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Analysis of Sharp-Crested Rectangular Side Sluice Gates in Sub-Critical Flow Regimes, Based on Spatial Variable Flow Theory and Sluice Gate Discharge Equation

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Extended Abstract

Introduction

A side sluice gate is an underflow and metering diversion device set into the side of a channel with the purpose of allowing part of the liquid to spill through the side. Review of the literature shows that in spite of the importance of the side sluice gate, little attention has been given to studying the behaviour of flow through this device. The available published works on side sluice gates found are those of Panda (1981), Swamee et al. (1993) and Ghodsian (2003). They related the discharge coefficient of the side sluice gate to depth of flow and gate opening. For this purpose, the side sluice gates, since flow control devices, are widely used in the irrigation channels to divert flow from a main channel to a secondary channel. The main purpose of present study was to determine the water surface profile, gate opening, and flow discharge through the sharp-crested rectangular side sluice gates in a subcritical flow regime in free and submerged flow conditions. This study also provides some approaches to differentiate the free or submerged flow conditions. For this purpose, two approaches of solving spatially varied flow equation in a sub-critical flow regime and the direct solution of the discharge equation of the side sluice gates in determining the flow characteristics of the side sluice gates was experimentally investigated.

Methodology

The first approach (Solving the Spatially Varied Flow Equation)

The general differential equation of spatially varied flow along a side sluice gate with decreasing discharge is:

$$\frac{dy}{dx} = \frac{\sqrt{2(E-y)}}{B\sqrt{g}\,(3y-2E)}\left(-\frac{dQ}{dx}\right) \qquad (1)$$

To determine the variation of flow discharge during the side sluice gate, the functional relationship for discharge equation must be defined. The velocity at each height V of the gate opening section is obtained as follows:

$$V = \sqrt{2g\,(H-Y)} \qquad (2)$$

Considering the discharge dQ passing through an elementary strip of length dx along the side sluice gate (Fig. 2c), the discharge per unit length of the side sluice gate is given by:

$$\frac{dQ}{dx} = -\frac{2}{3}C_d\ \sqrt{2g}\left[y^{3/2} - (y-a)^{3/2}\right] \qquad (3)$$

Swamee et al. (1993) and Gill (1987) considered the following relationships for determining the flow discharge per unit length of side sluice gates, which is the simplified version of Eq. 3.

$$\frac{dQ}{dx} = -C_d\, a \sqrt{2g\, y} \qquad \text{(Swamee et al. (1993))} \qquad (4)$$

$$\frac{dQ}{dx} = -C_d\, a \sqrt{2g\, (y - \frac{a}{2})} \qquad \text{(Gill (1987))} \qquad (5)$$

By inserting the Eqs. 3, 4, and 5 in Eq. 1, the governing differential equations were obtained in these types of flows in different conditions.

The second approach (direct solution of the side sluice gate discharge equation)

In this approach, assuming that the flow discharge variation along the sluice gate is constant and equal to the upstream water depth y_1, the equations for determining the flow discharge through the side sluice gate (Eq.. 3, 4, and 5) are re-written as follows:

$$\mathrm{Q} = \frac{2}{3} \mathrm{C}_d\, \mathrm{b} \sqrt{2g} \left[y_1^{3/2} - (y_1 - a)^{3/2} \right] \qquad \text{(Present Research)} \qquad (6)$$

$$Q = C_d\, a\, b \sqrt{2g\, y_1} \qquad \text{(Swamee et al. (1993))} \qquad (7)$$

$$Q = C_d\, a\, b \sqrt{2g\, (y_1 - \frac{a}{2})} \qquad \text{(Gill (1987))} \qquad (8)$$

Experimental Setup

The experiments of the present study were carried out on a physical model with a width of 1.5 m, a length of 17 m, and the depth of 0.8 m. In order to intake water, a branch channel with a width of 0.6 m and a length of 2.5 m in a distance of 8 m from the beginning of the main channel was used. In this study, the experiments were performed for a sluice gate with three different openings of 2, 4, and 7 cm with the width of 60 cm in two free and submerged flow conditions.

Results and Discussion

In order to determine the discharge coefficient of the side sluice gate, the first step was to study the variations of the specific energy and water surface profile along the side sluice gate. Then, by choosing the best relationship for determining the flow discharge of the side sluice gate, the two approaches of solving the equation of the spatially varied flow and direct solution of the side sluice gate discharge equation were examined. . Further, some approaches are presented to differentiate the free or submerged flow conditions, some fitting equations are given in order to estimate the discharge coefficient using various non-dimensional variables and step-by-step consideration of their effect.

Conclusions

In this study, the central axis of the main channel was introduced as a measuring axis in side sluice gates. Comparison of experimental profiles and those obtained from the solution of the differential equation governing the spatially varied flow indicates the proper agreement between experimental results and numerical solutions. In addition, by examining the results of solving the spatially varied flow equation, Gill (1987) 's equation was selected as the best equation for determining the flow discharge through side sluice gates, due to the simplicity and high precision. By examining the discharge coefficient in two mentioned

approaches, it was found that the discharge coefficient obtained from the direct solution of the discharge equation is well consistent with the solution of the spatially varied flow equation. Next, some approaches are presented to differentiate the free or submerged flow conditions. It was found that the discharge coefficient of the side sluice gate in the free flow conditions depends on the ratio of the flow depth to the side sluice gate opening and upstream Froude number, and in submerged flow conditions depends on ratio of the flow depth to the tail-water depth at branch channel and the ratio of the flow depth to the side sluice gate opening.

Keywords: Discharge Coefficient, Intake Channel, Irrigation Network, Measurement