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Experimental study of discharge coefficient for trapezoidal piano key weirs

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ABSTRACT

Piano Key Weirs (PKW) have been invented in the last decade to increase discharge capacity of hydraulic structures. Despite extensive studies on this type of weir with a rectangular plan form (RPKW), there are only a few pieces of research addressing trapezoidal piano key weirs (TPKW). In this experimental study, geometrical parameters of TPKW models were varied under different flow conditions and effects on discharge coefficient (C_d) were investigated. The C_d values were found to be mostly influenced by L/W whereas W_i/W_o had the least effect. Results also showed that TPKW has higher discharge efficiency in comparison with RPKW. This was believed to be related to formation of an "interference wedge" over the TPKW. Finally, quantitative values for distinguishing three flow regimes (i.e. nappe, transition and submergence) as well as criteria for design of TPKW are proposed.

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1. Introduction

Spillways are used to release excess discharge or control flow level in reservoirs [1]. To be more secure against floods, spillways with higher capacities have been needed in recent years. For this purpose, gated or free spillways can be employed but the latter are preferred [2]. Weirs are normally classified into straight, curved and folded types. In the latter class, labyrinth weirs increase the discharge capacity by providing longer total developed crest length within a fixed channel width. Labyrinth weirs can be constructed in different plan forms. Among these, a symmetric trapezoidal shape is more efficient than the rectangular plan form [2,3].

Piano Key Weir (PKW) has been introduced as an innovative type of labyrinth weirs. Plan form of these are similar but the apex of PKW is inclined and turns both in up-and downstream directions. In contrast to labyrinth weirs, PKW benefits from having certain overhangs which lead to smaller footprint of the structures [4]. Application of PKWs offers several advantages such as: increasing discharge capacity up to three times in comparison with straight linear spillways, capability of construction on existing and new gravity dams, economical efficiency, less maintenance costs, simple structure and ease of construction [5]. The first PKW was built in Goulours dam in France [6] and the next ones were constructed in St. Marc and Gloriettes dams [7].

Following primary experiments, Lempérière and Ouamane [8] presented characteristics of PKW as:

– Geometry of weirs is rectangular and similar to piano keys,
– Inlet and outlet parts are inclined,
– There are overhangs at upstream and downstream of weir.

Depending on characteristics of the overhangs, PKWs are classified into types A–D. In Type-A, identical up- and downstream overhangs are used whereas in Types-B and C only one overhang, located at up- or downstream, are employed respectively. Type-D has an inclined floor but it does not include any overhangs [9].

In recent decade, many pieces of research on various aspects of the PKW have been conducted. Early results of these studies have been mainly presented in specialized international conferences, held in 2011 and 2013 in Belgium and France respectively, and a third conference is scheduled for 2017 in Vietnam. Ribeiro et al. [10], Kabiri-Samani and Javaheri [9], Oertel [11] and Ghasemzadeh et al. [12] investigated the discharge coefficient of this type of weir. Machiels et al. [13] experimentally investigated the flow characteristics over a PKW. Pfister and Schleiss [14] and Ribeiro et. al. [15] carried out research on hydraulic design of this weir. Karaeren and Bozku [16] and Anderson and Tullis [17] compared performance of PKW and labyrinth weirs and concluded that PKW scored better. Taking pros and cons of the previous research into consideration, further research is still necessary not only to

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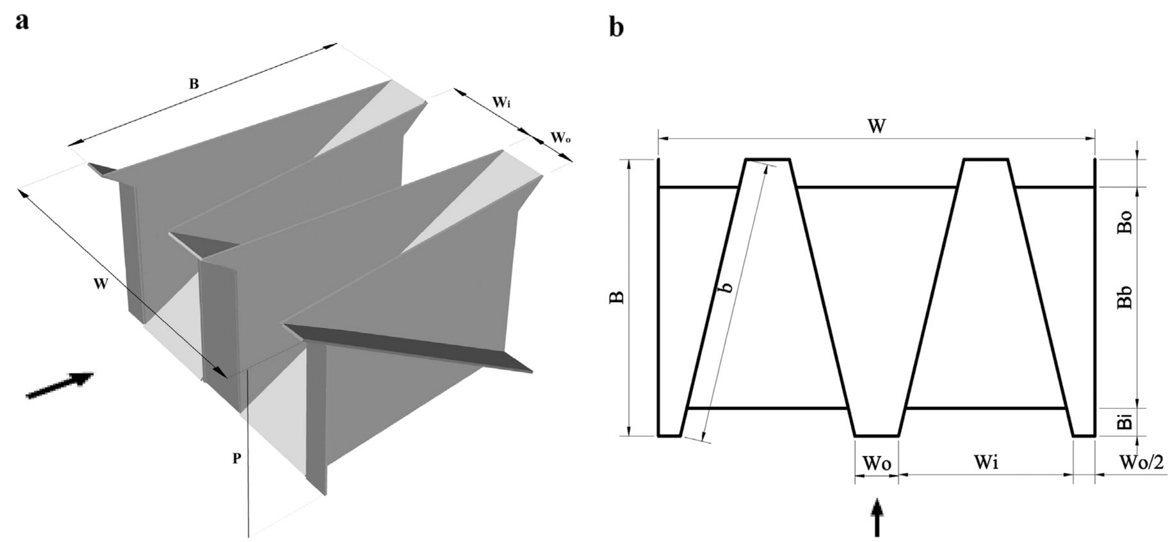

Fig. 1. Geometric parameters of TPKW; (a) 3-D view and (b) Plan form.

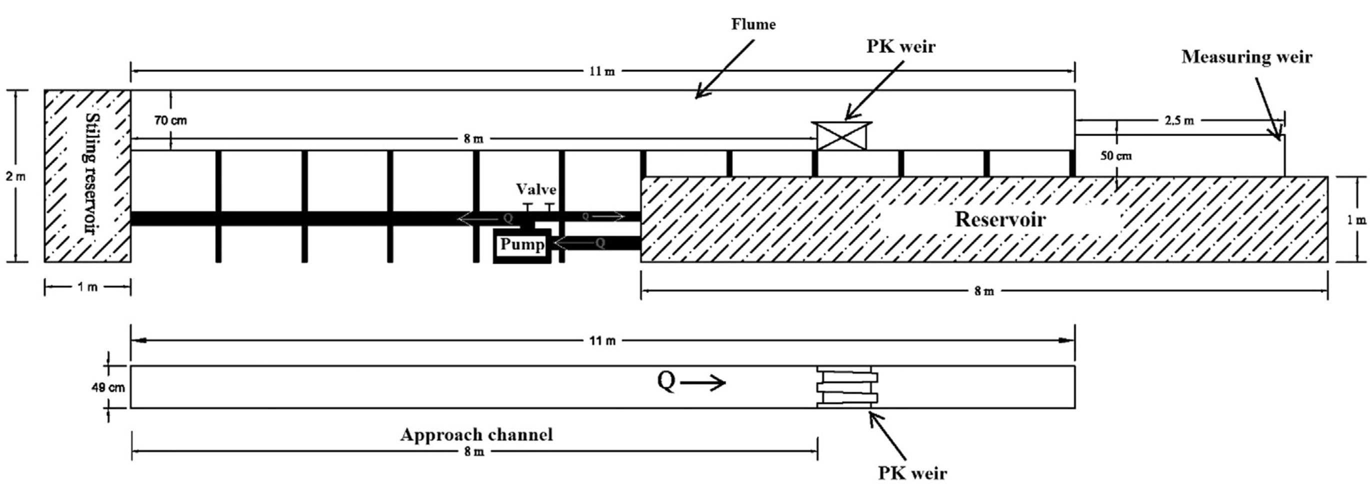

Fig. 2. Sketch of the experimental set-up.

Table 1
Specifications of experimental setups of present and previous studies; (a) Flume geometry and flow characteristics and (b) PKW geometry.

a

Reference	Q (l/s)	Length (cm)	Width (cm)	Height (cm)	Approach flow condition
Machiels et al. [13]	300	720	120	120	Channel (2.185 m)
Anderson [22]	7–240	730	90	60	Channel (3.7 m)
Noui and Ouamane [23]	–	800	75	110	Reservoir (9.9 m^3)
Ribeiro et al. [10]	13–220	300	200	100	Channel (3 m)
Kabiri-Samani and Javaheri [9]	10–70	1200	40	70	Channel (8 m)
Oertel [11]	5–100	990	80	80	Channel (4.667 m)
Present study	8–52	1100	49	70	Channel (8 m)

b

Reference	*W* (cm)	*B* (cm)	*P* (cm)	W_i (cm)	W_o (cm)	B_i and B_o (cm)	No. of cycles	Crest shape
Machiels et al. [13]	60	63	52.5	18	18	18.4	1.5	Sharp
Anderson [22]	90	50	19–22	10–14		–	4	Flat-top
Noui and Ouamane [23]	100	41–62.5	15–25	6.6–15	4.8–10	–	4–8	Flat-top
Ribeiro et al. [10]	50	33–100	10–28	10–20	10–20	7–40	1.5	Half-circular
Kabiri-Samani and Javaheri [9]	40	30–75	15–30	5–20	7.5–20	0–13	2	Sharp
Oertel [11]	80	48.9	19.69	10.5	8.4	12.91	4	Sharp
Present study	49	30–70	10–30	13.5–18.9	4.7–10.1	3–7	2	Flat-top

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