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Contribution to the study of the Piano Key Weirs submerged by the downstream level

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ABSTRACT: Dam reservoirs are confronted with two fundamental problems. The first is the master of floods and the second is related to the loss of storage capacity due to the silting of the reservoir. One possible solution to these problems is to raise the sill level of the existing weir by its renovation in PK-Weir.

The PK-Weir is built across the rivers and on dams where the limitation of discharge or water level must be ensured in normal or submerged flow conditions. Various studies and researches carried out on the PK-Weir have focused only in the normal flow conditions. The present paper presents a study on the effect of the downstream level on the performance of the PK-Weir.

This study will be based primarily on model experiments and following on the approaches of other authors for rectilinear or labyrinth weirs submerged from downstream.

1 INTRODUCTION

Generally, the weirs are conceived to operate under free flow conditions, this means that the downstream water level lies below the crest level of the weir. However, when the downstream water level exceeds the level of the crest, the weir is not any more in a free flow condition but rather submerged.

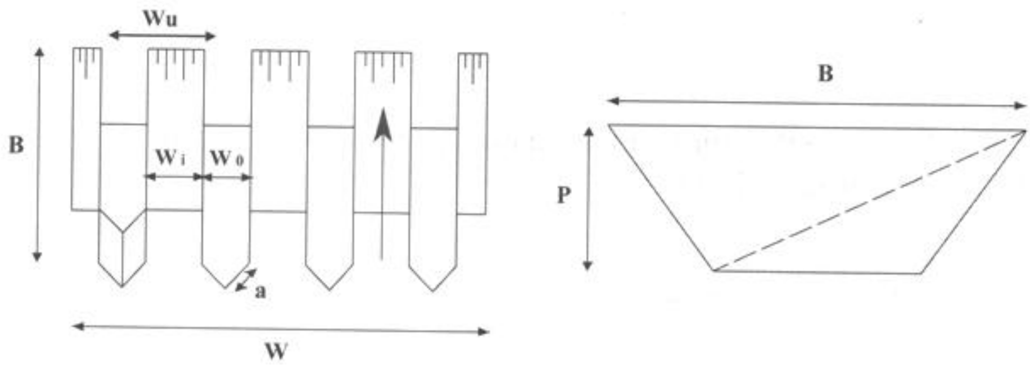
In the case of a weir installed in an irrigation channel or through a natural stream, working in submerged conditions, a higher upstream head is required to assure a discharge equal to the one evacuated under free flow condition. In case the section upstream of the weir is significantly larger than the width of the weir; that engenders the formation of a storage reservoir upstream, the downstream submersion will then cause a decrease of the evacuated discharge.

Research works in the field of labyrinth weirs submerged by the downstream level are essentially related to the work of Tullis et al. (2006) and to that of Lopes et al. (2009). These works showed that the submersion does not impact before the downstream water level exceeds the weir crest. If the downstream water level continues to increase, it tends finally to equal the upstream water level and the structure will not work any more as a control structure.

According to the work of Tullis et al. (2006), the performance of a submerged labyrinth weir can be exactly described with a small error, with regard to experimental data. The ratio which expresses the relative downstream head (Hd/Ho), seems to be relatively independent from the side wall angle of the labyrinth weir. When the angle of the wall increases, the performance of the submerged labyrinth weir approaches that of a linear weir. The work of Lopes et al. (2009) showed that the shape of the labyrinth weir crest and the angle of the side walls have only a small effect on the relative head of the submerged flow.

The functioning of the PK-Weir under submerged conditions was the object of only few preliminary studies, so it became necessary to verify experimentally the effect of submersion on the performance of this type of weir. This study was realized at the university of Biskra on a PK-Weir model of type A (Fig. 1), whose geometrical characteristics are given in Table 1.

The experimental study focused on two typical cases of submersions, the first considering a sill downstream of the weir and the second with the presence of a flow under a gate (Fig. 2).



a- Plan view

b- Cross section

Figure 1. Geometrical parameters of the experimented model.

Table 1. Geometrical characteristics of the experimented PK-Weir model.

PK-Weir model A	n°	n	L cm	W cm	P cm	B cm	W_0 cm	W_i cm	L/W	W_u/P	W_i/W_0
	A1m	4	498	99.2	20	48.48	11.3	13.5	5.02	1.24	1.2

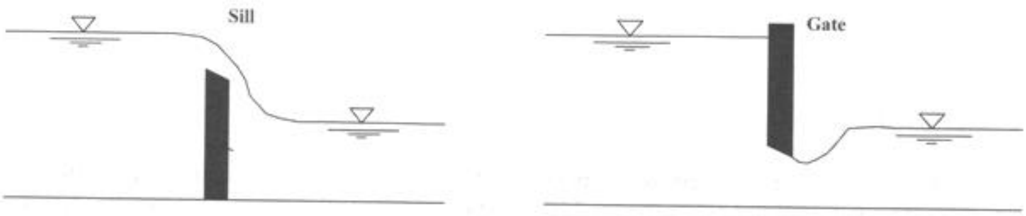


Figure 2. Typical cases of downstream flow.

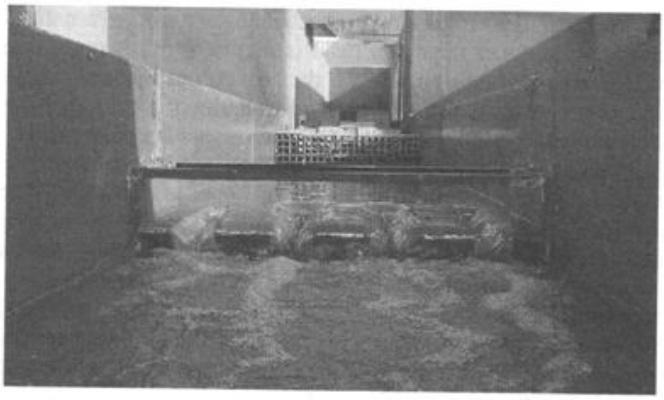


Figure 3. Experimental channel with the PK-Weir, downstream view.

2 EXPERIMENTAL PROGRAM

The work was realized in an experimental facility composed of a set of open channels allowing to simulate flow conditions upstream and downstream of hydraulic structures (Fig. 3).

The upstream and downstream flow conditions are described in Figure 4 for free and submerged cases.

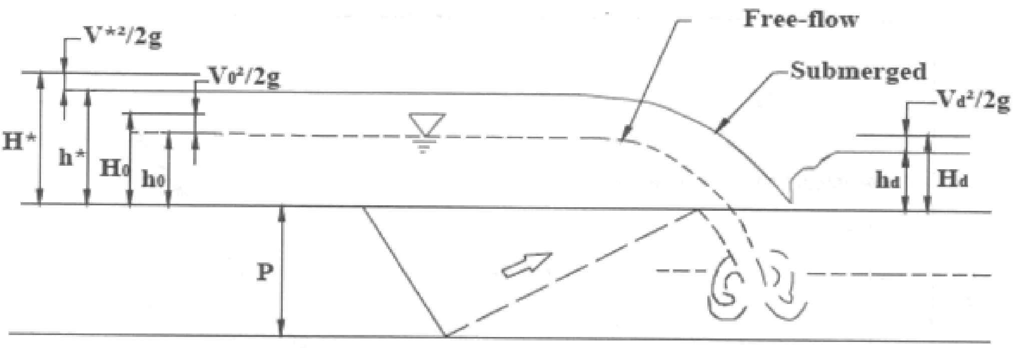


Figure 4. Definition of hydraulic parameters for the weir under free and submerged flow conditions.
Submerged flow
– H*: upstream total head; – h*: upstream piezometric head;
– H_d: downstream total head; – h_d: downstream piezometric head.
Free flow
– H_o: upstream total head; – h_o: upstream piezometric head.

3 EXPERIMENTAL RESULTS

Tests made on the model of PK-Weir were realized in two phases, the first with a free flow and the second with a submerged flow. These tests were realized to verify the effect of the submersion on the performance of the PK-Weir. So, several cases were considered, according to the configuration of the outlet slab, the magnitude of the evacuated discharge and the flow controlled by an obstacle downstream (gate and sill).

3.1 *Influence of the shape of the outlet slab (filling of outlet)*

Three rates of filling of outlets were tested (the slab of outlet as steps). The obtained results showed that the effect of submersion is independent from the filling of outlets. This shows that the arrangement of the slab in outlets does not affect the evolution of the upstream head with regard to the downstream head.

3.2 *Influence of the discharge*

To estimate the effect of the submersion according to the discharge, tests were realized for three values of discharge (Q = 38 l/s, 60 l/s and 80 l/s). The obtained results point out that the variation of the upstream level with regard to the downstream level is independent from the discharge (Fig. 6).

3.3 *Influence of the type of control structure downstream of the weir (gate and sill)*

The increase of the downstream water level can appear due to the influence of an obstacle downstream of the weir. Two cases can be considered in relation with the type of control structure, the first concentrates flow on the bottom (flow under gate) and the second imposes a free surface flow (over a sill).

The obtained results show, that flow on sill or under gate downstream from the PK-Weir has basically the same effect on the upstream part of the weir. According to Figure 7, the relative upstream total head for submerged conditions is not influenced by the type of control structure downstream of the weir.

3.4 *Effect of the submersion on the discharge coefficient*

The effect of submersion on the capacity of the PK-Weir can be determined by the variation of the discharge coefficient according to the rate of submersion. Tests made for various discharge

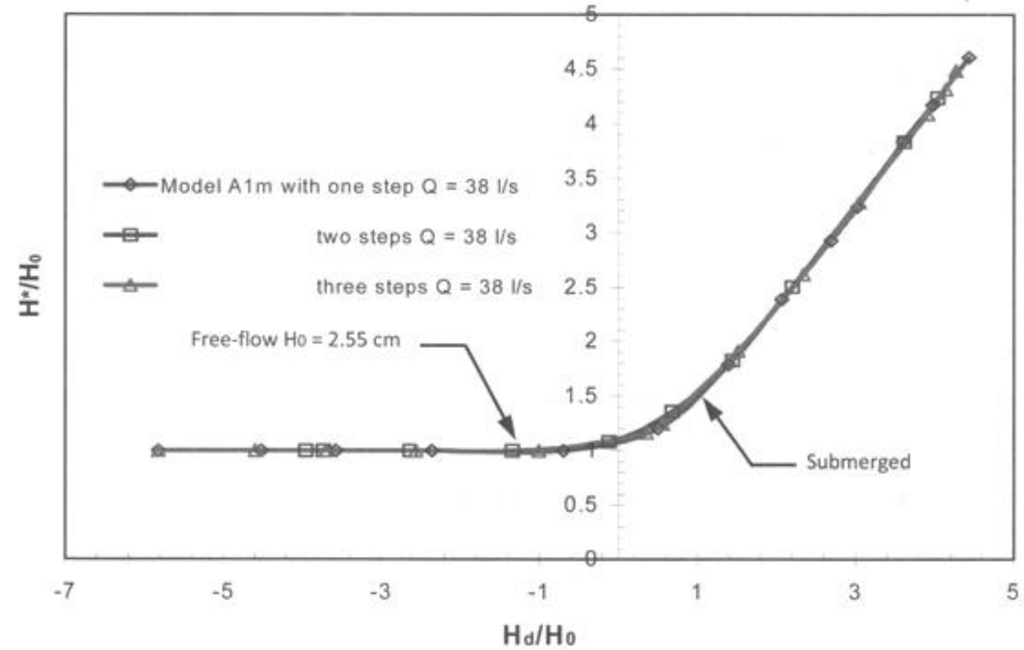


Figure 5. Relative upstream total head for submerged conditions: influence of the outlet slab configuration.

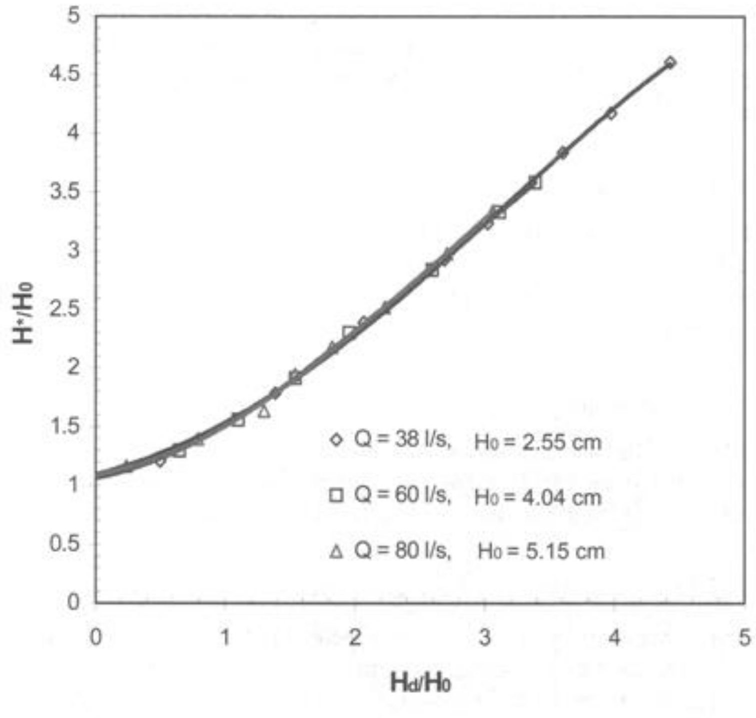


Figure 6. Relative upstream total head for submerged conditions according to the discharge.

values (Q = 38 l/s, 50 l/s, 60 l/s, 70 l/s, 80 l/s, 91 l/s, 100 l/s, 111 l/s and 122 l/s) under submerged flow and for Q = 30 l/s to 170 l/s for free flow. The results (Fig. 8) show that the PK-Weir under free flow conditions distinguishes by values of the discharge coefficient forming a superior envelope curve to the curves of submerged flow obtained for various discharges. The performance of submerged flow is strongly reduced for small heads and decreases more slowly for high relative heads.

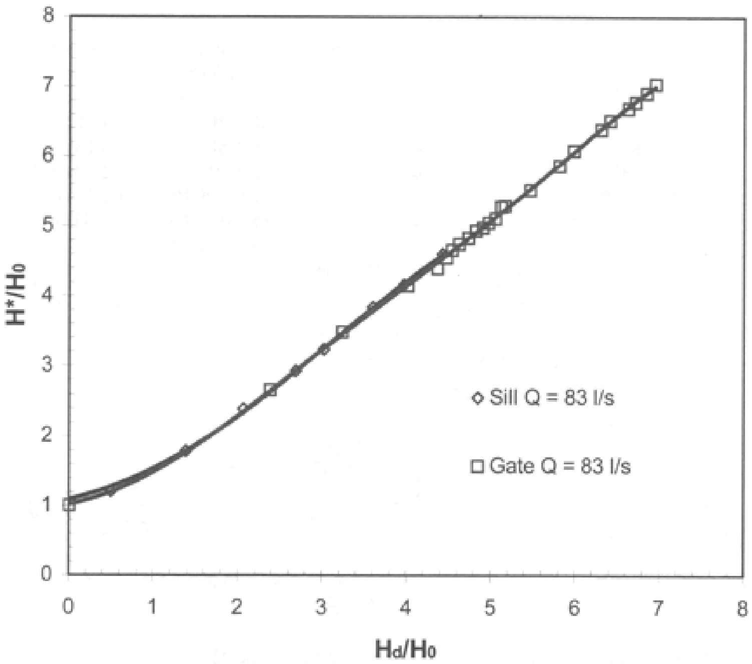


Figure 7. Relative upstream total head under submerged conditions, according to the control structure downstream of the weir.

The curves of submerged flow start from the envelope curve corresponding to the free flow, confirming that their initial conditions are in normal flow conditions.

When increasing the depth of the downstream water level, the weir becomes submerged. This submersion reveals itself by a fast decrease of the discharge coefficient for the small values of the relative upstream total head H*/P ($0.12 < H^*/P < 0.6$), this decrease losses of importance from a value H*/P about 0,6 and the curves of discharge coefficient become more flattened.

One may notice that the curves of submerged flow are shifted in an ascending way (from small to high discharge). The gap between the various curves is almost constant essentially for the values of $H^*/P < 0{,}6$. This gap which corresponds to an increase of discharge in the order of 10 l/s engenders an increase of the discharge coefficient of about 0.1 for the values of $H^*/P < 0.6$.

One may notice that for the small discharges the influence of the downstream level is more pronounced. This can be explained by the small upstream heads when the weir works with small discharges.

Figure 8 shows that the influence of submergence is more significant when the upstream head is small. Figure 9 shows clearly this effect. For example, with a discharge of 38 l/s and a downstream total head $H_d = 5$ cm the variation of the upstream total head is of 3.5 cm, whereas for a higher discharge of 122 l/s and with the same value of H_d, the variation of the upstream total head is only 1.5 cm, about 50 % of the value corresponding to the former discharge. This observation is not true for the high heads where the variation of H* is proportional to the variation of H_d.

Finally, it can be said that for the small values of H*/P, the effect of submersion is very important for small discharges, however, this effect decreases gradually with the increase of discharge what implies an increase of the upstream total head H*.

Results obtained experimentally are represented on Figure 10. This expresses the discharge coefficient related to the ratio of the downstream head reported to the upstream head. (Hd/H*). Figure 10 shows that for values of $Hd/H^* < 0.35$, the decrease of the discharge coefficient is small. On the other hand for values of the relative downstream head $Hd/H^* > 0.35$, the discharge coefficient decreases gradually and the distance between curves is reduced until the

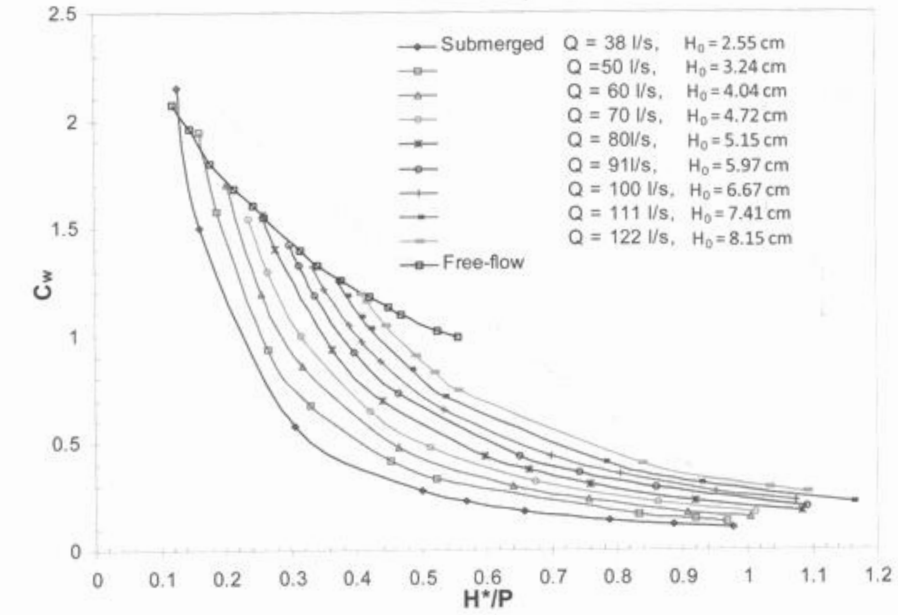


Figure 8. Effect of submerged flow conditions on the discharge coefficient.

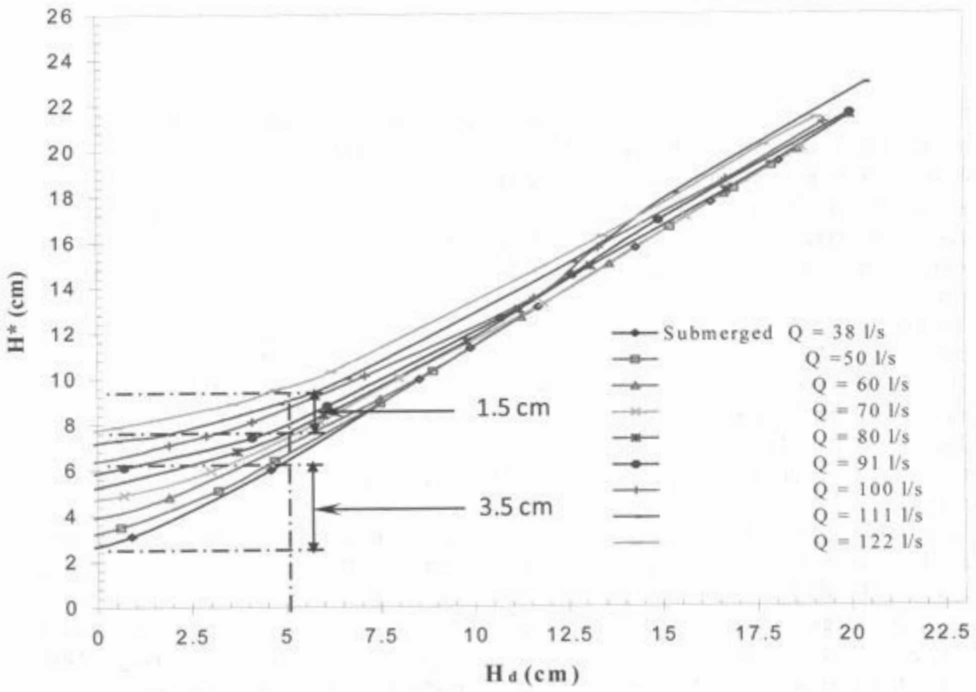


Figure 9. Effect of the downstream total head and discharge on the submerged total upstream head.

various curves converge and tend to become a unique curve for a value of Hd/H* close to unity (Hd/H* = 1).

These results show that for the small values of Hd/H*, the PK-Weir is influenced by the downstream flow only weakly, on the other hand for the large values of Hd/H* the effect of the submersion on the upstream discharge coefficient is visible.

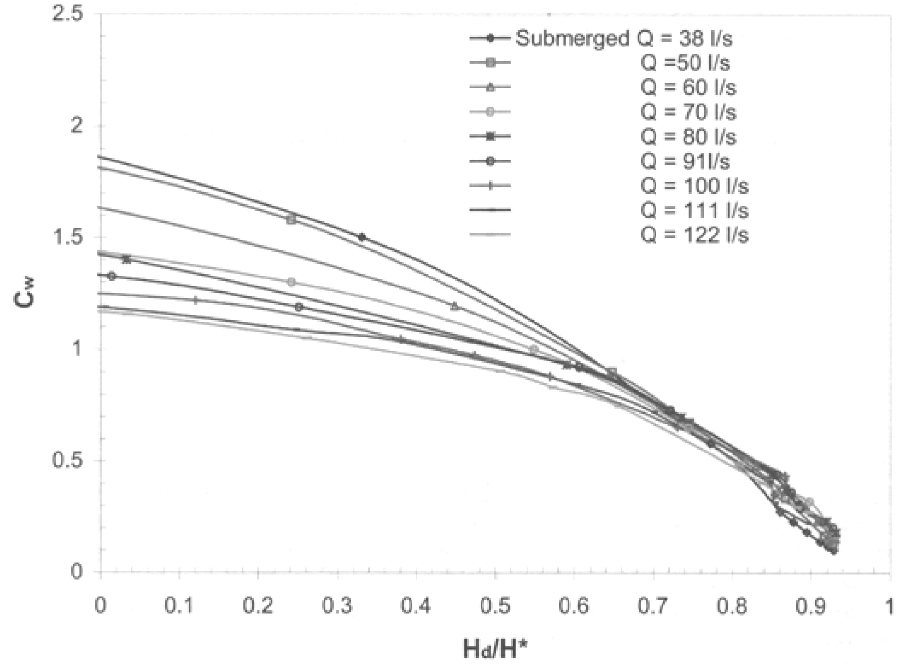


Figure 10. Effect of the downstream relative total head on the discharge coefficient.

4 CONCLUSION

The PK-Weir can be designed to operate with a downstream water level higher than the crest of the weir. The results obtained for several cases of functioning show that the reduction of the performance is noticeable only when the downstream water level is higher than the level of the weir crest. When the downstream water level exceeds the weir crest, the downstream conditions can influence the flow on the PK-Weir and consequently its performance is affected. This influence was found to be independent of the shape of the PK-Weir. The upstream water depth varies in a proportional way with the downstream water depth. It was noticed that the variation of the upstream level with regard to the downstream level makes in a proportional constant way for various discharges. Tests realized for two types of control structures downstream (gate and sill) revealed that for a same given discharge, the submergence effect on the relative upstream total lead is not influenced by the type of structure.

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