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The Effect of Upstream Overhang on Debris Blocking and Discharge Capacity of Piano Key Weirs

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1-Introduction

The capacity of an existing spillway can be increased by lengthening the spillway crest, or increasing the discharge coefficient or operating head, or any combination of these approaches. Labyrinth weirs are an effective hydraulic structure with the longest spillway crest. The Piano Key Weir (PKW) is a further develop type of nonlinear (labyrinth-type). This weir (PKW) is designed for free-surface flow control. The PK weir type can be divided into four groups according to the presence or absence of overhangs. In PKW type A, the upstream and downstream overhangs exist, and if PK weir is without downstream, upstream or both overhangs, it is B, C and D, respectively.

The PK Weir structure has a small effect on the structure of the dam, gate and other dam components, and also, in a constant head, the likelihood of blockage caused by floating debris in a PKW is less than the Labyrinth weirs. The floating debris can include branches and leaves of trees. Flooding in relatively dry areas can carry dried up branches and, in more critical conditions, cause land erosion or erosion of the banks of the river and the entry of trees into the river. The collection of floating woody debris in flow control structures, such as weirs, can lead to the reduction of the open flow area for water passage, and consequently reduced discharge capacity and safety. Woody debris, often combined with urban waste, can cause serious problems for hydraulic structures such as weirs, bridge decks or bridge piers.

In this study, the discharge capacity was investigated through 5 different geometries of the weir with different ratio length of overhanging and also the probability of woody debris collection using five models of wood and the location of the critical zone for obstructing the debris in the said weir were studied.

2- Dimensional analysis

One of the challenges associated with PK weir design is the large number of geometric parameters that affect discharge capacity (Fig. 1). The general function of the parameters effective to PKW discharge capacity can be expressed as shown in Eq.1:

$$f(P, W, W_i, W_o, B_b, B, B_i, B_o, T_s, D, L_d, H, Q, \rho, \mu, \sigma, g, \pi) = 0 \quad (1)$$

In Eq. (1), the height of PK-Weir P, total width of PK-Weir W, inlet key width W_i, outlet key width W_o, length of PKW B, PK weir footprint length B_b, upstream (outlet key) overhang lengths B_o, downstream (inlet key) overhang lengths B_i, weir wall thickness T_s, upstream hydraulic head H, flow discharge Q, diameter of debris D, length of debris L_d, the dynamic viscosity μ, density ρ, surface tension σ, acceleration of gravity g, and likelihood of blockage π. Using the dimensional analysis method, relation (2) is introduced as the final equation.

$$\pi = f\left(\frac{P}{H}, \frac{B_i}{B_o}, \frac{D}{H}, \frac{L_d}{D}, \frac{L_d}{H}\right) \quad (2)$$

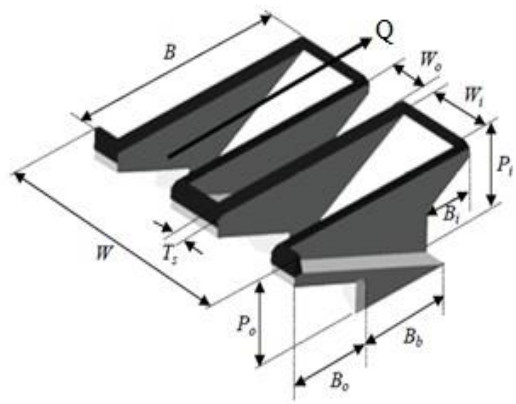

Fig. 1. Fundamental parameters on PKW

3- Model Specifications

The PKW models used in this study were made of glass with 4mm thickness, and also their width of the inlet and outlet keys is 15 and 10 cm, respectively. In Table 1, other geometric parameters of the studied models are mentioned.

Table. 1 parameters of PKW geometry

Symbol model	PKW_0	$PKW_{0.5}$	PKW	$PKW_{1.25}$	$PKW_{1.5}$
B_i/B_o	0	0.5	1	1.25	1.5
L/W	4.22	4.69	5.16	5.39	5.62
P	25	25	25	25	25
B	30	30	30	30	30

For investigating the probability of woody debris collection using two model wood trunks and rootstocks, respectively (Fig. 2).

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Fig.2. model debris including, trunks (from 1 to 4) and rootstocks (5)

In this study, at various discharge conditions, 20 to 33 trunks and rootstocks with every size class were added randomly at the flume in at least 2 m upstream of the PKW. At each stage of the experiment after blockage, the samples on the weir were held for a while to ensure that the blocked debris do not move to the other weir, and then these were removed and counted.

4- Finite Element Analysis

In this research study, by using PKW models, laboratory and debris, the discharge capacity, probability of collection and most probable location have been investigated. As it is seen in Fig. 4, the $PKW_{1.5}$ and $PKW_{1.25}$ produced 15% and 10.5% higher discharge efficiency (higher Cd values) than the other PKW models. In a general conclusion, it can be said that the flow rate and the discharge coefficient of the $PKW_{1.5}$ model are better than the other models. Upstream overhang geometry existence and its rise length increase the inlet flow area, and result in a reduction of inlet velocities, flow contraction, and energy loss.

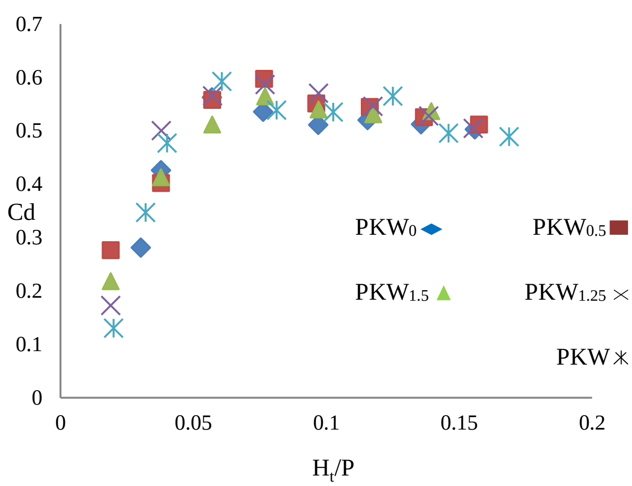

Fig.4. Cd vs. Ht /P Data for 5 ration upstream-to-downstream overhang

For investigating the blockage in these weirs, the likelihood of collection (π) has been used. Here, Π is equal to the ratio of trapped elements to the number of supplied elements. Eqs. 1 and 2 have been proposed for determining the blocking probability of debris in two trunks and rootstocks conditions.

$$P = -0.919\left(\frac{D}{H}\right)^2 + 2.26\left(\frac{D}{H}\right) - 0.409 \quad (3)$$

$$R^2 = 0.822 \quad 0.2 \le \frac{D}{H} < 1.3$$

$$P = 3.455\left(\frac{D}{H}\right) - 0.547 \quad (4)$$

$$R^2 = 0.912 \quad 0.16 \le \frac{D}{H} \le 0.44$$

In the above equations for the least and the most values, the blocking probability is 1 and 0, respectively.

Fig.3. A view of blockage the rootstock in PKW

5- Conclusions

Based on the experimental and analytical results, the following conclusions are drawn:

1- The existence of upstream overhang in the weir structure, in addition to preventing the decreased flow of the weir, also causes increases in the discharge capacity of PKW.
2- The probability of blocking, in addition to the type of debris (trunk and rootstock), has a direct relationship with the diameter and length of the debris. However, the results of this study indicate that the diameter of debris relative to its length is an effective parameter on the obstruction.
3- The most likely location for blockage is different based on the water depth on the weir, the diameter of debris and their type. However, the exit key section is the most critical point in terms of obstruction and most of the debris are blocked in this section.