Ain Shams Engineering Journal (2016) 7, 917–924

Ain Shams University

Ain Shams Engineering Journal

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CIVIL ENGINEERING

Modeling of flow characteristics beneath vertical and inclined sluice gates using artificial neural networks

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Received 13 October 2015; revised 21 December 2015; accepted 30 January 2016
Available online 24 February 2016

KEYWORDS

Sluice gate;
Inclination angle;
Discharge coefficient;
Neural networks

Abstract In this paper, artificial neural networks (ANNs) modeling method with back propagation algorithm was employed to investigate the flow characteristics below vertical and inclined sluice gates for both free and submerged flow conditions. Two ANN models were developed yielding two generalized equations to predict the discharge coefficient (C_d) values for both modes of flow. The model network for free flow entailed four input variables, namely, dimensionless upstream water depth, Froude number, Reynolds number, and inclination angle, whereas, the C_d value represented the only single output variable. For submerged flow ANN model, a fifth input variable was added, which is the dimensionless tailwater depth. The two ANN models were trained and validated against 420 data sets collected from previous experimental studies. The results indicated that ANNs are powerful tools for modeling flow rates below both types of sluice gates within an accuracy of ±5%.
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1. Introduction

Policy of water saving relies on the precision of flow discharge measurements. Sluice gates are widely used for controlling discharge and flow depth in irrigation channels and in hydraulic structures such as barrages. Thus, accurate flow rate computations below sluice gates in all flow conditions are inevitably required. Sluice gates are classified into different categories based on different criteria. Based on the downstream water level, they are classified as sluice gate discharging free and submerged flow, whereas, on the basis of alignment with channel axis Mansoor [1] classified them as normal sluice gate, if the gate is normal to the axis of the channel, side sluice gate, if the gate is parallel to the axis of the channel, and skew sluice gate when the gate is inclined to the axis of the channel. Further, a gate inclined with vertical is classified as inclined or planar gate (Fig. 1).

Flow through the opening of normal vertical sluice gates has been the subject of investigation for many academicians and researchers. On the other hand, little work has been done on flow under inclined sluice gates. Henry [2] studied the diffusion of submerged jet downstream of a normal sluice gate and

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Peer review under responsibility of Ain Shams University.

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http://dx.doi.org/10.1016/j.asej.2016.01.009
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Notations

ANN	artificial neural networks	L	length of sluice gate (m)
B	gate width (m)	Q	discharge (m^3/s)
b	sluice gate opening height (m)	Re	Reynolds number (dimensionless)
BPN	back propagation network	RMSE	root mean square error
C_d	discharge coefficient (dimensionless)	Y_1	upstream flow depth (m)
Fr	Froude number (dimensionless)	Y_t	tailwater flow depth (m)
g	gravitational acceleration (m/s^2)	θ	sluice gate angle (radians)

developed a useful diagram for discharge coefficient (C_d) in free and submerged flow conditions. Based on the experimental curves demonstrated in [1], Swamee [3] proposed equations for both free and submerged flows as well as criterion for submergence. Ferro [4] carried out experimental study on simultaneous flow over and under a sluice gate. Clemmens et al. [5] examined submerged radial gates. Spulveda [6] explored various calibration methods for C_d of submerged sluice gates. Belaud et al. [7] studied the contraction coefficient under free and submerged sluice gates. Cassan and Belaud [8] investigated flow characteristics under normal sluice gates using both experimental and numerical methods. Wu and Rajaratnam [9] explored solutions to rectangular sluice gate flow problems.

The side sluice gates and skew sluice gates are often used to divert the discharge in the side channel in irrigation, urban sewage system and during flood operation. Little published work namely [10–12] is available on side sluice gates. On skew sluice gates, Swamee et al. [13] conducted experimental study under free and submerged flow conditions covering a wide range of hydraulic parameters. Montes [14] developed method of solution for flow under planar sluice gates and suggested that the discrepancy between experimental and theoretical values of contraction coefficient is due to the energy loss associated with the vortex formation at the upstream region of the gate.

Flow under sluice gate (Fig. 2) may be evaluated quite simply through the one-dimensional equation of energy. The more direct form of the discharge relationship is as follows:

$$Q = C_d\, b\, B\sqrt{2gY_1} \quad (1)$$

where C_d is the gate discharge coefficient; Q is the discharge; b is the gate opening; B is the gate width; and Y_1 is the upstream water depth.

The artificial intelligence based modeling represents an efficient tool to investigate flow characteristics below gates. Buyalski [15] discussed several algorithms to predict discharge under radial gates. The use of artificial neural networks (ANNs) modeling for prediction and forecasting variables in water resources engineering has been increasing rapidly. An ANN is a mathematical model based on some features of human brain and nervous system storing and dealing with information. It has an ability to capture a relationship from giving patterns, and hence is suitable for application in the solution of complex problems, such as classification, non-linear modeling, forecasting, fitting, control and identification as stated in [16,17]. In this context, a number of applications of ANNs for prediction, forecasting, modeling and estimation of water resources variables (water discharge, sediment discharge, rainfall runoff, ground water flow, precipitation and water quality, etc.) were examined by Mustafa et al. [18]. The back-propagation network (BPN) is one of the most popular feed-forward networks in ANNs. The BPN has the advantages of a simple structure, mature algorithm and powerful function, so it becomes a useful technique for solving hydroscience problems.

In this paper, two ANN models using the back propagation algorithm were developed to investigate the flow for both free and submerged flow conditions under vertical and inclined sluice gates. The developed ANN models yielded two simple generalized equations to predict the C_d value and to account

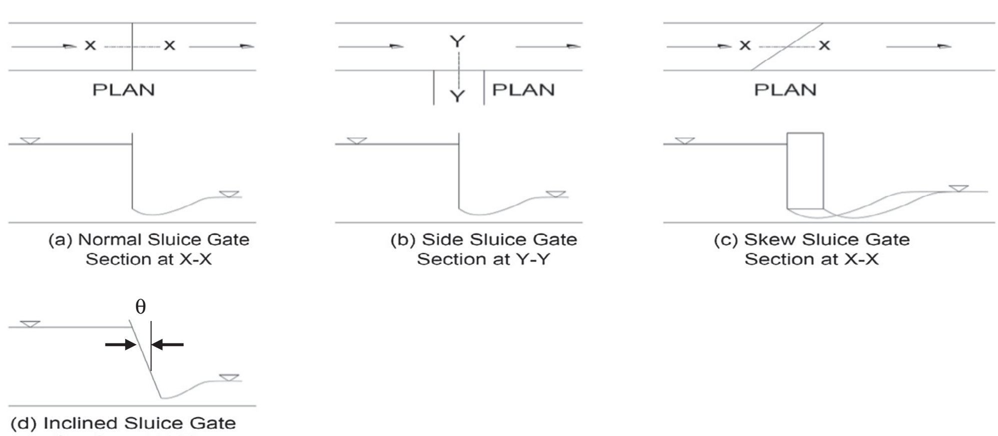

Figure 1 Types of sluice gates after Mansoor [1].

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