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ISSUES SEEN IN EXISTING CONCRETE DAMS AS THE RESULT OF COMPREHENSIVE INSPECTIONS

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ABSTRACT: As an effort to extend dam service life, comprehensive dam inspections were systematized in Japan in 2013, and comprehensive inspections are being carried out on dams that are roughly 30 years old. Comprehensive dam inspections is carried out by each dam manager applying technological expertise to perform a comprehensive fact-finding survey and evaluation of the soundness of the state of maintenance and degree of deterioration of civil-engineering structures of the dam, which are the constituent elements of each dam. Comprehensive soundness of civil-engineering structures of dams in particular, are evaluated by additionally performing advanced surveys on items which cannot be easily surveyed in daily and periodical inspections for methodological and cost reasons, and items which could deteriorate over time. This study organizes the results of comprehensive dam inspections controlled under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) implemented for dams in Japan in recent years, looks at issues to note during comprehensive dam inspections, methods for examining issues, procedures for evaluating examination results, and summarizes the trend in maintenance issues for concrete gravity dams.

Keywords: Existing dam, Comprehensive dam inspection, Civil engineering structure, Other dam facilities, Dam measurement

1. EFFORTS TO EXTEND DAM SERVICE LIFE IN JAPAN

Dams are critical social infrastructure with functions that have an extremely high level of social impact, including flood control and water use. Dams that have been in use for 50 years or longer currently account for about 10% of all dams under the control of Japan's MLIT, while dams that have been in service for at least 30 years account for roughly 50% of all dams, and the number of dams where deterioration or damage from the passage of time will be actualized, or where maintenance costs for facilities upkeep and repairs will climb, is expected to increase in the future. Because dams are vital facilities that must be maintained and operated for many years, it is critical to understand the state of deterioration and damage at an early stage and make repairs as necessary at the appropriate time, and these actions are linked to minimizing maintenance expenses and maintaining long-term dam safety and functions. With this viewpoint in mind, in 2013 MLIT enacted the Comprehensive Dam Inspection Implementation Guidelines and Interpretation ("Implementation Guidelines") [1], which will newly systematize comprehensive dam inspections to be implemented on a cycle of about 30 years[2].
We consider that this paper is to organize the results of comprehensive 16 dam inspections implemented in recent years and summarizes the maintenance issues for concrete gravity dams, and to contribute to the implementation of rational comprehensive inspections in the future through a survey of deterioration status awareness and a survey of repair techniques.

2. CONCRETE GRAVITY DAM MAINTENANCE

The Implementation Guidelines notes that, “For comprehensive dam inspections, verify the status of maintenance cycle execution and the check and inspection records including daily check and regular inspection, and evaluate comprehensively the soundness of dam from a long-term point of view as a matter of course. For dam civil engineering structures, evaluate comprehensively soundness by performing an additional examination for items that, from the perspective of technique and cost, are highly difficult to inspect during daily checks, and for those items in daily checks or regular inspections for which a possibility of deformation in the future is considered.”, and seeks to arrange maintenance schedules based on considerations such as evaluations of soundness according to the items below.
a) Maintenance of measurement function
b) Continuous measurement to evaluate soundness
c) Continuous understanding of the state of deterioration
d) Action to address individual issues
e) Organization of various types of data, etc.

Based on the results from analyzing common issues and the status of additional examinations, and comprehending the points to note and trends in maintenance for the comprehensive inspections of concrete dams implemented in recent years, we selected and inspected the following each matter as topics that deserve closer scrutiny for items b) and c) in the paper.
“Continuous measurement to evaluate soundness”
・Measurement of dam body deformation
・Measurement of uplift pressure and seepage volume at foundation drainage holes
・Measurement of seepage volume at joint drainage holes
“Continuous understanding of the state of deterioration”
・Method for evaluation and repair of dam body deterioration progress
・Method for evaluation and repair of seepage impact on dam body deterioration
・Method for evaluation and repair of foundation drainage hole function
・Water analysis of rock contact surface seepage and evaluation of seepage path
・Analysis and evaluation of ditch sediment of drainage gallery

3. MATTERS TO SCRUTINIZE BY ITEM DURING COMPREHENSIVE DAM INSPECTIONS

3.1 Measurement of dam body deformation

In the Ordinance Concerning Structural Standards for River Administration Facilities, Etc. (“the Structural Ordinance”), measurement of dam body deformation is required for dams with a dam height of 50m or more. In many places, dam body deformation measurements of concrete gravity dams are made by direct plumb line measurement in a single location established at the maximum cross section, but in locations where parts of the bedrock geology are poor, there also are dams for which measurement and monitoring are performed by inverted plumb line. For dams with low dam height, some dams have no deformation measurement instruments and deformation is not measured, but there also are dams where the crest reference point is being measured and the amount of deformation controlled.

Together with a rise in the reservoir water level during test impoundment, the measurement values change on the downstream side, but no remarkable accumulation is evident.

While no measurement is required for dams with a dam height of less than 50m, some measurement is preferred so that any signs of deformation might be detected, because dam body deformation is an important item for evaluation of safety. There also are cases where a comprehensive inspection provides the opportunity to monitor and record the condition of the horizontal joint openings or gaps, as one supplement to deformation measurement.

3.2 Measurement of uplift pressure and seepage volume at foundation drainage holes

Under the Structural Ordinance, the measurement of seepage volume and uplift pressure at concrete dams is required. Foundation drainage hole seepage volume has been seen to increase temporarily at some dams directly following a large-scale earthquake, but the volume gradually falls, and over the long term generally exhibits a declining trend.

While dams where the measurement value has partially exceeded the design uplift pressure have been seen, such uplift pressure is not a problem on a stability analysis, and generally a declining trend is seen with the passage of time after initial impoundment.

Foundation drainage hole problems such as drainage conduit blockage and hole conduit corrosion with the passage of time, and the deterioration of Bourdon tube-type pressure gauges, have been confirmed to be common.

The method of uplift pressure measurement is an issue common to each dam. To measure uplift pressure under the conditions acting continuously on a dam, or to reduce the uplift pressure load on a dam, use of the partition hole measurement method (measured by closing each other holes) as a measurement standard is recommended for uplift pressure measurement, but here and there dams where the pressure is being measured by total hole blockage method (measured by closing all holes) , for reasons such as past experience with use of the method or to shorten the measurement time, also were seen. With regard to the uplift pressure measurement method, making measurements with the partition holes blocked rather than the total holes blocked, and taking measurements after a “stabilization period” has passed to allow uplift pressure to stabilize, is preferred in order to reduce the load on the dam body and ensure its stability.

Moreover, examples were seen where the valve blocking time until measurement has been decided based on experience without verifying the time until the uplift pressure has stabilized, and for these dams, the time to stability is being confirmed by an additional examination and an evaluation of the validity of the measurement method performed.

For seepage volume, it also is important to check the precision of the measurement instruments etc. by a comparison of each hole’s measurement results and the measurement results for total volume based on a triangular weir. In addition, when recording and organizing the measurement results, it is best to organize the data by matching it with records from times such as earthquakes, floods, and equipment upgrades.

3.3 Measurement of seepage volume at joint drainage holes

Although seepage from joint drainage holes rarely becomes a significant problem for dam body stability, measures are required from the viewpoint of extending dam service life if the seepage volume is substantial.

For many dams, seepage from joint drainage holes frequently increases at initial impoundment, then decreases and stabilizes with the passage of time.

At many dams, measurements of joint seepage volume are not made at each hole, and the total amount of joint seepage volume is calculated by measuring the foundation drainage hole seepage volume when uplift pressure is measured and subtracting this from the total seepage volume in the drainage gallery area.

Same as foundation drainage holes, it is preferable to measure whether there is seepage from each hole, and the status for the joint drainage holes.

Figure 1 shows the adhesion of free lime to the hole discharge port. A preferable approach is to give drainage hole discharge ports a shape that makes measurement feasible, such as turning the outlet downward (Figure 2).

Furthermore, depending on the dam, watestops might not be installed on the downstream side of non-overflow sections, and cases where seepage in the drainage gallery increases during rainfall were seen.

Figure 1：Free lime adhesion to joint drainage hole

Figure 2：Joint drainage hole (example of shape that enables measurement at each hole)

Another problem for the formulation of maintenance policies is poor recordkeeping, such as when the records of countermeasure works for large seepage from joint drainage holes cannot be stored, or when the structure of waterstops or joint drainage holes cannot be confirmed from drawings, or when onsite confirmation isn't possible even though drawing descriptions are available. Organizing and retaining records such as facility schematic diagrams is helpful for maintenance.

3.4 Method for evaluation and repair of dam body deterioration progress

Concrete dam body deformations are classified as either initial flaws or deterioration that advances with time. Initial flaws are mainly defects such as cracks that occur during construction or immediately thereafter because of construction-based problems; major flaws are addressed when they are confirmed. Minor flaws that are not addressed frequently will have to be re-evaluated during a comprehensive inspection, because up until the inspection nothing has been left behind as a record.

Much of the deterioration seen in the dam bodies of concrete dams typically is freeze damage; damage also is caused by deterioration from alkali aggregate reaction attributable to aggregate, and by expansive harmful mineral substances. In addition, potential cracks forming during construction will sometimes expand over time and cause concrete splinters to flake off. It is vital to understand appropriately such detrioration and predict the progress of deterioration, but the evaluation is difficult if time series data are not obtained, making it important to show accurately a maintenance plan that makes it possible to monitor changes in dam condition over an extended period by means of comprehensive dam inspections.

Although cracks in construction joints and parts of spillway channel walls and the occurrence of seepage and efflorescence on the upstream and downstream sides of dam bodies have been noted frequently in cases up to now, damage at a level that would directly affect the dam body has not been seen.

Moreover, examples can be noted where cracks have entered concrete structures such as the spillway channel walls or footing. Because reinforcing bar corrosion is a concern with such reinforced concrete structures, examining the effects on rebar also is important.

As additional examinations, efforts such as deterioration diagnosis using infrared cameras, drone photography of components that cannot be viewed directly, surveys of aggregate laumontite content, strength tests based on cores, and tests of chloride ion content are being implemented.

Because confirmation of strength with a test hammer and neutralization tests can be implemented simply to verify the status of dam body concrete deterioration, their implementation in basic inspections is well established, and it was confirmed there was no remarkable deterioration. In addition, there also have been many cases recently where the extent of concrete surface flaking has been checked by means of infrared camera photography; an example of inspection using an infrared camera is shown in Photo 3 and Photo 4.

Because comprehending the extent to which dam body concrete surface deterioration has progressed is so important for future maintenance, we are working to organize a list of cracks and other damage for each dam and understand present conditions.

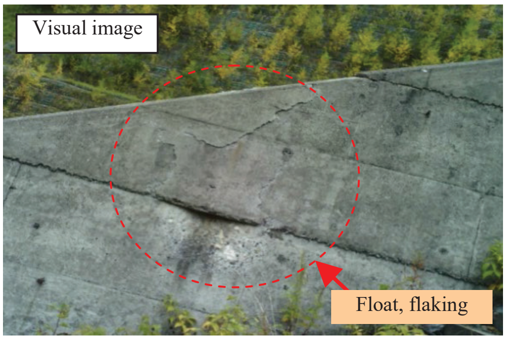

Figure 3: Image of visible concrete deterioration area

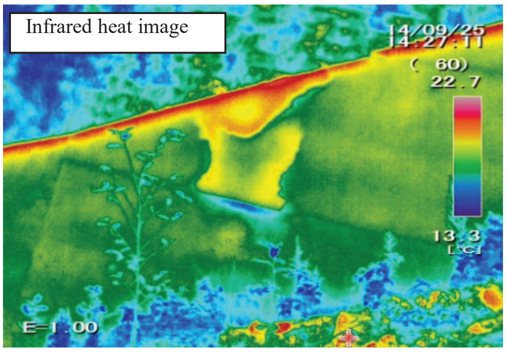

Figure 4: Example of heat image taken with an infrared camera

3.5 Method for evaluation and repair of seepage impact on dam body deterioration

Because of the possibility seepage from the horizontal construction joints or transverse joints on the downstream side of a dam will hasten dam body concrete deterioration, a proper evaluation is necessary when performing a comprehensive dam inspection. While seepage from horizontal construction joints or efflorescence precipitation can be seen at many dams, cases where seepage has caused noticeable advanced deterioration of the dam body are rare. Because the amount of seepage and locations where it occurs will vary depending on the season and water level behind the dam, it is important to understand the differences in external conditions.

3.6 Evaluation of effectiveness foundation drainage hole function

Function of foundation drainage holes installed a dam's foundation must be properly maintained, because these are both a facility for measuring seepage volume and uplift pressure and a critical facility used to reduce uplift pressure in the foundation rock and improve dam stability. There are many cases, however, where the loss of this uplift pressure alleviation function is thought to be a real possibility when the foundation drainage holes become blocked with free lime or other materials over the course of dam operation.

Verification inside the holes (insertion of an inspection rod, verification by camera inside the holes, survey of the change in water level inside the holes, etc.) is effective as a means to confirm drainage hole function, and for blocked holes confirmed, a study of countermeasures such as re-boring are required.

For holes without drainage water, a survey of the change in water level inside the holes (pumping test) is conducted by lowering the water level inside the holes using a bailer (in-hole water sampler device) and confirming the change in water level (has the water level recovered) after passage of a fixed time (typically after 24 hours). A pumping test makes it possible to perform effectively a function evaluation even if drainage hole conditions are difficult to understand sufficiently through direct observation.

The majority of dams are stable because dam seepage volume from the foundation drainage holes exhibits a downward trend over time after initial impoundment, and no upward tendency in uplift pressure is seen as well.

Although these are not a problem if impermeability has increased because of foundation rock blockage, a blockage confirmation inspection of foundation drainage holes is implemented for dams where impermeability is thought to be the result of foundation drainage hole deterioration and blocking is feared.

3.7 Rock contact surface seepage

Although seepage sometimes occurs in the rock contact surface with downstream toe of the dam, if the volume is significant it is necessary to comprehend the origin and path and investigate countermeasures. Dams where seepage from downstream rock contact surface has been confirmed at the footing region or areas abutting the surrounding earth have been noted, and in all instances, the water is being exuded slowly and no remarkable seepage has been seen. While the bulk of this seepage was at the level of a slow trickle, and the precise volume was not grasped during daily observations, should the seepage volume be substantial, daily monitoring will be necessary to understand the change over time and change because of factors such as weather conditions.

As an additional examination, we are implementing water analyses and inferring percolation routes by comparing the water quality characteristics of the seepage and samples such as water from the reservoir, water from the surrounding mountain streams, and groundwater.

3.8 Ditch sediment

Precipitate sediment originating in the seepage can be found in the drainage gallery ditch, along stairs, and in the triangular weir for seepage measurement. If the volume is substantial its source and path must be understood to evaluate the foundation rock's stability. It is important to understand where the ditch deposits are originating and the quantity flowing out, which requires regularly cleaning the ditch so the conditions over time can be understood. The impurities contained in seepage from the foundation drainage holes also must be examined carefully and the knowledge gleaned reflected in daily management.

Furthermore, because the presence or absence of outflows of foundation rock constituent materials that serve as an indicator of foundation rock seepage failure is a critical viewpoint, it is important to evaluate an investigation of ditch deposits based on the conditions of the foundation rock, such as the extent of the foundation rock consolidation or weakness of the fault or seams. If an outflow of foundation rock constituent materials from a specific foundation drainage hole has been confirmed, it becomes necessary to investigate carefully whether there is any concern of foundation rock seepage failure.

In any investigation concerning ditch deposits it becomes important to first confirm the circumstances and volume of the deposits based on a general survey inside the drainage gallery and verify the properties of the deposits visually, and understand the accumulation characteristics for the dam in question.

If the amount of deposit material is determined as the result of a survey to be comparatively large, its origin should be surmised by gathering samples from locations that show the representative characters, conducting tests such as a grain size analysis, fluorescent X-ray diffraction, and X-ray diffraction, and understanding the percentage of amorphous material, the involvement of iron bacteria, and the amounts of substances such as quartz, plagioclase, calcite, and mica contained in the samples.

Furthermore, if there is a high probability the foundation rock is the origin of the deposit material, a monitoring survey to identify the effluent pathway and study carefully the depth of concern of a foundation rock seepage failure must be conducted, and steps to address the situation undertaken if necessary.

Precipitate has been confirmed in the drainage galleries of several dams in recent years, and the causes of its occurrence have been surmised based on additional examinations and the issues that require careful attention for maintenance have been organized and reflected in maintenance policy.

While “rock fragments, etc. associated with foundation rock deterioration and failure”, “slime during foundation drainage hole excavation”, “precipitation of substances in groundwater”, and “materials originating in human activity (adhered substances during drainage gallery entry and egress)” have been considered as possibilities for the origin of the materials deposited (precipitated) in drainage gallery ditch, once the characteristics of each of these potential sources have been understood it might be feasible to surmise the origin of ditch deposits by comparing their components (mineral composition and granularity).

Using the samples gathered, we performed a componential analysis to understand the percentage of amorphous material, the involvement of iron bacteria, and the amounts of substances such as quartz, plagioclase, calcite, and mica contained in the samples, and used this as base data to surmise the origin.

Here the methods are shown in Table 1 as componential analyses, and while each possessed the characteristics shown in the table, further improving the precision for specific mineral substances will be possible by implementing these methods in combination.

When we analyzed the dams in this study mainly by fluorescent X-ray diffraction and powder X-ray diffraction, and also included observations by polarizing microscope for some dams, the deposits were judged to have been generated by a chemical reaction attributable to the water quality of the infiltrating water and the dam body concrete and not to have originated in the foundation rock, and we evaluated the substances were not exuded from damage to the foundation rock. For deposit control, priority monitoring will be important in the future as well as a crucial control factor for understanding whether there is expansion of the percolation path from the foundation rock.

Table 1：Summary of typical element analysis methods and points to note for ditch sediment

Method of analysis	Summary	Points to note
Stereomicroscope	Stereoscopically viewed aggregate and crystalline morphology of minute mineral substances in spaces between rock and ore, and the rock and ore composition, at about 20-40 times magnification. Although identical to identification by the naked eye in the sense of identifying mineral substances by external appearance, magnification is higher than by loupe (usually about 10 times) and could be viewed stereoscopically.	Mineral color and three-dimensional form are judged by the naked eye through a microscope, and judgments of general rock-forming minerals such as quartz and feldspar are possible to some degree, but judgments with a high degree of precision and judgments of distinctive mineral substances are difficult.
Polarizing microscope	Rock (flake) slides are prepared and the types and composition of minerals contained in the rocks examined. Magnification is about 50-400 times. Because slide preparation is difficult for rocks containing powdery or fragile mineral substances, such rocks are not examined in many cases. For loose sediment, flakes are produced after fixing the sediment once with an adhesive, etc.	Using the various optical properties unique to minerals, accuracy is high for specific minerals but requires a high degree of expertise. When used together with X-ray diffraction, can also deal with various mineral compositions.
X-ray powder diffraction	Identification of types of mineral substances is made from data based on the atomic arrangement (crystallographic structure) of the minerals. X rays are incident on the crystalline material, and when each atom scatters the X rays and the scattering intensity is recorded for each scattering angle, the unique scattering spectrum of the material is obtained. The diffraction angle positions and strength are unique to each crystallographic structure, and mainly inorganic compounds can be identified from the diffraction patterns. This is especially effective for identification of mineral substances having the same chemical composition but different atomic arrangements.	Non-crystalline materials such as organic substances, and substances with poor crystalline structures that do not display a diffraction pattern, cannot be detected. When specifying substances such as clay minerals a fixed orientation analysis involving several separate preprocessing steps is required.
Fluorescent X-ray analysis	Samples are irradiated with X rays, causing the fluorescent X-rays of the various wavelengths generated to be incident, and by continuously changing the angle of the crystals, the strength of the diffraction X rays is measured sequentially. From the X-ray strength obtained, the types of elements composing the sample and their rough content are examined.	This is a method for examining the composition and content of the elements in the rocks; it cannot specify the mineral composition directly. The method is effective when the accuracy of the material’s origin is increased through use in combination with other methods.
Granularity analysis	The origin (genesis) of deposits is surmised by analyzing grain size and comparing this with the results from studying the genesis of the original materials.	Can be applied only if there are characteristics in the grain size composition of the original materials.

4. CONCLUSION

In this study we have selected and organized issues from the viewpoint of extending the lifetime of existing dams, based on examples of comprehensive dam inspections implemented after formulation of the Implementation Guidelines. From the results we selected issues common to existing dams and items that need to be measured and analyzed to diagnose deterioration, and summarized the investigation procedures and evaluation methods.

In the future, comprehensive inspections of dams will be used to extend dam service life by repeating the PDCA management process based on a 30-year cycle. We will continue observing closely to see whether maintenance based on plans to extend service life will demonstrate results in the future.

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