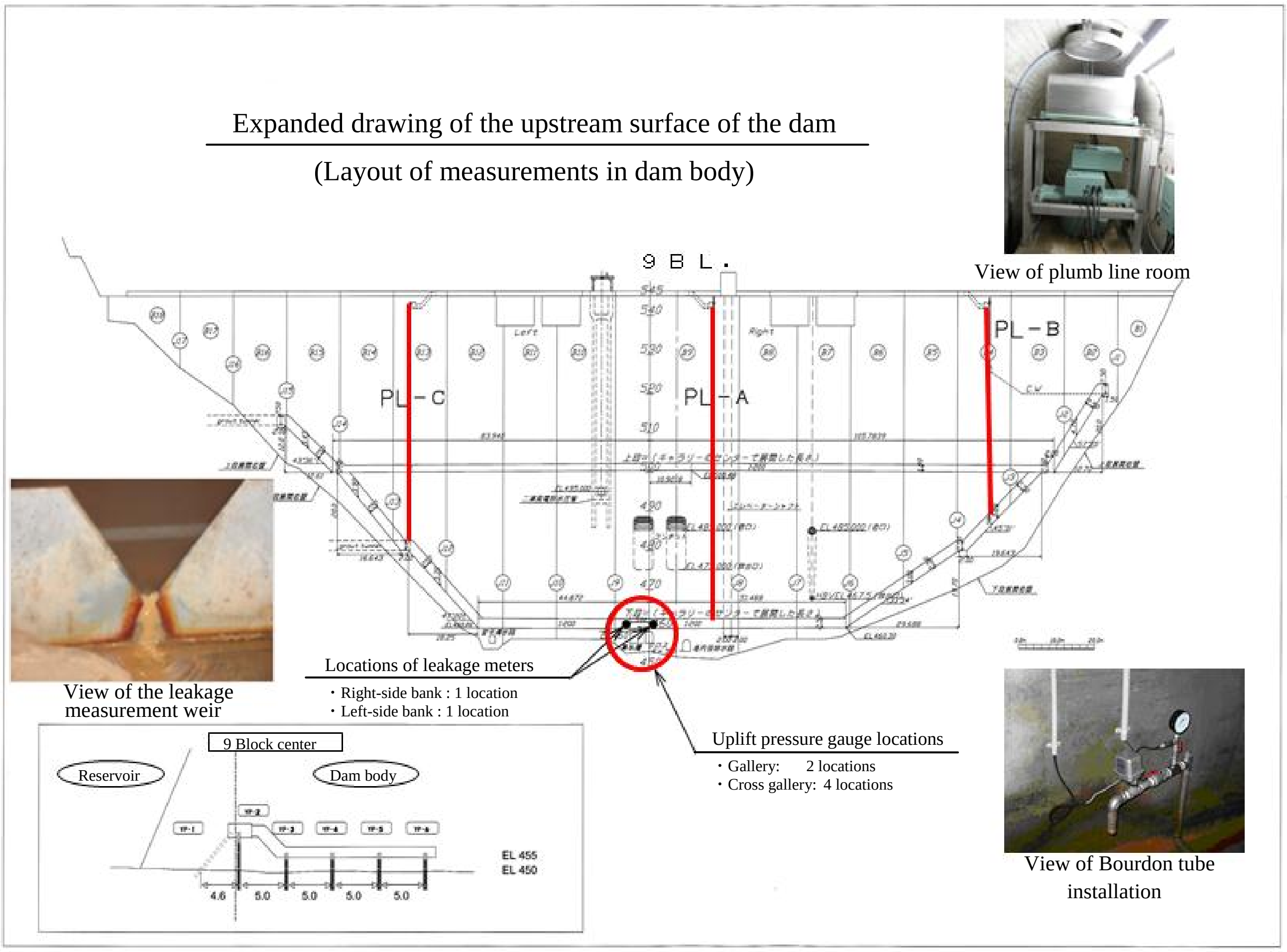

Fig.3. Locations of measuring instruments

To improve this, the weir must be regularly cleaned at the same time as cross-checking the actual flow rate and measured flow rate (including the actual depth and measured depth).

[2] Deformation
The deformation is measured at the maximum section (9BL: PL-A) and at the plumb lines on a total of three measurement lines on the left and right banks. A view of the plumb line room is shown in Fig.3.
Actual deformation and measured deformation (system transmission value) must be cross-checked.

[3] Uplift pressure
Uplift pressure is measured at six points in the upstream and downstream direction on the maximum section (9BL) and in the Bourdon tube. A view of the Bourdon tube installation is shown in Fig.3. , and Fig.4. shows the results of a Bourdon tube valve closing test.

The data shows that in the open state before closing the valve, pressure (about 0.02 to 0.03 MPa) was measured, so it is necessary to review the initial value setting and to confirm the consistency of the values indicated on site with the measured values (system transmitted value).

2.3.2 Monitoring deterioration
1) Priority items for deterioration monitoring
Among the problems identified by the preceding overall inspection, monitoring of the following items must be given priority in order to monitor deterioration.

i) Monitoring rising leakage
Fig.6. shows the change over time of leakage (total amount) in recent years, and Fig.5. shows the correlation of reservoir level with leakage.

Leakage is not high overall, but in recent years, during the period of high reservoir level (winter to spring), it tends to rise. Leakage is closely correlated with air temperature and reservoir temperature. And we already know that most leakage occurs from joints (J2, J3, J5, etc.) by a 2005 survey. So it is assumed that leakage from joints increases.

It is therefore necessary to regularly measure leakage from individual joints to identify the joints that are causing the increase in leakage and to monitor leakage from those joints.

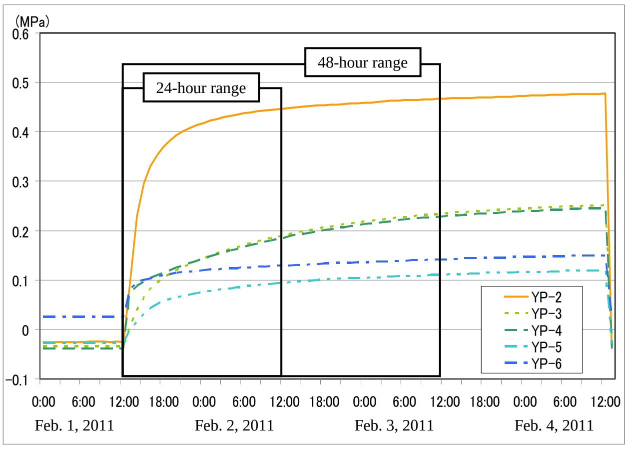

Fig.4. Results of valve closing test of the Bourdon tube

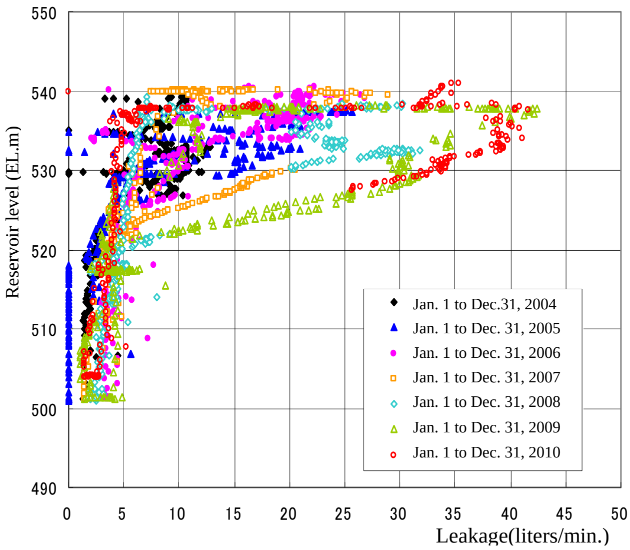

Fig.5. Correlation of roir level and leakage

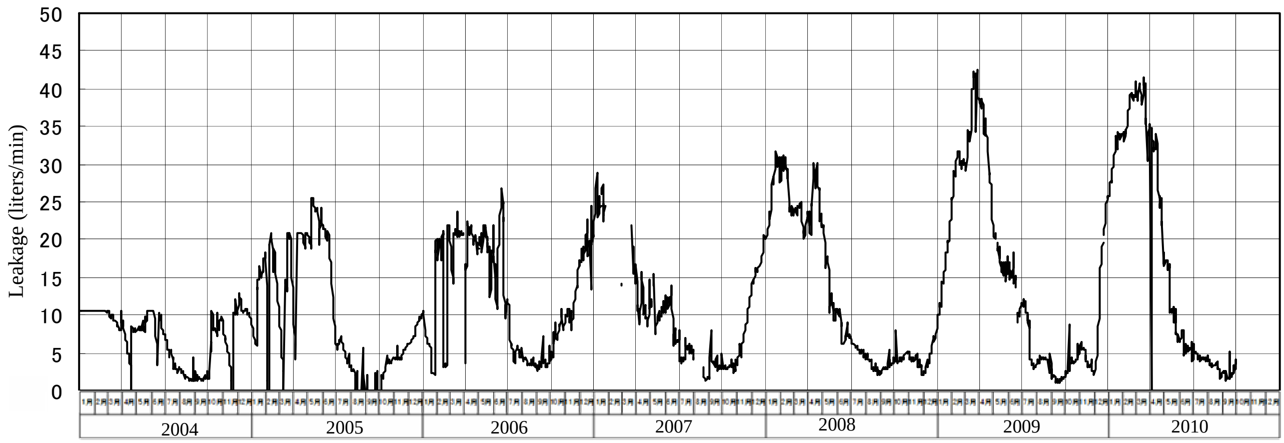

Fig.6. Chart of change of leakage over time

ii) Monitoring deterioration and deformation of dam body

As examples of deterioration or deformation of a dam body, Figs.7. to 9. show views of cracking of downstream piers of crest bridges and level differences of piers and crest bridges (max. subsidence of the bridge = approx. 4 cm).

Bridge subsidence is likely to be caused mainly by deterioration or crushing of supports, and may damage downstream piers. It is therefore necessary to perform monitoring with priority on whether the deformation is advanced. Detailed surveys must also be performed to identify the causes of deformation and to study and implement countermeasures.

2) Items which can be relaxed

Reduction in the frequency or termination of measurement of the following items when stipulated conditions are satisfied should be studied.

i) Patrol frequency

Because the Futase Dam body appears to be stable, patrol inspections of its condition are now performed once a week, but when a dam has been in service for 5 to 10 years, the standard patrol inspection frequency may be relaxed to once a month.

ii) Measuring deformation

Double control, by plumb lines and by a total station, is performed. A comparison of precision shows that plumb lines are generally superior, so if plumb line measurements have been reliable, the total station measurements can be terminated.

3) Adoption of new measurement technologies

In order to evaluate the soundness of dam body concrete, detailed surveys of cracking on the downstream surface of the dam body and observations of the change of cracking over time are effective. However, such measurements have not yet been done.

In recent years, many new technologies have been developed to survey the distribution of cracking of large structures, including total stations with built-in crack scales, digital cameras, and Computer Assisted Drafting (CAD) techniques. Furthermore, many new technologies have been developed to survey the depth of cracks, including those applying phase variation and damping of surface waves during elastic wave diffraction.

The relative merits of these new technologies are likely to vary according to the location where used. Therefore, technology for objectively evaluating their applicability to the Futase Dam and confirming that their measurement precision and economic efficiency are beneficial must be adopted.

2.3.3 Preparing to large earthquakes

After a large earthquake, it is essential to determine immediately whether the dam body has been damaged and the locations of such damage. Effective ways to do this are to measure the leakage and uplift pressure at each location, then these values can be used as indexes of whether any change has occurred by comparing them with values during first filling and at normal situation.

Fig.7. View of cracking of the downstream pier

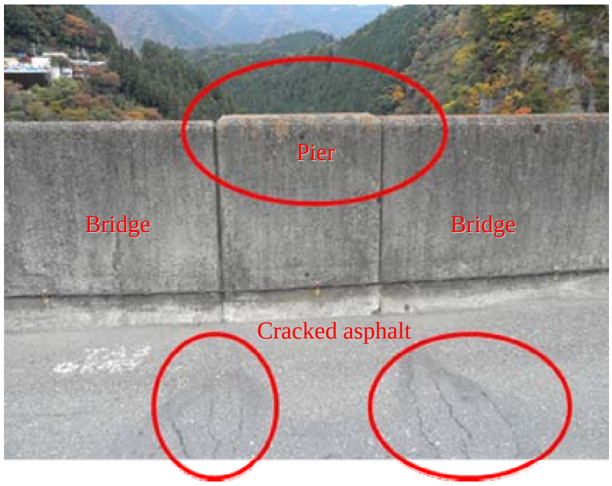

Fig.8. Level differences on the piers and bridge

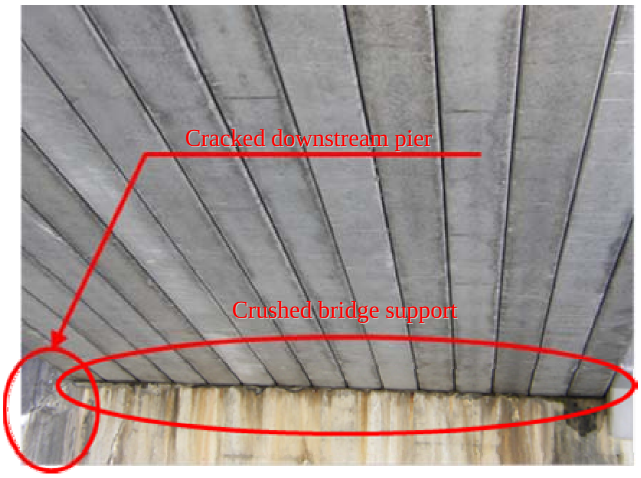

Fig.9. State of bottom surface of the bridge

Instead of integrating measurements into a single leakage measurement, measurements are performed for a number of blocks. Leakage from the foundation bedrock, leakage from joints, and leakage from the natural ground are classified and organized in advance. Thus, when a large earthquake damages the dam body, its location must be confirmed quickly.

If based on the above, one foundation drainage hole must be re-bored in each block, and leakage and uplift pressure must be measured at each hole once a month.

2.3.4 Building and using a database

The measurement results are stored in a database and critical values for safety management are set. Based on this, changes in behavior over time are monitored and when the values show rising or falling trends, the causes are surveyed, and appropriate measures such as repairs or renovations are performed as needed. We should store data including the results of patrol inspections, state of deterioration, and repair history in the database.

3. CONCLUSIONS

We conducted an overall inspection of the Futase Dam fifty years after it was completed. Based on the results, we studied cases of efficient management of the dam and measures to extend the service lifetime of its discharge equipment.

As a result of the case studies, the following items were identified as future challenges for dam maintenance.

(1) Expansion and standardization of dams subject to overall inspection

This overall inspection identified many challenges related to ensuring the reliability of measured data, monitoring deterioration, and responding to large earthquakes, and countermeasures to resolve each challenge were proposed.

In the future, dams which have been in service for long periods will require active overall inspections. Based on the results, patrolling and inspecting dams and measurement management methods should be established as general standards.

(2) Follow-up after overall inspections

It is important to follow up the results of the overall inspection and proposed improvements in the medium and long term to confirm that the improvements have been permanently implemented. These should include analysis and evaluation of the results of surveying deteriorated and damaged locations, studies of repair methods, and analysis and evaluation of the results of patrol inspections. The measured data should be continuously monitored and their permanency confirmed.