Effect of the Downstream Level on the Performance of the PK-Weir and Linear Weir

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Abstract: *The Piano Keys Weir (PK-Weir) represents a new solution which allows increasing weirs capacity (and/or) the capacity storage of the volume water of existing dams. However, the analysis of the geometrical and hydraulic parameters still of research for the improvement of this new type of weir. Different studies and researches made on the PK-Weir were focused on the improvement of the geometrical shape and the studies of the flow of this type of weir. The present work represents a study on the effect of the submergence on the upstream flow of PK-Weir and linear weir.*
This study is based mainly on the experimentation of the two physical models which is supported by an analysis of the results.

Key words: *PK-Weir, Linear Weir, Free flow, submerged flow.*

1. INTRODUCTION

The Piano Key Weir (PK-Weir) can be realized through artificial or natural streams as a spillway dam and in a reservoir where the limitation of discharge or water level is required by operating in a submerged conditions or a free flow. The flow on the PK-Weir is considered submerged when the downstream level of water affects the upstream level by increasing the upstream head of water that is required to pass a discharge equal to that in conditions of free flow.
The PK-Weir are classified according to the presence or absence of the overhangs (Lemperiere et al., 2011) : type A with upstream and downstream overhangs, type B with only upstream overhang, type C with only downstream overhang and type D, without overhangs.
In 2013, Electricité De France (EDF) have presented an experimental study on three models of PK-Weirs type A ,B and C to determine the efficiency of discharge in the same submerged conditions (H^* and H_d). This study has shown that the type C was less effective than the type A to $0<H_d<0.9H^*$, whereas the type B was more effective than the type A to $H_d< 0.5H^*$, and the type B was more effective than the type C to $H_d< 0.8H^*$ (Cicero et al., 2013).
Tullis et al (2012) presented an experimental study for two models of labyrinth weir and the PK–Weir to determine the effect of submergence on the flow of these two types of weirs. The comparison of the obtained results about the two types of weirs showed that the PK-Weir appears to be relatively more effective than the labyrinth weir to the low submersion (S<0.75). However, this is reversed to the highest levels of submergence.
Ho Ta Khanh (2012) presented an experimental study about three types of weirs (rectangular labyrinth and PK-Weirs types A and D) that operating in submerged flow conditions. This study has shown that the difference between the rectangular labyrinth and the PK-Weir of type A and D isn't very important, however a slight advantage to the PK-Weir of type D for the large floods.

The objective of the present research is to verify the effect of the submergence on the hydraulic performance of PK-Weir and linear weir by an experimental way. The verification is interested:

- Influence of the lateral contraction.
- Comparison of the results obtained on the different models and a model PK-Weir of Tullis et al (2012).
- Determination of the nature of the flow and the coefficient of submersion S.

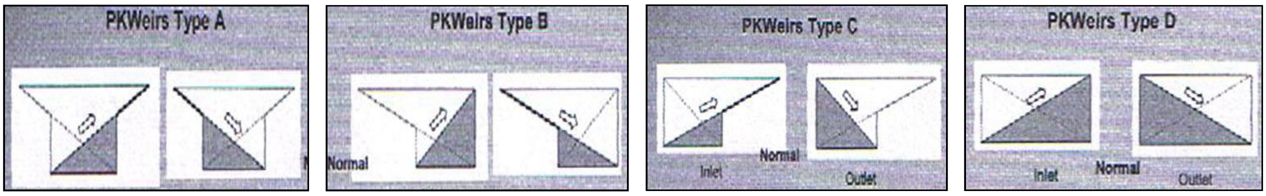


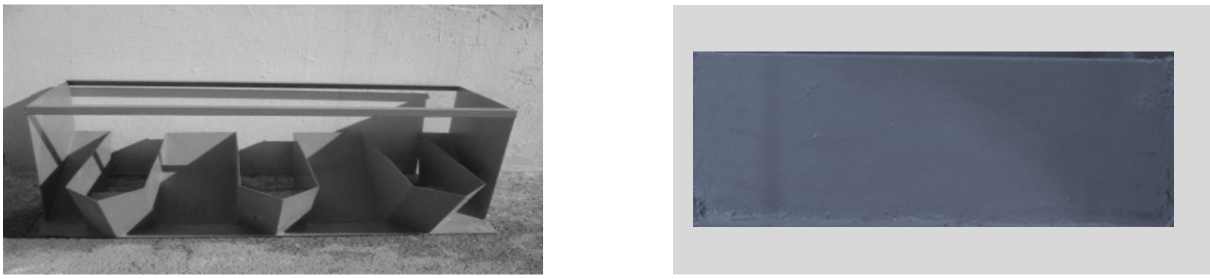
Figure 1 – Different type of PKW (A,B,C and D)

2. EXPERIMENTAL PROGRAM

With an aim of determining the influence of the effect of the submergence on the upstream flow weirs, tests on small-scale models were conducted at the Laboratory of Hydraulic Planning and Environment at the University of Biskra.

2.1. Definition of the experimental models

The experimental study was performed on two different models of weirs configuration, the models were made with e = 0.002m thickness walls. The geometric characteristics of these models are listed in the Table 1.

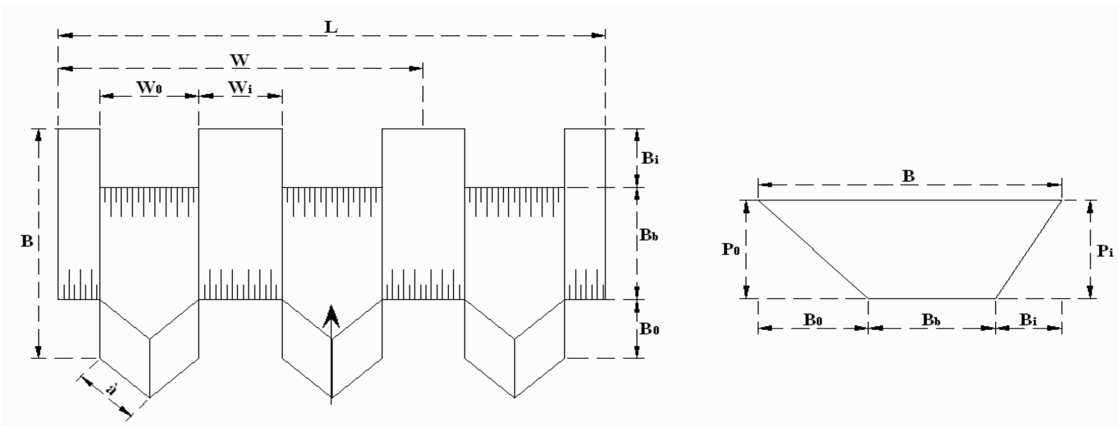


a)- PK-Weir type A2m. b)- Linear weir

Figure 2 – Model of weir

Table 1 Geometrical characteristics of the experimented model (dimensions in meters).

Model of weir	n_0	n	L	W	W_0	W_i	B	B_0	B_i	B_b	$P_0=P_i$
PK-Weir (A)	A2m	1.5	2.66	0.66	0.18	0.15	0.47	0.12	0.12	0.23	0.20
Linear weir	-	-	1.05	-	-	-	-	-	-	-	0.20



a- Plan view b- Cross section

Figure 3 – Geometrical configuration of the model A2m

2.2. Description of the test facility

The experimental work was conducted in the laboratory facility comprising a supply channel with 0.95x0.95 m cross section and 5 m length. This channel is connected to the simulation basin, with a square shape 5x4 m and 2.1 m height. The weir model is inserted at the outlet of the simulation basin. The so-called return channel is 3 m long and 1.9 m wide, connected to outlet.
The experimental procedure has been as follows:
After having fixed the flow which passes through the channels, we measure the level of water upstream in the free flow conditions. While holding the constant discharge, we are increasing the water level downstream of the weir by the installation of a sill or the closure of a gate which is located at the downstream end of the reception channel. After stabilization of the flow we take the measurements of water depths upstream and downstream of the tested model. Once this operation is carried out we increase another time the height of the sill or the closure of the gate to increase the downstream level and we operate in the same way as previously (Figure 4).

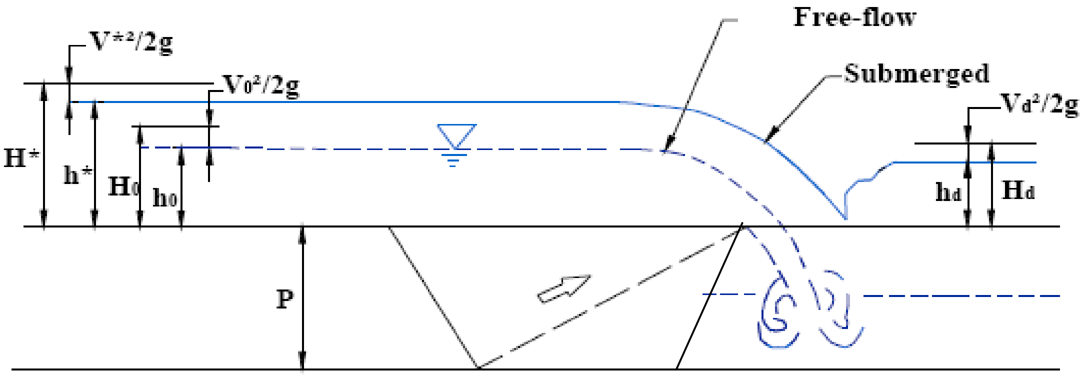


Figure 4 – Definition of hydraulic parameters for the weir under free and submerged flow conditions

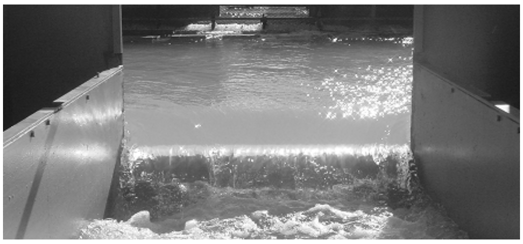
Submerged flow :	- H*: upstream total head;	- h*: upstream piezometric head;
	- H_d: downstream total head;	- h_d: downstream piezometric head.
Free flow :	- H_o: upstream total head;	- h_o: upstream piezometric head.

3. RESULTS

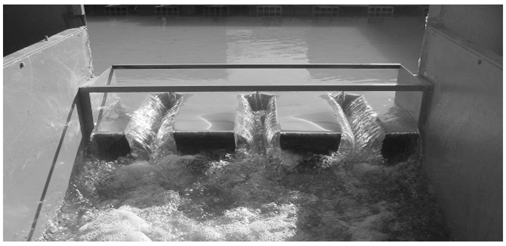
This study proposes to present the tests results of two models. These results are expressed either by the relative upstream head (H^*/H_0) according to the relative downstream head (H_d/H_0) or by the ratio (H_d/H^*) depending on the ratio ($(H^*-H_d)/H_0$) or by the ratio (H^*/P) depending on the ratio ($(H^*-H_d)/P$).

3.1. Comparison of the flow between the PK-Weir type A2m and linear weir

The comparison between the PK-Weir model and the linear weir which operate in free flow conditions according to the figure 6 which shows the difference between the both curves of discharge is almost constant for a range of a head lower than the height weir (P=0.20m). The increased discharge of the PK-Weir relative to the linear weir with the same width is around 2,0 time for the lower heads at the higher of weir. This shows that the PK-Weir can be a more effective solution than the linear weir.



a)- Linear weir



b)- PK-Weir type A2m

Figure 5 – Free flow on weir

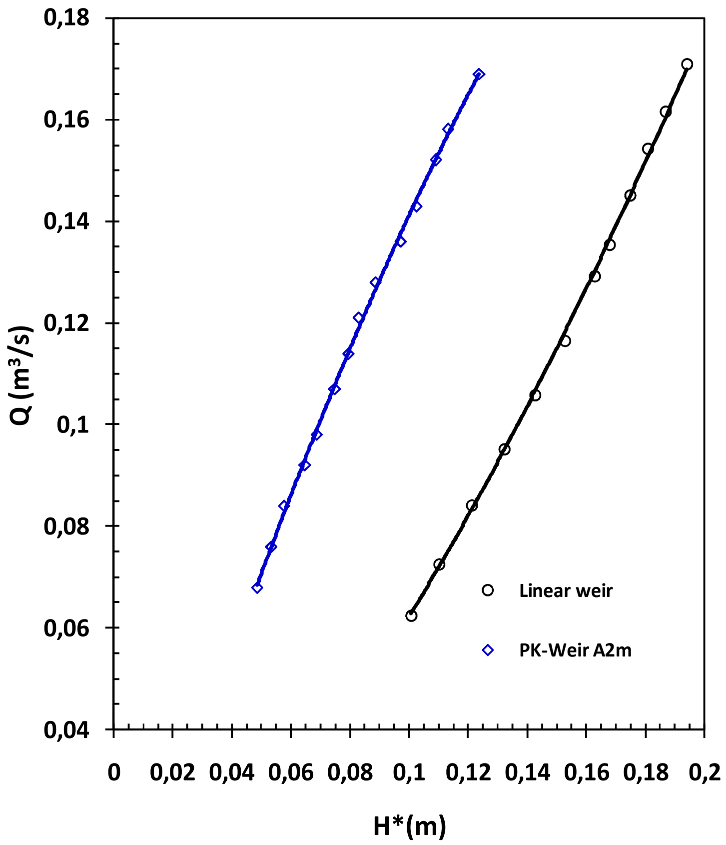
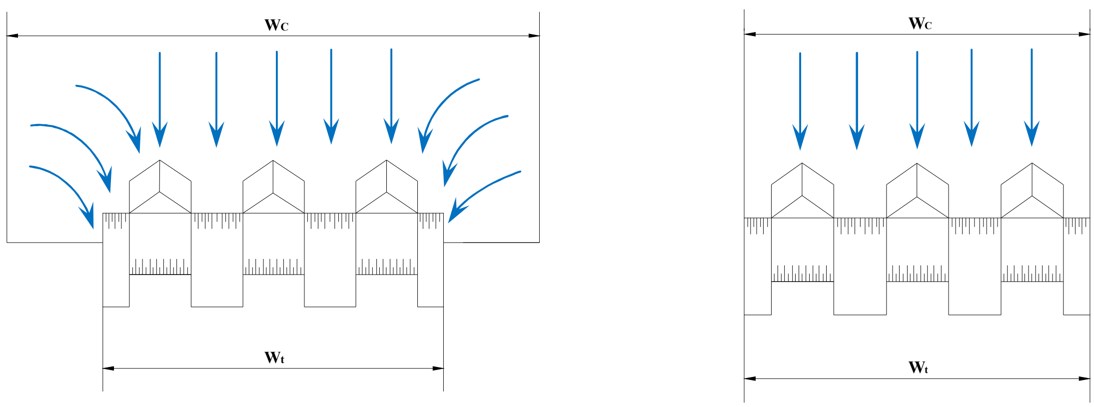


Figure 6 – Comparison of the flow between the PK-Weir type A2m and linear weir

3.2. Influence of the lateral contraction

Verification of the effect on the contraction of the submerged flow requested tests that were made on two models with and without lateral contraction (figure 7), The first arrangement corresponds to a width of inlet channel equal to the width of the PK-Weir Wc=Wt. The second disposition corresponds to a width of inlet channel equal four times the width of the spillway Wc=4Wt.

The obtained results point out that the variation of the upstream level with regard to the downstream level is independent from the contraction type.



a- With lateral contraction (Wt<Wc) b- Without lateral contraction (Wt=Wc)

Figure 7 – PK-Weir with and without lateral contraction

The graphs of figure 8 clearly show that for both types of contraction and for a given flow, the variation of the relative downstream head compared to the relative upstream head is done in a proportional manner.

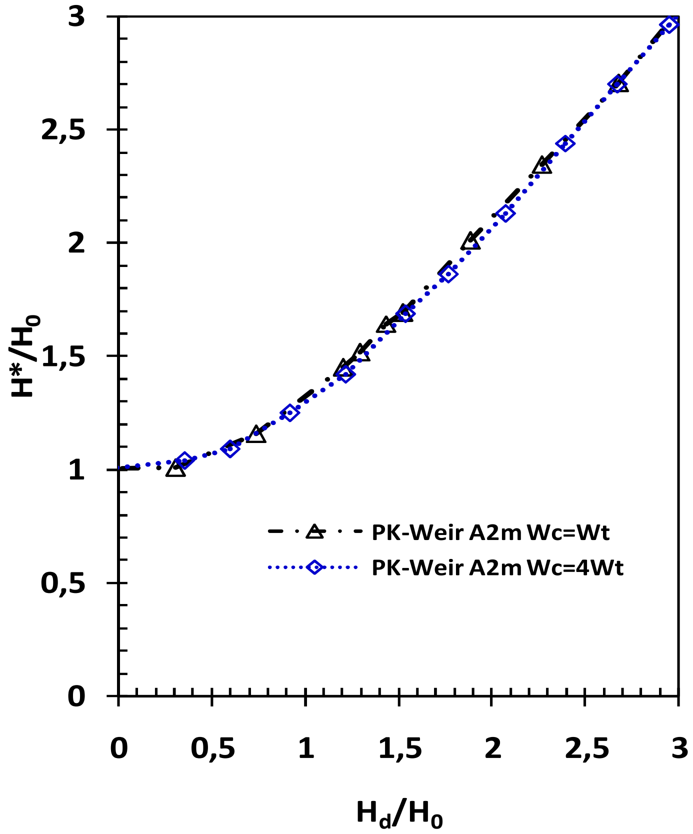


Figure 8 – Relative upstream head according relative downstream head (model type A2m)

3.3. Comparison of the results obtained on the different models and a model PK-Weir of Tullis et al (2012)

The variation of the upstream head on the PK-Weir and on the linear weir operating in a submerged flow conditions has been compared with the curve of reference of PK-Weir obtained by Tullis et al (2012). This comparison shows that the three weirs behave similarly to the submerged flow conditions (figure 9).

According to figure 10, the experimental results on the PK-Weir in submerged conditions are shown; when the ratio $(H^*-H_d)/H_o$ tend to 1, the downstream water level approaches the crest level of PK-Weir and the upstream head approaches the free flow condition (in other words $H_d/H^* = 0$). On the contrary, If the submersion level $(H^*-H_d)/H_o$, decreases, the value of H_d/H^* approaches the submerged condition (it means $H_d/H^* = 1$) and the PK-Weir submerged does not operate as an organ of control. That can be observed also for the results obtained from the model of linear weir (figure 11)

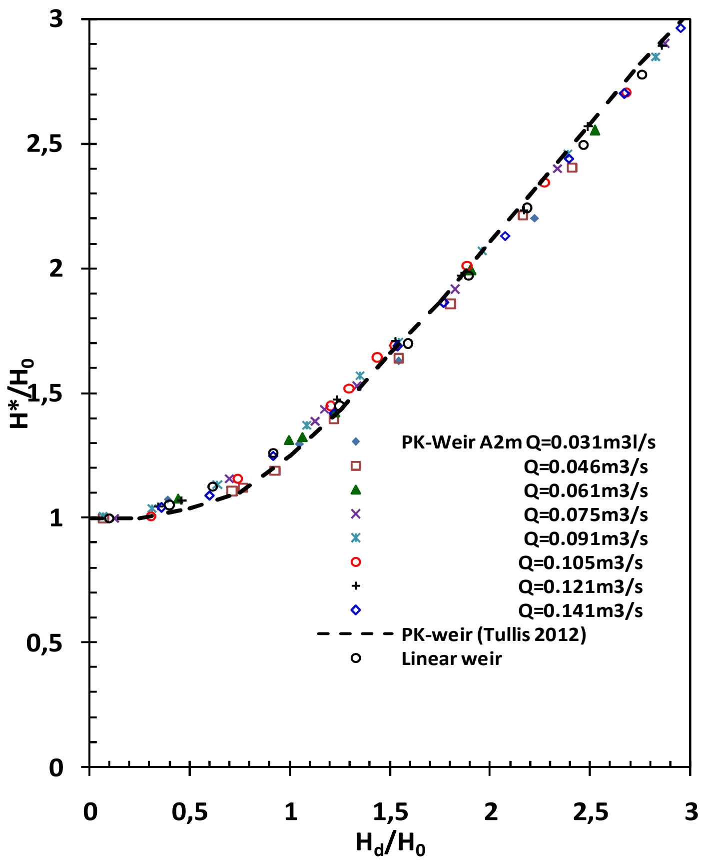
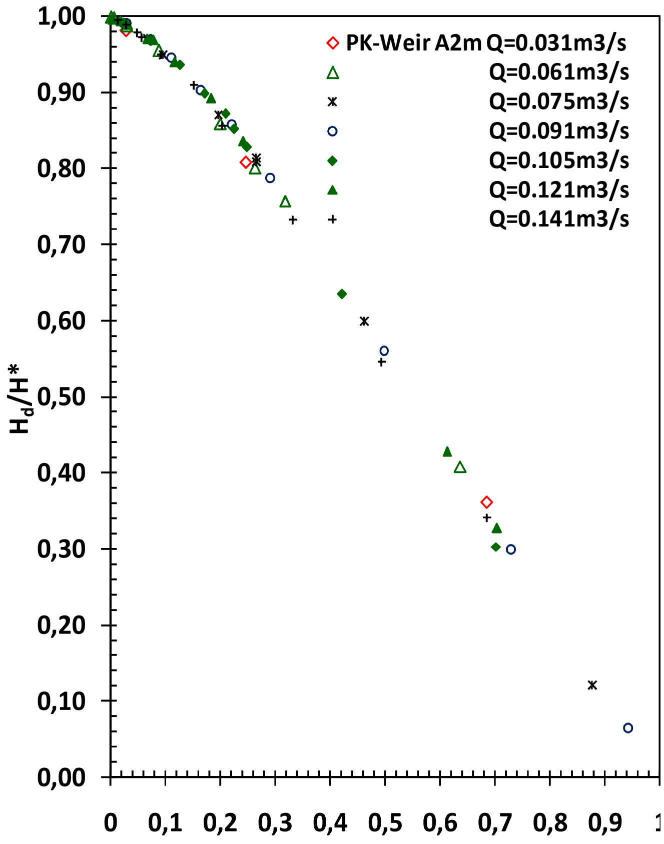


Figure 9 – Comparison of the effect of submergence between the PK-Weir type A2m, the linear weir and a model PK-Weir of Tullis (2012).



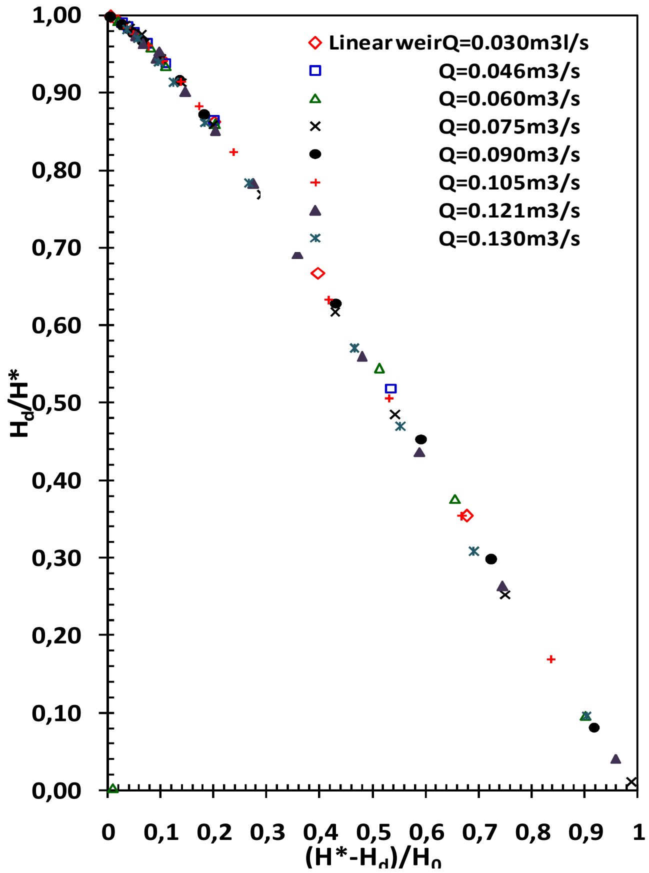
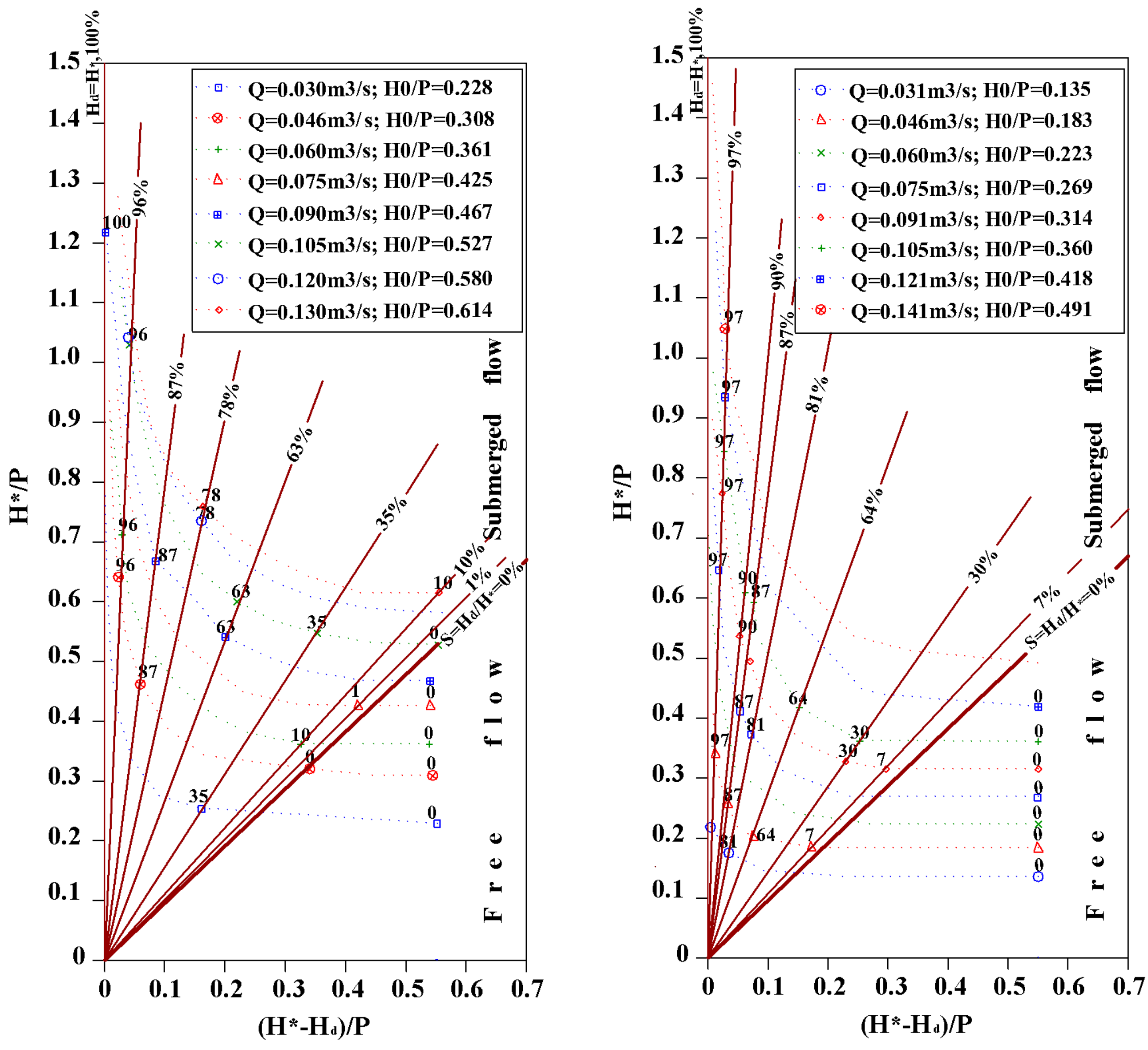


Figure 10 – H_d/H^* vs $(H^*-H_d)/H_0$ (PK-Weir A2m)

Figure 11 – H_d/H^* vs $(H^*-H_d)/H_0$ (Linear weir)

3.4. Determination of the nature of the flow and the coefficient of submersion ($S = H_d/H^*$)

Determining the nature of the flow and the coefficient of submersion ($S = H_d/H^*$) for two weirs (PK-Weir and weir linear) can be determined by the relative upstream total head H^*/P according to the ratio $(H^*-H_d)/P$ and ratio H_d/H^*.



a- Linear weir b- PK-Weir A2m

Figure 12 –Determination of the coefficient percentage of submergence S and nature of the flow of PK-Weir and linear weir

Figure 12 can be used for two manners, on one hand, in the search of the limited submerged, it means the report H_d/H^*, between a free flow regime and a submerged flow regime and on the other hand. In the search of the submersion coefficient S of flow. The measure applied, to the two reports H^*/P and $(H^*-H_d)/P$ gives a projection on figure 12, which indicates the percentage of the coefficient of submergence S and the type of flow of the PK-Weir and linear weir.

4. CONCLUSION

The testing of the two weirs type PK-Weir A2m and linear weir at the University of Biskra allows studying the functioning of the weirs under free flow and submerged conditions.
The results of the physical modeling tests with two different weir models showed that:

- Under free flow conditions
  - The PK- Weir can be more effective solution than the linear weir.

- Under submerged flow conditions
  - The tests realized on the model of PK-Weir shows that the variation of the relative downstream head compared to the relative upstream head is done in a proportional manner and independent from the contraction type (with and without lateral contraction).
  - The comparison of the effect of submerged between the PK-Weir A2m, linear weir and model PK-Weir of Tullis et al (2012) shows that the three weirs behave the same way in terms of a submerged flow.
  - The diagram in figure 10 can be used to determine the coefficient of submergence S and the type of flow of PK-Weir and linear weir.

5. REFERENCES

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