Development of Damage Estimation System Using Seismic Motion Data Measured at Dams

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1. Introduction

The probability that Nankai Trough earthquake will occur within the next 30 years is estimated to be 70 to 80 %, which has heightened the sense of urgency of a large-scale earthquake affecting a wide area. In the unlikely event that a dam suffers serious damage as the result of a large-scale earthquake, in addition to the direct damage to the dam, the effects on the flood control function and water supply will also continue for extended period. Therefore, when a large earthquake strikes, a grasp of the damage of multiple dams and early construction of the necessary support system are demanded.

At present, seismic motion data is collected at many dams, but in many cases, the maximum value of acceleration is used to judge the necessity of special inspections of the individual dams, and it has not been possible to use this data to predict damage or directly use the diverse data contained in the seismic motion data.

Therefore, the Large-scale Hydraulic Structure Division constructed a dam damage estimation system (hereinafter, instantaneous estimation system) for realizing early construction of the necessary support system, based on instantaneous predictions of the damage of multiple dams from seismic motion data and ranking of the dams in order of priority for inspections.

2. Overview of the System

The instantaneous estimation system can make judgments of whether anomalies have occurred or not, as shown in **Fig.-1** and ① to ③ below, and transmit the judgment results.

① Using a distance attenuation equation, the system estimates the acceleration of the dam foundation bedrock from information concerning the scale of the earthquake and location, depth, etc. of the epicenter, which can be obtained from the Japan Meteorological Agency immediately after an earthquake occurs, and judges the possibility of that anomalies have occurred based on the results of an advance analysis and the results of inspections conducted following earthquakes in the past.

②The system judges the possibility of anomalies based on the results of an advance analysis and results of inspections following past earthquakes from the maximum acceleration calculated from the seismic motion data observed at the dam, which is collected through the seismic motion data collection system.

③Using the data collected through the seismic motion data collection system, the system detects anomalies by using AI technology. The AI-based anomaly detection function was incorporated in the instantaneous estimation system after conducting the test described in the following section.

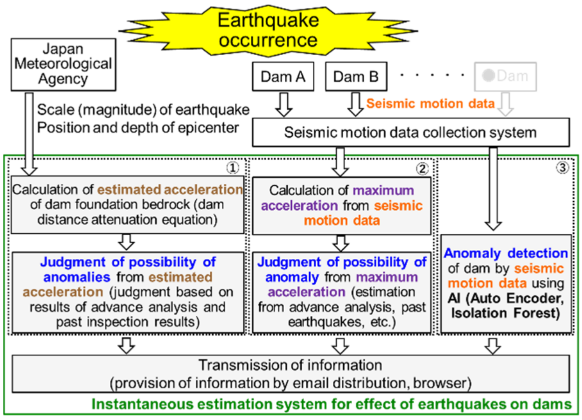


Fig.-1 Overview of the instantaneous estimation system

3. Trial of Judgment by AI

In dams, it is known that the eigenfrequency of the dam body changes when a dam is subjected to comparatively large seismic motion. Among various seismic records of dams, the dam crown reflects the response of the dam body. Therefore, based on the observation records of the dam crown, a trial of anomaly detection using AI technology was conducted. As the AI technologies used in the trial, various AI technologies were compared, and two technologies, Encoder and Isolation Forest, were selected.

Auto Encoder is a self-encoding system, and is one type of unsupervised learning using a neural network. The model first compresses (encodes) normal seismic data input, and after retaining feature values, reproduces the input decoded by restoration processing to its original dimension, (**Fig.-2**). Detection of anomalies is performed based on the difference in the reproducibility of the normal data and anomalous data when seismic motion data that appear to be anomalous are input to a model trained by learning using normal seismic motion data.

Isolation Forest is also a type of unsupervised learning method, but uses a decision tree that classifies a large volume of data (Ⓐ to Ⓕ in the example in **Fig.-3 (a)**) by using a tree structure. In this process, Isolation Tree splits feature values by randomly setting the threshold value of randomly selected feature, and then performs splitting repeatedly until all the features have been isolated (**Fig.-3 (b)**). A large number of splitting operations is required for the feature values of normal data, which are difficult to isolate because their values are close, but the feature values of anomalous data can be isolated easily, with only a few reiterations of splitting, because of the difference between their values and those of the normal data.

As an example of the trial results, the two AI tools evaluated “data assuming a decrease in the eigenfrequency of a dam due to the occurrence of cracking in the dam or opening of crevices in the dam” as the anomalous data, and data in which 60 waveforms which did not correspond to that data were used as the normal data. Based on the learning results, the anomalous data and normal data were judged, as shown in **Table-1**. (Here, the normal data were not used as learning data.) As the result of this trial, the anomaly judgments by Auto Encoder had a higher detection rate than the judgments by Isolation Forest.

It should be noted that, at present, this is a trial only for certain designated dams. Therefore, it will be necessary to further improve the accuracy of anomaly detection by accumulating additional learning data, while continuing and expanding the trials.

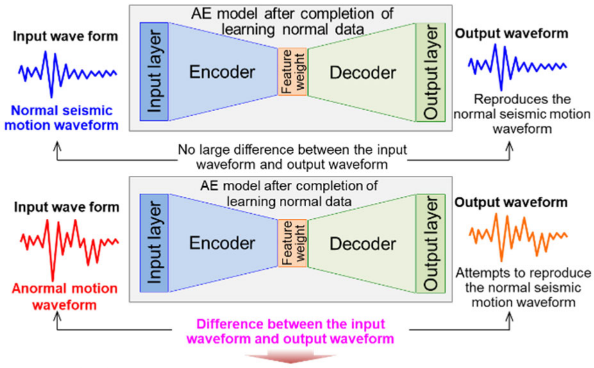
3. Research Outcomes and Future Plans

When using the system developed through this research, in addition to email transmission of information, the system can also be accessed via the network system in MLIT (**Fig.-4**). As a result of this research, it has become possible to estimate the whether the damage assumed after an earthquake occurs or not, and if so, the degree of that damage, and to share information with those involved in dam management in MLIT at an early timing.

In the future, we plan to promote introduction of the seismic motion data collection system for transmission of seismic motion data from dam administration offices, which is necessary for wide dissemination of the instantaneous estimation system, and improve the accuracy of anomaly detection by collecting seismic motion data by the seismic motion data collection system and accumulating learning data.

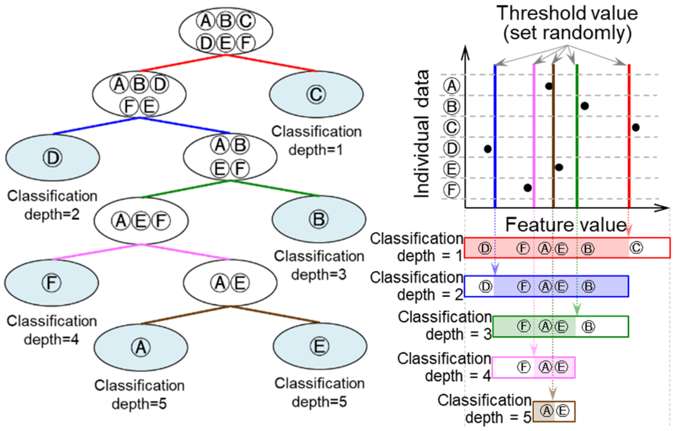
☞For more information:

1) KOBORI Toshihide et al.: Initiatives for Collection and Effective Utilization of Seismic Motion Data Observed in the Dam Body, Civil Engineering Journal, Vol. 66, No. 6, pp. **-**, 2024.



If “difference” exceeds the set value, judge as anomaly.

Fig.-2 Outline of Auto Encoder



(a) Isolation tree (b) Splitting by feature value

Fig.-3 Outline of Isolation Forest

Table-1 Example of trial results

AI method		Auto Encoder			Isolation Forest		
Item	Dam name	Frequency (actual)	Number of anomaly detections by AE	Detection rate	Frequency (actual)	Number of anomaly detections by AE	Detection rate
Abnormal data (eigenfrequency changes)	Dam A	5	5	100%	5	4	80%
	Dam B	4	3	75%	4	1	25%
	Dam C	0	0	-	0	0	100%
	Total	9	8	88%	9	5	56%
Normal data (no change in eigenfrequency)	Dam A	7	0	0%	7	0	0%
	Dam B	8	0	0%	8	0	0%
	Dam C	12	0	0%	17	0	0%
	Total	27	0	0%	27	0	0%

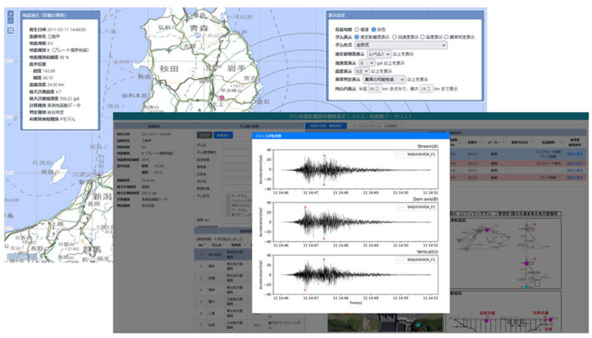


Fig.-4 Example of access of estimation results by web browser