The Piano Key Weir is the solution to increase the capacity of the existing spillways

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Introduction

The new methods of evaluation of floods and the progress registered in the field of the numerical modeling showed that the maximal probable flood for an existing dam can increase considerably by comparing it with the initial conception flood. If the spillway does not allow the passage of the flood updated in suitable conditions, so, the structure requires a modification to increase the space of flood storage and the capacity of the weir.
It is possible to increase the capacity of these works by their rehabilitation to avoid the problem of submersion, so several solutions are conceivable (A. Ouamane and Al, 2007).
Most of the existing dams are equipped with free flow spillways, whose hydraulic functioning is governed by the laws of the free flow and represents most simple and effective solutions.
The discharge evacuated with a free sill weir is given by the universal relation:

$$Q = \mu L \sqrt{2g} h^{3/2} \qquad (1)$$

Where
μ: discharge coefficient
L: crest length
g: Acceleration of the gravity
h: Total head on the weir.
At first sight of the relation (1), one can think naturally that the increase of capacity of the existing spillways can be obtained either by the elongation of the crest length of weir L or by reduction in the level of the sill to increase the head H.
The linear elongation of the crest cannot be feasible because of width of weir which is limited or the conditions topographic local not favorable. However, the rehabilitation of the existing weir by a weir with non-rectilinear crest can increase in a significant way the length of the sill. Concept is to modify shape of the weir to increase the efficiency of the crest. This increases strikingly discharge by unity of width for a given operating head (A. Ouamane and Al. 2007).
The reduction in the level of the existing sill to increase the head would involve a considerable loss of the useful volume corresponding to the superior slice of storage.
Some solutions which can be adopted to increase the spillways capacity and consequently, increase the safety of existing dams. These solutions correspond to the rehabilitation of existing weirs by the modification of the weir crest, into labyrinth crest, or Piano Key Weir (P.K.Weir).
Many studies and tests on hydraulic models were realized in the Hydraulic Development and Environment Laboratory - University of Biskra - (Algeria) for the development and optimization of these solutions. These tests have studied the P.K.Weir so that it can be realized on existing structures and have an economic efficiency.
The piano key weir may multiply by about 3 the discharge of a free flow spillway. The model B with an upstream overhang seems the most cost effective and is analysed below.

1. Piano Key Weir (P.K.Weir)

The Piano Key Weir is characterized by a broken axis in plan as labyrinth weir so that the water flow is presented with a greater length of crest compared with a linear weir occupying the same lateral space. (fig. 1). The purpose is to increase the discharge per unit width of structure for a given operating head.
It can be used for the new dams or the existing dams which require an increase of the capacity of the weir and\or storage capacity. It can be placed on reduced sections of dams existing or new, allows the evacuation of specific discharges until over 50 m^3/s/m and multiplies by up to three the discharge of a Creager weir.
Attempts on physical models realized since the 2002 in Biskra's (Algeria) university allowed to define some forms which are based on:

- a rectangular layout
- an inclined floor of upstream and downstream alveoli.
- a reduced length of the bases due to overhangs.
- a reduced width of elements due to the rectangular shape.

So, two models of P.K.Weir were selected, the first with an upstream and downstream overhangs (model A) and the second with only an upstream overhang (model B) (fig.1 and fig.2) (F. Lempérière and al., 2003)

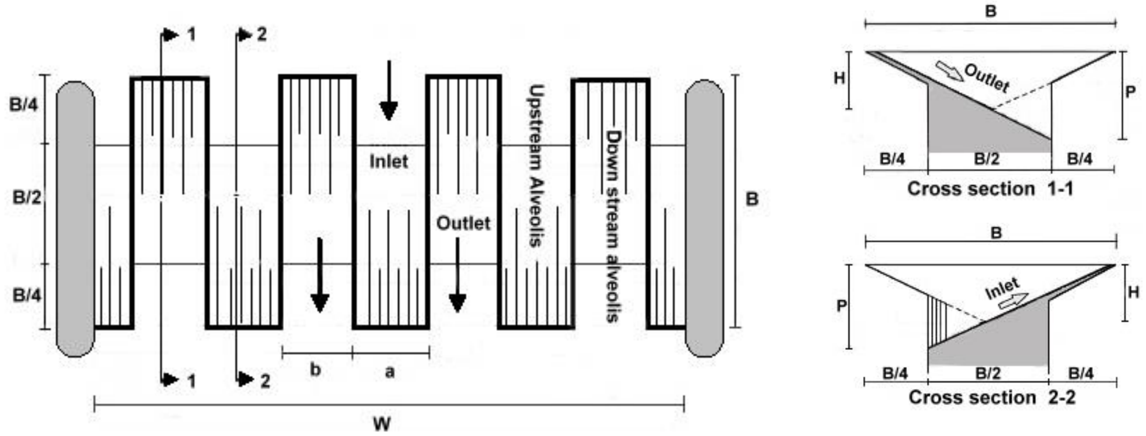

Fig. 1 Layout of P.K.Weir model A

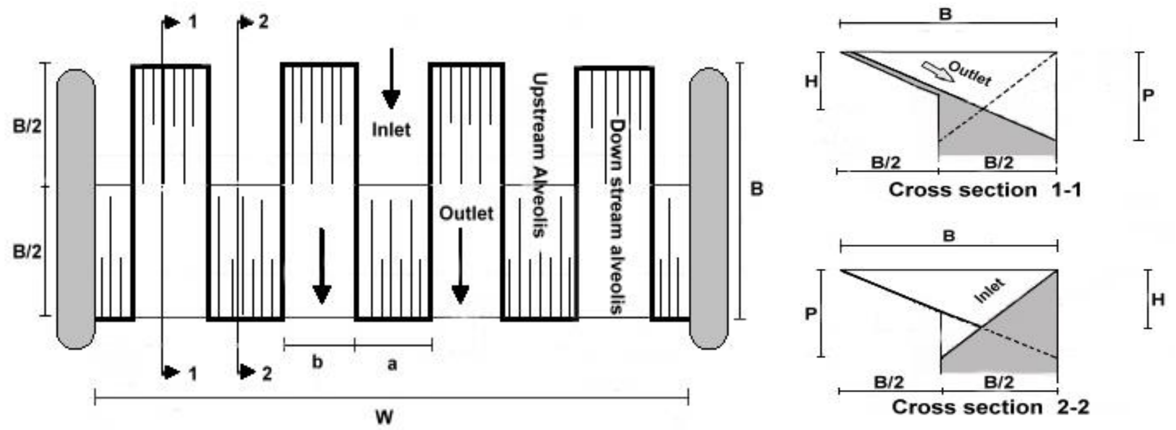

Fig. 2 Layout of P.K.Weir type B

a: width of the upstream alveolus b: Width of the downstream alveolus H: maximum height of walls
P: weir height B: Length the lateral wall W: Total Width of the weir L: Total length of crest

1.1 P.K.Weir type A

The P.K.Weir type A was studied in a extensive way to understand its behavior and to define the influence of each of geometrical parameters on the flow (A.Ouamane and al, 2006). However, the P.K.Weir type B was the object only of some preliminary tests.

Results obtained on P.K.Weir type A leads to “standard” designs which seems close to the best compromise between hydraulic efficiency, easiness of construction and cost. Such “standard” designs include :
- hangover slopes between 2/1 and 3/2
- width of the inlets 1.2 times that of outlets “e” (for type A)

For “H” between 3 to 5 m, the ratio N=L/W should be about 4 to 6.

For smaller “H”, the ratio N could be more important.

Model testing showed that, if “h” is the head of water, the specific flow for type A is close to $4hH^{0.5}$ for the heights most often used ($0.25H<h<1.5H$), instead of $2.2h^{1.5}$ for a traditional Creager spillway.

The outflow of a traditional Creager crest is hence multiplied by almost 4 when h = 0.25 H, by 3 when h = 0.4H and by 2 when h is around 0.8H. The increase in specific flow (in $m^3/s/m$) is nearly 1.8 $H^{1.5}$. A saving in head of water (i.e storage) of nearly 0.5H is obtained (F. Lempérière and al, 2007).

1.2 P.K.Weir type B

To check the behavior and the performance of P.K.Weir type B several tests detailed on selected forms were then carried out recently at the Hydraulic Developments and Environment Laboratory of the University of Biskra. The tests carried out on fourteen small-scale models of P.K.Weir type B gave a basis to optimize the increase in the discharge of P.K.Weir according to relationship's between the length, the height, the width and slope of apron, in particular according to the relationship between the length of the crest and its width N=L/W.

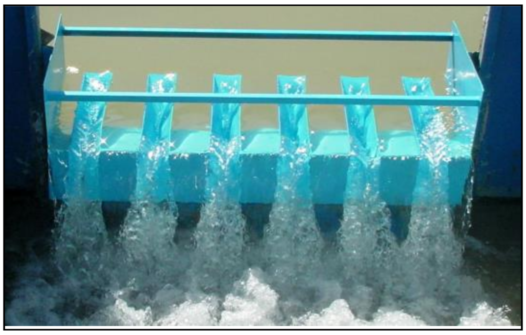

Fig.3 Flow with low head on the P.K.Weir type B

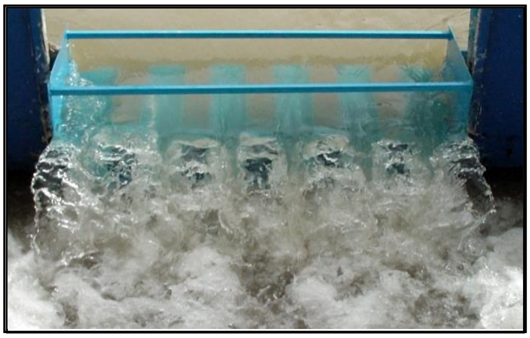

Fig.4 Flow with high head on the P.K.Weir type B

2. Program experimental of P.K.Weir type B

Experimental work was led in an experimental device of simulation of reservoir made up of a supply channel having a section 1.0 x 1.5m and 5.0 m of length. This channel is connected to a basin of simulation of reservoir having the form of a square 4x4m and 1,8m of height. The entry upstream of the basin of simulation is equipped with a metal grid and a brick wall, which makes it possible to ensure a uniform flow. A series of pressure outlet are placed in the basin of simulation at various places making it possible to measure the water pressure in each point. The models of P.K.Weir are inserted to the outlet of basin of simulation. A restitution channel of length 3m and of width 1m is connected to the outlet of basin ensuring the role of a chute of spillway.

Fig.5 Overview of experimental device

2.1 Presentation of the results

The capacity of evacuation of a non-linear weir is generally expressed by the coefficient of discharge, which derives of the universal equation, which expresses the flow, which passes through a weir:

$$Cw = \frac{Q}{W\sqrt{2g}h^{3/2}} \qquad (02)$$

C_W: coefficient of discharge — Q : flow which pass through the weir (m^3/s)
W: width of the weir (m) — h : total head (m).

The coefficient of discharge is given according to the couple of the measured values, the discharge (Q) and the head of water over the P.K.Weir (h), the other parameters of the equation (02) are constant for a given weir.

The dimensional analysis applied to the P.K.Weir type B showed that the coefficient of discharge can be expressed by an adimensional relation of the shape:

$$C_w = f\,(h/P,\ L/W,\ W/P,\ a/b) \quad (03)$$

P: maximum height of weir L: developed length of the weir h: total head on the sill
a: Width of the upstream alveolus b: Width of the downstream alveolus W: Width of weir

Consequently, the effeciency of the P.K.Weir will be according to these four adimensionals parameters following: h/P, W/P, L/W, and a/b. These parameters derive directly from the geometry of the P.K.Weir and the operating head, they are so of main importance. The efficiency on the P.K.Weir can be also affected by the parameters of secondary importance resulting from details of construction, as the shape of entrance under overhangs, the slope of apron, the length of the lateral walls and the shape of the outlet.

2.1.1 Comparison for P.K.Weir type B and Creager weir

The flow on the P.K.Weir is completely different from the flow on the Creager weir; it is characterized by two type of flow according to the head on the sill of weir.

- For low and medium heads, the flow is characterized by two discharging nappe, the first in the form of a jet of the bottom which flow along the inclined apron of the downstream alveolus and the second in the form of a screen more or less thin according to the load on the weir.
- For the high heads the two discharging nappes become interdependent constituting so a single nappe, consequently the hydraulic efficiency decreases.

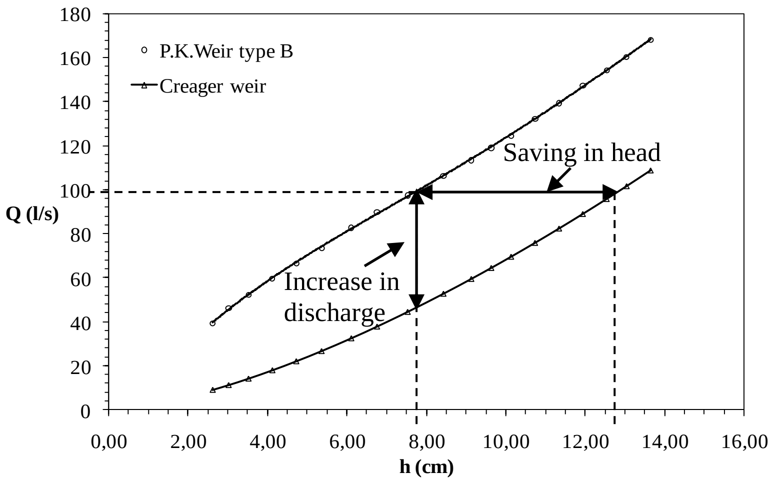

Fig. 6 Diagrams comparison for P.K.Weir type B and Creager weir

The discharge which passes by the P.K.Weir is widely superior to that of the Creager weir, in particular for the low and medium heads. It is from 3,5 to 2,5 times for the heads lower than the half of the height of the weir (h/P < 0,5) and reach a value of the order of 1,5 times for values of heads equal or superior to the height of the weir. This shows that the P.K.Weir can be a solution to evacuate high discharges under low heads.

2.1.2 Comparison for P.K.Weirs type A and B

The comparison of two P.K.Weirs types A and B show that the absence of overhang downstream for the type B allows an increase of discharge about 10 % with regard to the P.K.Weir type A. This result shows that model B without overhang downstream can be a solution for large discharges.

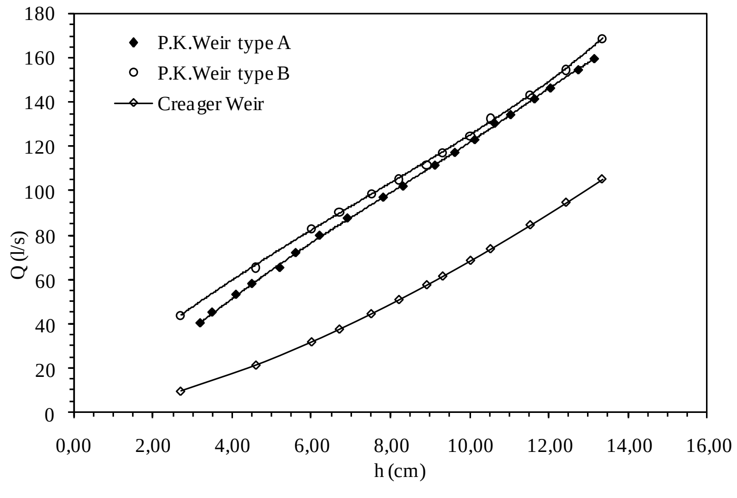

Fig. 7 Diagrams comparison for P.K.Weir type A and P.K.Weir type B

2.1.3 Ratio of the vertical aspect, W/P

The ratio of vertical aspect which represents the vertical geometry can have two indications, the first reflects the effect of the height variation for a width of cycle fixes and the second indicates the influence of the variation of the width for a height of weir fixes. The results of the tests obtained on three models of same geometry and different height of weir indicate that the coefficient of discharge of P.K.Weir is depend on parameter W/P. In other words, the capacity of evacuation is dependent of the height of P.K.Weir. The increase of the height of 25% increases the capacity of evacuation from 5 to 8% (Fig.8).

Consequently, one can say that the height of the weir affects faintly the performance of P.K.Weir.

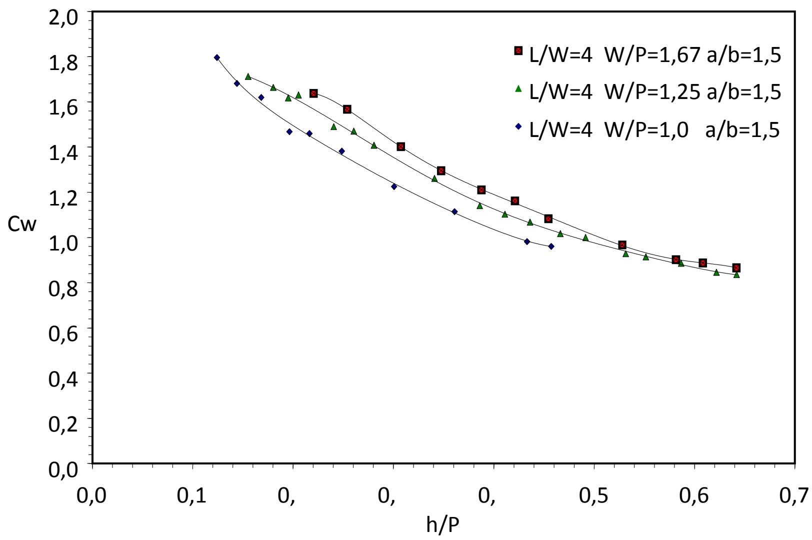

Fig. 8 Coefficient of discharge according to the ratio of vertical aspect W/P

2.1.4 Relative Length, L/W

Generally, the ratio L/W which expresses the rate of the elongation of the weir crest with regard to its width influences the flow remarkably, so the performance of the P.K.Weir grows with the increase of the ratio L/W.

To verify the importance of the impact of the ratio L/W on the capacity of the P.K.Weir type B, three models of various ratio were experimented (L/W=4, 6 and 8) with same slope of apron alveoli (P/B=0,36).

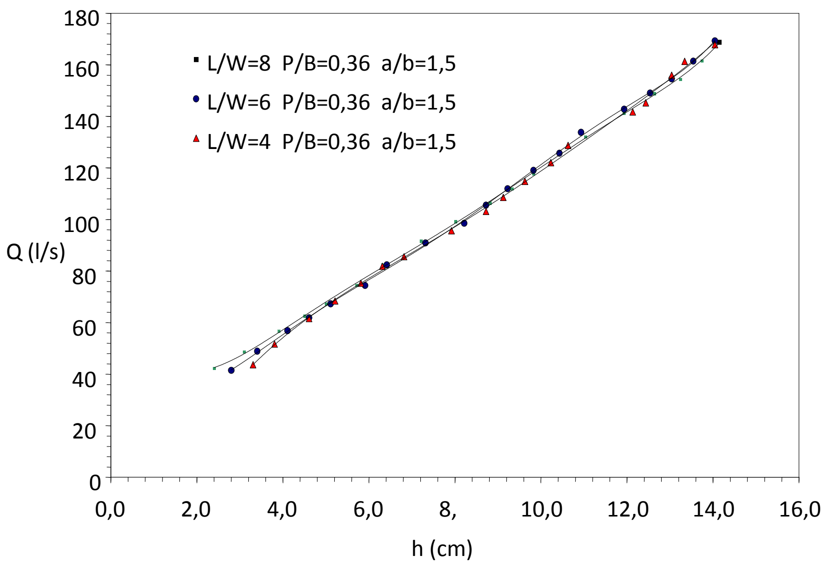

Fig.9 Discharge according to ratio L/W

The obtained result showed that the increase of the ratio L/W does not lead automatically to an increase of discharge (Fig.9). This is not justified as far as hydraulic. Consequently, a second series of models was tested increasing the slope of apron to P/B=0,5. Obtained results showed that ratio L/W influences strikingly the capacity of discharge of the P.K.Weir type B(Fig. 10).

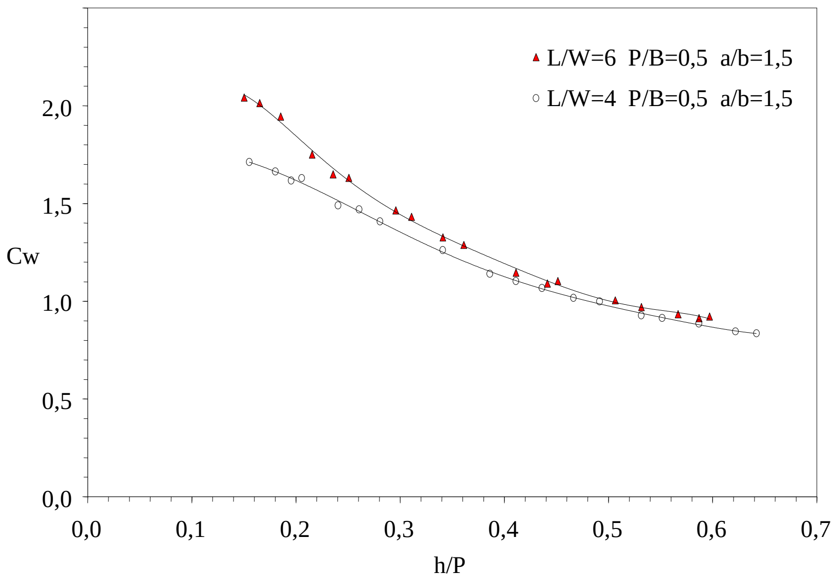

Fig.10 Coefficient of discharge according to ratio L/W

The diagrams (10) shows that effectively the increase of the ratio L/W from 4 to 6 allows to grow the capacity of weir in a significant way. This increase is of 10 % for the medium relative heads.
The difference between the two cases of tests corresponds to the change of the slope of aprons. So, one can say that for slope of aprons of the P.K.Weir type B lower than 0,5 the variation of the ratio L/W has no effect on the capacity of Weir.

2.1.5 Impact of the alveoli width

The geometry in plan of P.K.Weir type B is characterized by two alveoli of rectangular form, the first of width (a) oriented towards the upstream and the second of width (b) directed towards the downstream. The slope of the apron of the alveoli is dependent of the length of the lateral walls and the height of the weir, so the flow in the upstream and downstream alveoli can be different.

The choice of the width of alveoli (a) and (b) can be interesting as far as hydraulic performance and economic efficiency. The best choice consists in determining the width of the alveoli which allows to have the most high hydraulic performance. This is interesting economically because concrete volume remains the same and modification concerns only the disposal of the side walls.

To check the impact of the variation of the width of the alveolus three cases were considered (a/b = 0.67, 1.2 and 1.5).

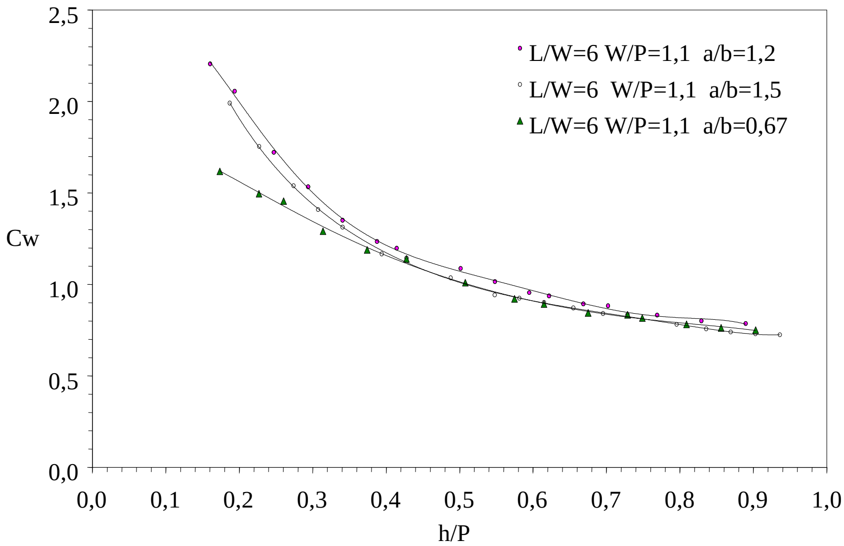

Fig.11 Coefficient of discharge according to the width of the upstream and downstream alveoli

The diagrams 11 show that the choice of a relative width a/b=1,2 allows to have a more high hydraulic efficiency about 5 % with regard to the other models. So, the optimum is situated near a/b=1,2.

Obtained result shows that it is possible for the same width of an element of P.K.Weir type B and at the same cost to increase the width of the upstream alveolus of 10 % and to reduce consequently the width of the downstream alveolus. This increases efficiency about 5 % without any additional expence.

Conclusion

The P.K. weir is a very cost effective solution for multiplying by 2 or 3 the discharge of existing weirs or increasing significantly the storage of existing dams. For new dams the spillway length may be divided by 3 or the nappe depth divided by 2.

The best shape appears the Model B with a single upstream overhang.

Optimized efficiency may be for a ratio L/W close to 5, a slope of about 0,4 or 0,5 and inlet alveolus wider than the outlets (a/b = 1,2).

The increase of specific discharge as compared with a Creager weir is roughly (in $m^3/s/m$) $2H^{1,5}$, H being in m the PK weir walls maximum height.

For instance for H = 4m, the increase of discharge is about 15 $m^3/s/m$. This increase is about the same for a wide range of nappe depths.

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