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ScienceDirect
Comput. Methods Appl. Mech. Engrg. 278 (2014) 80–100
Computer methods in applied mechanics and engineering
www.elsevier.com/locate/cma

Input disturbance predictive control of shallow water flows

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Received 6 June 2013; received in revised form 30 September 2013; accepted 24 April 2014
Available online 24 May 2014

Abstract

The purpose of this paper is to describe the predictive control of flood flows over the surface of reservoirs in a mountainous area, with a complicated terrain shape. It is expected that damage to villages around the reservoir can be reduced if the water elevation of water discharge is controlled using an artificially constructed aqueduct. The control method uses the first-order adjoint equation and the numerical technique used is the finite element method. In order to control water elevation, prediction of input discharge is necessary, and optimal discharges can accordingly be determined. Predictive control of water flows is carried out in this study. The adjoint equation method is applied to obtain the optimal control. A performance function is used as the index of the optimal control, which is defined by the sum of the square of the computed water elevation at the target points. As a minimization technique, the weighted gradient method is applied. The gradient of the extended performance function with respect to the control of water discharge is obtained by solving the first-order adjoint equation. The predictive control method employed in this paper is a technique to make prediction of the input disturbance and compute the optimal control value at a certain time duration. The shallow water equation based on the water discharge and elevation is used as the governing equation. As the spatial discretization, the finite element method based on the linear function interpolation is employed. As the temporal discretization, the two-step explicit scheme is applied. After verification based on the predictive control of the water elevation in simple rectangular channel and sinusoidal water elevation model, the present method is applied to flood control of the Ikari reservoir located in the Tochigi prefecture in Japan.

Keywords: Input disturbance predictive control; Water systems of the Ikari and Kawaji reservoirs; Finite element method; Shallow water flow; First-order adjoint equation

1. Introduction

Flood control of a multiple water storage reservoir system comprising rivers and aqueducts is one of the important themes in water resources management. The paper deals with phenomena on two dimensional planar surface of reservoirs located upstream of rivers. For example, it is possible to suppress flood water waves created by sudden rainfall or the opening of the upper dam gates using the predictive control. An example is the aqueduct project of the Ikari and Kawaji dam reservoirs in Japan. Many dams have been constructed to prevent floods over the Tokyo area and

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http://dx.doi.org/10.1016/j.cma.2014.04.016
0045-7825/

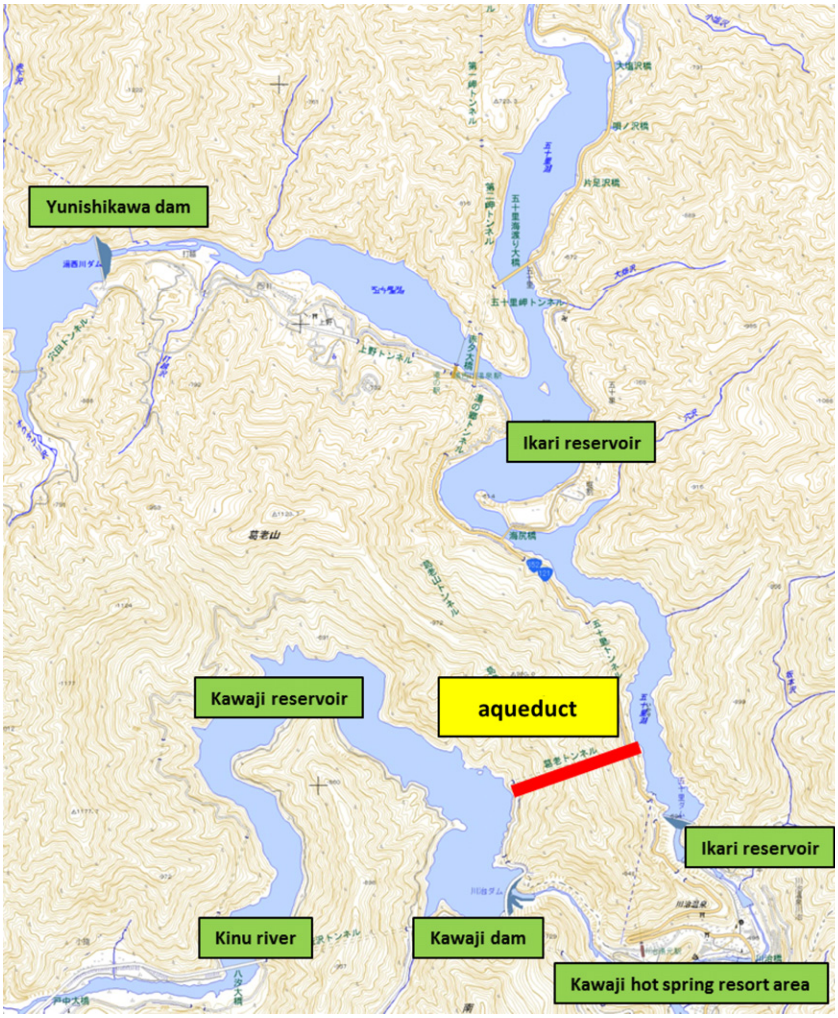

Fig. 1. Kinu river (geospatial information authority of Japan).

two of these are the Ikari and Kawaji dams. Reservoirs of both dams are connected by an artificial aqueduct to allow water to flow from the Ikari reservoir to the Kawaji reservoir, as shown in Fig. 1. Downstream of the Ikari reservoir, a popular hot spring resort area is located. Sightseeing boot trips downstream the river constitute an important industry around this area. Therefore, all of the water from the Ikari reservoir cannot flow to the Kawaji reservoir at normal seasons. Through the existing aqueduct, the overflowed water can be allowed to flow from the Ikari reservoir to the Kawaji reservoir to prevent flooding at downstream resort.

The aim of this study is to consolidate the operational system with a predictive control method based on the adjoint equation and finite element methods. The target points are located downstream, two rivers flow into the reservoirs from upstream. The problem is to determine water discharge of the aqueduct located in the middle of the reservoirs as functions of time so as to minimize the water elevation at the target point. The two-dimensional finite element method is successfully used in combination with the adjoint equation method for the following reasons.

(1) A complicated computational area should be used, because the water storage area consists of multiple valleys.
(2) The inflow from the upstream direction is not limited to one direction. Multiple inflows enter the water storage area.
(3) To ensure the stability and accuracy of the computation, the adjoint equations based on the finite element method are employed to derive the exact expression for the gradient of the performance function with respect to the control variable.