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The hydraulics of parallel sluice gates under low flow delivery condition

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ABSTRACT

In this paper the flow through parallel sluice gates under low flow conditions and with some of the gates closed resulting in symmetrical or asymmetrical gate installations was studied experimentally. The current stage–discharge formula for single sluice gates cannot be used for either free flowing or submerged parallel sluice gates. Then, on the basis of experimental observations, the effect of the closed gates was considered to develop a submergence distinguishing condition curve formula. For both free and submerged regimes, the Π-theorem along with the incomplete self-similarity concept was used to develop head–discharge formulas for symmetrical and asymmetrical gate installations. The proposed formulas were then calibrated using the compiled experimental data. The new approach is shown to be applicable within the entire range of operation, i.e. from free to submerged flow regimes as well as the transition zone.

1. Introduction

Gates have been widely used in irrigation networks for regulating water surface elevation or measuring flow rates. In this regard a head–discharge formula would be a key issue for the network designers. Usually the gate width is almost equal to the channel width. Such a gate installation is termed “single gate installation”; however, in wide channels this could be impractical due to operation and maintenance difficulties. In wide channels usually two or more gates are installed in parallel and called “parallel gate installation”. According to gate openings the operating conditions of parallel gates might be classified as follows:

(1) Gates with same opening sizes, which is not a preferable operation condition. Since, in most cases it might not be easy to manually open the gates so that the openings have identical dimensions and for low discharge delivery such a case requires small gate openings resulting in trapping debris [1].
(2) Only some gates are in operation, others are closed. The open gates ordinations can be divided into symmetrical and asymmetrical cases. This operation condition is applied in low flow delivery conditions.
(3) Gates with different opening sizes.

Depending on the tail water depth and the amount that the gate is opened, all cases might experience free or submerged flow conditions. Although a sound background can be found in the literature for both free and submerged single sluice/radial gates e.g. [2–11] very limited studies on sluice or radial gates installed in parallel exist. Nago and Furukawa [12] conducted some experiments in a channel having a sudden expansion with negative vertical step, lateral expansion, and both lateral expansions and negative step. They proposed many graphical solutions in order to find both free and submerged discharge coefficients. Employing the energy and momentum equations, Clemmens et al. [13] indicated that the downstream flow conditions would significantly affect the distinguishing condition curve. They showed that for a radial gate having a smaller width than its channel width, the available submerged head–discharge methods are inappropriate for the case of parallel sluice gates with closed gates at least near the transition from free to submerged flow conditions.

Clemmens [1] indicated that the submergence transition zone should be avoided in parallel radial gate operations to achieve reliable water measurement. In this regard he evaluated the performance of Energy–Momentum (EM) method proposed by Clemmens et al. [13] to distinguish the flow condition of each radial gate. However, he did not propose any head–discharge formulas for parallel sluice gates. On the basis of the mentioned EM method and by incorporating the effect of the downstream channel width, Bijankhan et al. [14] developed a theoretical distinguishing condition curve permitting to calculate the maximum tailwater depth for which the free flow regime occurred.

In this paper the flow through parallel sluice gates with both symmetrically and asymmetrically closed gates will be analyzed

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Notation

a_1, b_1, c_1, d_1, λ_2, a_2, b_2, c_2, and d_2	empirical coefficients;
a_f and b_f	constant parameters
B	channel width;
b	gate width;
C_c	contraction coefficient;
DRF	Discharge Reduction Function;
f_1	a functional symbol;
F_1	functional symbol;
g	acceleration due to gravity;
K	critical depth;
K_e/w	experimental values of K/w
Q	discharge;
Re	Reynolds number;
Relative error	$(R) = (K - K_e)/K_e \times 100$,
y_*	maximum downstream flow depth for which the free flow condition occurs;
y_{*L} and y_{*U}	The lower and upper limits of the blank data zone;
y_p^*	maximum downstream depth for which the free flow condition occurs through parallel sluice gates;
y_1	the upstream depth;
$y_j (= C_c w)$	jet thickness;
ψ	a functional symbol;
ρ	water density;
μ	water viscosity;
α, β, and γ	constant parameters;

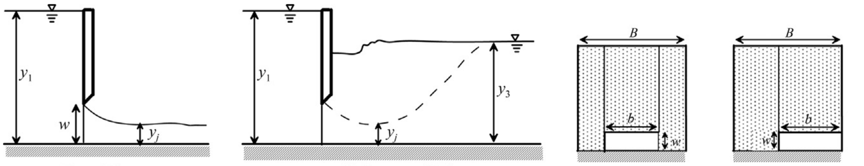
theoretically and experimentally for free and submerged flow conditions. This is a very practical case existing for either parallel gates with closed sides or the gates installed in a channel with sudden expansion. It is shown that the current head–discharge formulas used for single sluice gates cannot be employed to calibrate parallel sluice gates cases. On the basis of the experimental observations, a new approach is presented to distinguish the hydraulic jump type occurred in a rectangular channel downstream of parallel sluice gates with closed ones. Furthermore, a distinguishing condition curve formula including the effect of the closed gates is developed. Afterward, employing the Π-theorem and the incomplete self-similarity concept a generalized head–discharge formula was proposed and calibrated using the compiled experimental data for both free and submerged regimes. The proposed formula is applicable within the entire range of operation, i.e. from free to submerged flow regimes as well as the transition zone.

2. Experimental setup

The experiments were performed in a 1.179 m wide, 1 m high and 7 m long Plexiglas flume located at the hydraulic laboratory of the Irrigation and Reclamation Engineering Department, University of Tehran. The flume was supplied by an elevated constant head tank and an electromagnetic flow-meter with the accuracy of ± 0.5% was installed on the feeding pipe to measure the flow rate. Water depths were measured using point gages with accuracy of 0.1 mm. The tail water depth, y_3, was adjusted using a tail gate installed at the downstream end.

The flow through parallel sluice gates with both symmetrical and asymmetrical closed gates is simplified to the flow in an open channel through a cross-section that is blocked except for a symmetrical or asymmetrical gap of dimensions $b \times w$ located at the bottom of the channel as shown in Fig. 1 which also indicates the parameter used. Geometric characteristics of the parallel sluice gates used in the present study are summarized in Table 1.

First the free flow condition was established in each test for a given discharge and the flow depth upstream of the gate was measured. Then, the tail gate was adjusted incrementally until the upstream water depth begun to respond to the downstream variation. This condition was taken as the beginning of the transition zone from free to submerged flow condition. Submerged flow regime occurred with further increase in the tail gate height in which both flow depths upstream and downstream the gates were recorded.



Free Flow Submerged Flow Symmetric Case Asymmetric Case

Fig. 1. Schematic sketch of the parallel sluice gates configuration under free and submerged flow conditions of low flow delivery condition.

Table 1
Geometric characteristics of the parallel sluice gates.

	b/B	Q (l/s)		y_1/w		y_3/w	
		Free	Submerged	Free	Submerged	Free	Submerged
Symmetrical	0.31	15.2–19.4	15.2–18.9	22–34.6	23.8–37.6	–	2.3–8.9
	0.48	21.7–31.6	17–28.6	17.9–36	12.3–37.1	–	2.1–14.8
	0.65	27.9–45.6	21.6–40.8	15.7–38.2	11–40.4	–	2.47–12.1
Asymmetrical	0.48	21.4–28.7	21.5–27	19–33.9	20.5–41	–	2.7–13
	0.57	23.5–36.2	18–33.5	17–38.9	11.7–41.9	–	2.7–12.8
	0.65	28.9–42.4	29.1–37.7	18.4–38.9	19.2–40.5	–	2.6–12.4
Single gate	1	38–64.6	38.8–59.6	11.8–33	13.1–37.9	–	5.2–14.8