Development of Soundness Diagnosis / Monitoring Technologies for Supporting the Life Extension of Dams

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1. Introduction

In order to ensure proper performance of the functions of dams over the years, various inspections to keep them in good condition are very important. For this reason, in addition to the safety inspections, which consists of daily inspections by patrol and measurement, extraordinary inspections in the event of an earthquake, etc., and periodic inspections by third party, a "Comprehensive Dam Inspection", in which the dam condition is checked in detail, soundness assessment is conducted, and maintenance policy for the future is prepared in order to extend the life, has been recently implemented.

For such detailed inspections, development and dissemination of diagnostic techniques to conduct condition surveys and long-term behavior analysis of dams as objectively as possible are essential. Development of displacement monitoring techniques using satellite-based SAR and studies for the utilization of vibration monitoring, which NILIM has been conducting, are part of the activities stated above. Furthermore, attempts to grasp the condition of sites efficiently by combining drone or underwater robot technology with various measurement devices have rapidly advanced in recent years. However, there are no effective technologies for efficiently grasping the internal state of the dam body. At present, the internal state is in some cases investigated by survey boring, but there are many issues to address, such as the difficulty of grasping the area of deformation inside the dam body and work in high places, and survey costs. Hence, this paper introduces a study on the non-destructive examination method for grasping, particularly, the internal state of a dam body.

2. Development of non-destructive inspection technologies for dam body

When a crack or other deformation is found on the surface of a concrete dam body, an assessment of its impact on the body stability is needed. For such events, it is desired to establish an effective non-destructive examination method that can supplement the boring survey, which presents limitations on survey points , and grasp propagation inside the dam body.

At present, the non-destructive examination methods that have actually been used to detect cracks inside of concrete structures are limited, and one of them is the high-frequency impact elastic wave inspection method. This technique localizes the position by striking the surface of the structure with a hammer to generate elastic waves and measuring the reflected waves from the discontinuity inside the dam body and the propagation velocity. It has been used for concrete piles and used in part on a trial basis to grasp the state of horizontal construction joints, which are important for a concrete dam body to be stable. Then, in order to grasp the applicability of this method to dams, we conducted measurement tests to examine to what extent the location could be identified and the condition assessed, using large concrete test pieces with a separation plane and an actual dam body. Consequently, the location of the existing separation plane in the test piece corresponded to the reflected waves and, in the field test, measurement results generally corresponded to the locations of cracks determined by boring (Fig. 1). However, variation was found in the relationship between the state of the separation plane in the test piece (contact area ratio) and the reflected wave amplitude, and some reflected waves were also detected from the locations other than where crack were in the field test. Based on these results, we are going to summarize how to use this technology and points of attention.

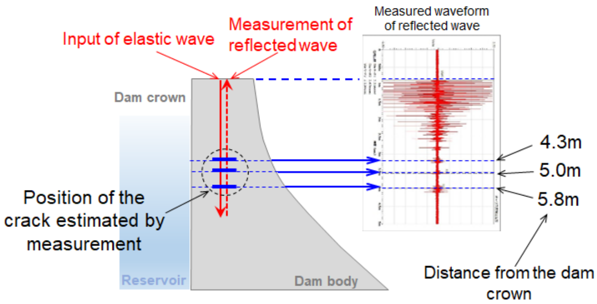

Fig.1 Crack survey of concrete dam body by high-frequency impact elastic wave inspection

In order to further advance the development of the non-destructive inspection technology, which is effective for detecting deformation inside mass concrete structures but has not been used widely at home and abroad, NILIM is simultaneously advancing technical development in cooperation with universities and other organizations that have more expertise and advanced knowledge (research funded by MLIT's River Erosion Control Technical Research Development System, Table 1).

Table 1 Contents of research and development and research institutions

Study	Contents of R & D	Research institution
(1)	Crack detection and strength distribution detection methods for concrete dams using low-frequency elastic waves	Tokyo Metropolitan University, etc.
(2)	Crack progress and assessment in the concrete dam body using the ultra-broadband SA sensor	Kyoto University, etc.
(3)	Visualization assessment technology without destruction of the crack / joint surface of the concrete dam body using remote monitoring system infrared light / elastic waves	Toyama Prefectural University, etc.

Of the projects above, Study (1) (Table 1) is investigating whether or not cracks inside the dam body can be detected from the delay in arrival time and decrease in low-frequency elastic waves, which are expected to penetrate large-scale structure such as dams (Fig. 2).

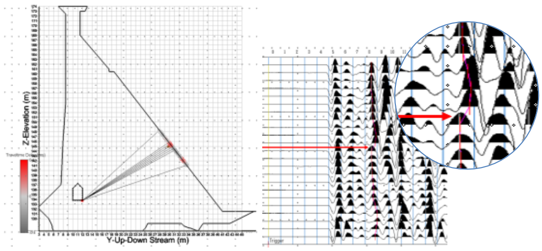

Fig. 2 Crack estimation by low-frequency elastic waves (Observed waveform between the inside and surface of the inspection gallery, and delay)

Study (2) (Table 1) is developing technology for detecting internal deformations including cracks using a sensor that enables elastic wave observation in a wide frequency band and elastic wave tomography technology (Fig. 3), aiming to develop a method for monitoring internal conditions using Acoustic Emission (AE), which propagates a very small elastic wave inside the dam body.

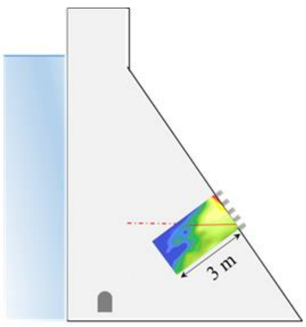

Fig. 3 Crack depth estimation by elastic wave tomography (Comparison of the results of boring survey and output)

Study (3) (Table 1) is exploring the applicability of various analysis methods (Fig. 4), where elastic waves are used for detecting cracks inside the dam body, in combination with surface condition surveys conducted with infrared light (UAV) and visible images. Estimates made from elastic wave measurements in each project are generally consistent with the results of cracks found by boring survey, so we are encouraged to continue research into the practical use of the technologies.

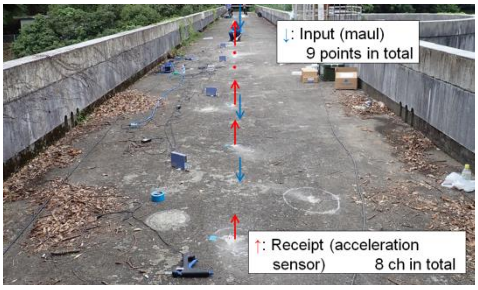

Fig. 4 Survey of cracks inside the dam body with elastic waves (Implementation of surface wave survey)

In addition, NILIM is studying injection materials for survey to promptly grasp the depth of cracks that arise in case of a massive earthquake, etc. with focus on electric survey technology as non-destructive examination technology for fill dams. The results of field tests conducted in the past show that cracks can be detected from the difference in specific resistance from the dam body material and a material obtained by mixing electrolyte (calcium chloride water solution) with a commercial self-filler, and that the crack depth can be reproduced relatively well because the material readily fills cracks and permeates less into adjacent areas (Fig. 5).

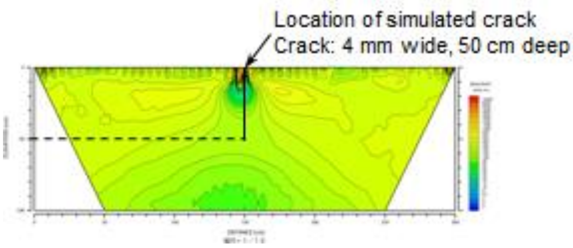

Fig. 5 Example of crack detection by electric survey (banking ground)

3. Future development

For the various survey technologies introduced in this paper, we intend to continue the study on how to apply them to dams, points of attention, etc. and summarize them in the technical data available from field inspections together with existing various survey / diagnosis techniques.