Development of an AI-Based Tool to Enhance Dam Safety Management Decision-Making

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1. Introduction

The basic and essential method to ensure safety in dam maintenance and management for detecting abnormalities includes monitoring a range of measurement data, such as water leakage, deformation (displacement), and pumping pressure, along with visual inspections. During Japan's rapid economic growth period from the mid-1950s to the early 1970s, numerous dams were constructed. Many of these dams have been in operation for a long period and are now showing signs of aging. Consequently, there is growing concern about the shortage of experienced safety staff responsible for monitoring dam conditions through patrols and measurements to detect any abnormalities in the dams. Given this situation, it is crucial to develop methods that allow for accurate assessment of dam abnormalities, even when individuals with limited experience in dam management are appointed as dam managers.

Hence, the Large-Scale Hydraulic Structure Division conducted a study on artificial intelligence (AI) technology designed to assist dam managers in making accurate decisions regarding the presence of abnormalities. We then developed a tool named the Dam Safety Decision Support Tool, hereinafter referred to as the Decision Support Tool.

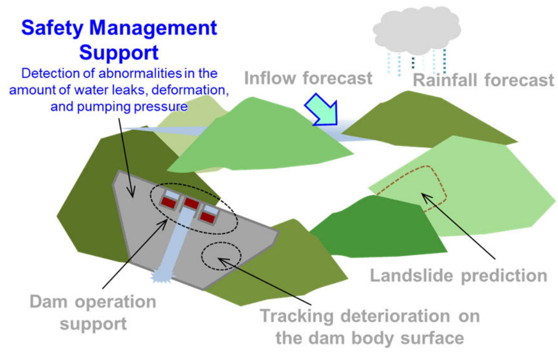

Figure 1. Example of AI use in dam maintenance and management

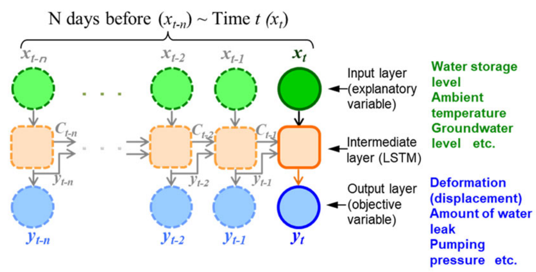

Figure 2. Outline of the LSTM model

2. Purpose of the Decision Support Tool

As illustrated in Figure 1, AI technology is employed in the various aspects of dam maintenance and management. This includes the assessment of operational elements, such as rainfall forecasting, inflow prediction, and operational support. It is also utilized to evaluate dam robustness, covering aspects, such as landslide forecasting and the detection of deterioration in the dam wall surface. The Decision Support Tool is designed to assist dam managers in ensuring the safety of dam embankments. By providing information on measurements like the amount of water leakage, deformation (displacement), and pumping pressure, the tool enables dam managers to assess any abnormalities.

3. AI technologies used in Decision Support Tool

It is known that the deformation (displacement) of a concrete dam's embankment is influenced by water storage levels and temperature, and these factors undergo repeated cyclic changes. Likewise, the amount of leakage and pumping pressures fluctuate repeatedly because of various factors, including ambient temperature, groundwater levels in the surrounding mountains, and the water storage level. Based on these factors, the system needs to identify abnormalities by comparing forecasted values, which consider factors like water storage level and ambient temperature, with actual measurements. To achieve this, we utilized Long Short-Term Memory (LSTM, shown in Figure 2), a deep-learning algorithm suitable for time-series data regression problems. LSTM takes past time-series data into account as long-term memory to produce forecasts.

The following is an example of a trial calculation for the deformation (both upstream and downstream components) of a gravity-type concrete dam embankment (with a height of approximately 120 meters) learned using LSTM. In the model depicted in Figure 2, time-series data, including water storage level and temperature (both ambient and embankment temperature), were input as explanatory variables in the input layer, while the output layer is the embankment deformation (displacement). Figure 3 illustrates a comparison between the forecasted (estimated) embankment displacement generated through the learning and the actual measurements. The figure also displays the outcomes of multiple regression analysis, a traditional method. It is evident that the forecast produced by LSTM closely matches the actual measured values.

Since LSTM can generate highly accurate forecasts, we believe that dam managers can employ the system for early abnormality detection by establishing appropriate thresholds for deviations from actual measurements.

4. Decision Support Tool

We designed the Decision Support Tool to allow officials from the dam management office to input and output data, as well as set parameters, effortlessly using Microsoft Excel, a spreadsheet software. The Decision Support Tool analyzes time-series data, including the

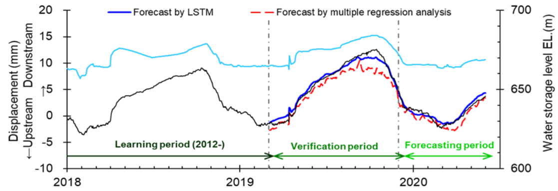

Figure 3. Example of trial calculation (forecast of embankment deformation (displacement))

Table: Applications of the Decision Support Tool

Scenes in which Decision Support Tool can be used	Purpose
Checking past behavior	Assess the likelihood of abnormalities by analyzing trend changes
Confirmation of the day's behavior	Detect abnormality by comparing deviations from past trends
Prediction of future behavior	The system predicts cases when dam conditions remain stable despite anomalies by analyzing historical trends. This prediction serves as a safety management indicator.

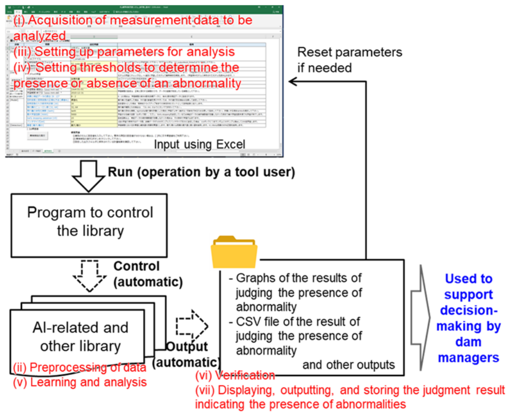

Figure 4. Functions of Decision Support Tool

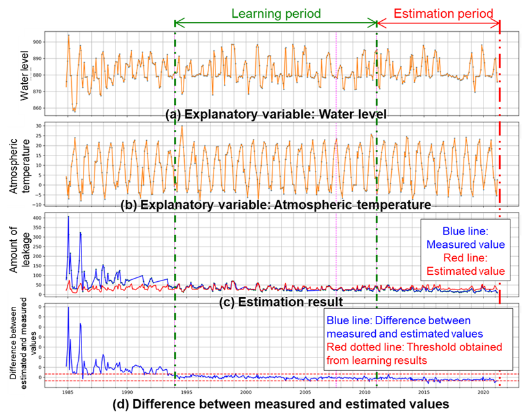

Figure 5 Output example (confirmation of past behavior (amount of leakage))

amount of leakage, deformation (displacement), and pumping pressure. It identifies a condition as "abnormal" when its forecast, derived from the learning of past data, deviates from actual measurements.

(1) Scenes in which the tool can be used

The Decision Support Tool is designed for the following situations: checking past behavior, checking behavior of the day, and predicting future behavior as outlined in the table.

(2) Function

Figure 4 outlines the functions of the Decision Support Tool. The Decision Support Tool first generates time-series data for the analysis subject in a CSV file format. It then automatically executes processing steps (i) to (vii) outlined in Figure 4 within its system.

(3) Output example

As an example of the Decision Support Tool's output, we present the results obtained from examining the past behavior of water leakage in the embankment of a gravity concrete dam (with an approximate embankment height of 110 meters). The total leakage served as the objective variable, while the explanatory variables included water storage level and temperature. Figure 5 displays the output results, which is the diagrams generated in step (vii) of Figure 4.

Figure 5 (d) illustrates the threshold used by dam managers as an indicator for their decisions. The dam manager can use this threshold to assess any abnormalities.

5. Conclusion

We utilized LSTM, an AI technology, to create the Decision Support Tool designed specifically for dam managers' use. In the future, we intend to continue trial implementation of the Decision Support Tool with dam managers. Based on the trial findings, we will enhance the tool and create operational manuals.