Labyrinth and Piano Key Weirs II – PKW 2013 – Erpicum et al. (eds)

Improvement of labyrinth weirs shape

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ABSTRACT: The labyrinth spillway is an effective means in order to increase the capacity of the dam spillway. The concept of the labyrinth is to change the plan form of the crest then to increase its actual length and permit the passage of a higher discharge. This type of weir is particularly suitable for sites where topographic conditions limit the extent of its width. In addition, the labyrinth weir is characterized by an economic cost of construction and a more important efficiency than the standard weir. However, the non-rectilinear shape of crest labyrinth weir creates a disturbed three-dimensional flow at each discontinuity of the weir axis. These flow conditions reduce the performance of labyrinth weir. It is possible to make some changes to the classical shape of labyrinth weir to improve its hydraulic performance and make it more economical. These changes concern the plan shape of crest labyrinth weir, the form of the upstream and downstream apron of the cells and the shape of the walls of the spillway.

1 INTRODUCTION

The labyrinth weir is often used when the width of the weir or the maximum head is limited. The cost of the labyrinth weir is relatively low compared to weirs with gates, this led to its use simultaneously to increase the storage and discharge capacity of the spillway.

Although the labyrinth weir has been the subject of several applications, some changes in classic shape can have a positive effect on the hydraulic and economic performance.

The geometry in the plane of the crest of the labyrinth weir is characterized by a discontinuous centerline. This thus results in a complex flow mode (Lux & Hinchliff, 1985), which is considered as three-dimensional.

The literature shows that the flow over a labyrinth weir is influenced by the angle formed at the point of discontinuity of the crest. The effect of the latter causes a reduction of the discharge coefficient which is amplified when the head on the weir increases.

The analysis carried out by Indlekofer & Rouve (1975) showed that the flow on the labyrinth weir is rather complicated with a three-dimensional flow. Thus, the flow over the weir is divided into two areas, one near the corner characterized by a disturbed three-dimensional flow area, followed by two-dimensional flow area. The area defined by the disturbed three-dimensional flow is characterized by a discharge coefficient lower than that of the area to be two-dimensional flow.

The importance of the reduction of discharge coefficient depending of the head on the weir and the importance of the angle of the corner. Thus, for a maximum head on the sill of weir, the disturbed flow affects the entire length of the crest, therefore, lower values of discharge coefficient are obtained.

The study conducted at the University of Biskra in 1998 (Unpublished report) for four models of labyrinth weirs of triangular shape and different angles, showed that the coefficient of discharge is minimal for the lowest values of the angle and increases with the increase thereof.

It has to be noted that it is possible to make some changes in the configuration of the labyrinth weir to reduce the flow disturbance and consequently improve the hydraulic efficiency.

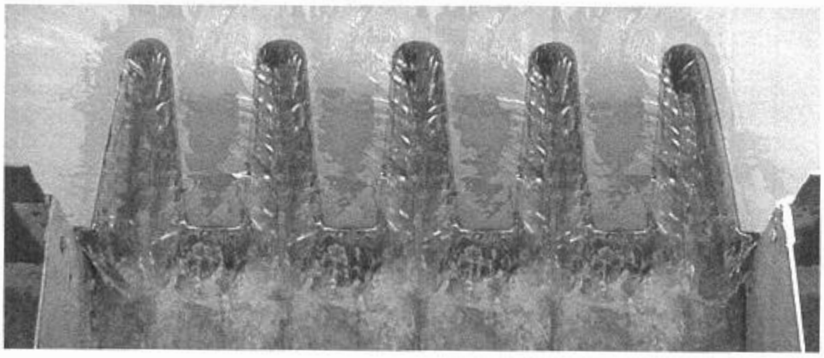

Figure 1. Labyrinth weir model with rounded front wall.

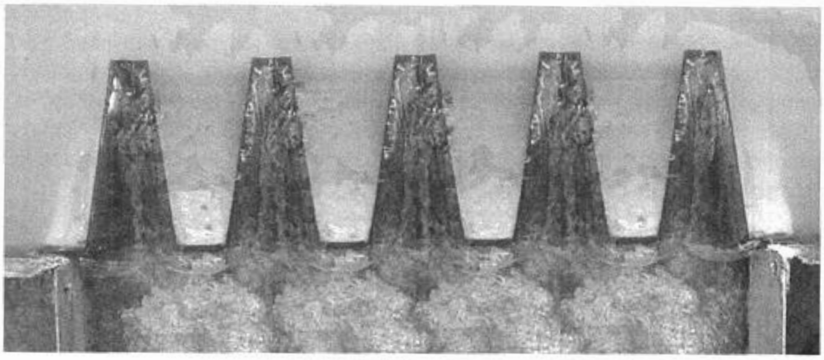

Figure 2. Model labyrinth weir with flat front wall.

2 IMPROVING THE ENTRANCE SHAPE

The main parameter that promotes flow disturbance and therefore reduce the performance of the labyrinth weir, corresponds to the discontinuity of the weir crest. Thus, to reduce the effect of this discontinuity, the profiling of the front wall of the labyrinth weir may have a positive effect on the hydraulic efficiency.

The shape of labyrinth weir proposed by Blanc & Lempérière (2001) is one of the economic forms of weir. This configuration is essentially characterized by a rounded entrance which improves its hydraulic performance.

An experimental analysis of the hydraulic performance has concerned two models of labyrinth weirs with the same geometrical sizes and a trapezoidal shape, the first with a flat shape of the upstream wall and the second with a rounded shape.

The comparison of results obtained on two models of weir (Fig. 3) noted that the design of a rounded shaped entrance leads for an improving of the performance of about 10%. This can be explained on the one hand, by the profiled shape of entrance which facilitates the flow on each side of the front wall along the latter. On the other hand, the rounded shape eliminates the discontinuity points and thus reduces the effect of the disturbance at the top of the weir. These two effects of the profiled shape have a positive affect the hydraulic performance.

3 ADAPTATION OF LABYRINTH WEIR FOR EVACUATION OF LARGE DISCHARGE

During the design the labyrinth weir of Ute dam in New Mexico (USA) the USBR has encountered difficulties relating to the dimensions of the weir walls (Hinchliff & Houston, 1984). Structural

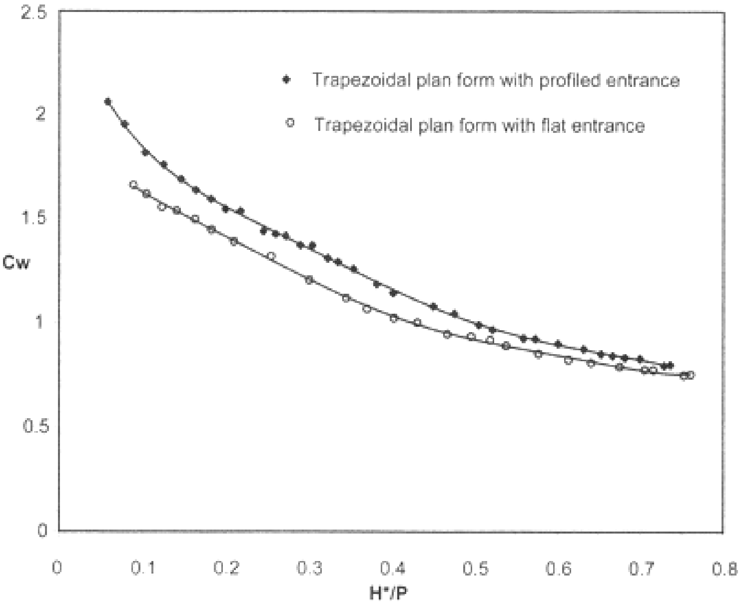

Figure 3. Flow coefficients according to the entrance shape of labyrinth weir L/W = 3.9 W/P = 1.

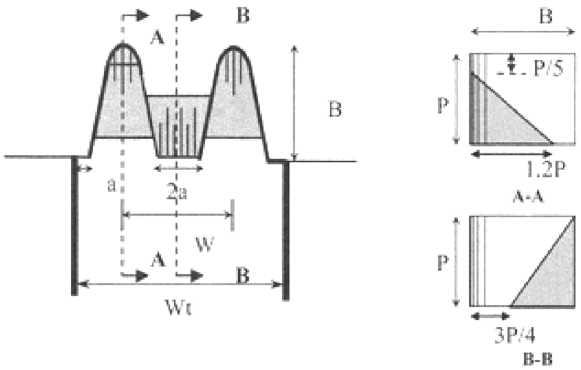

Figure 4. Schematic of labyrinth weir with entrance profiled and alveoli partially filled.

analysis of the labyrinth weir of Ute dam showed that the large hydrostatic heads caused by the height of the walls (P = 9 m) and the head on the sill of labyrinth (H = 5.8 m) required large quantities of reinforcement steel (03 tons/ml) (Lux III & Hinchliff, 1985). This makes the use of non-economic labyrinth weir for high discharges. As reported by the literature, the labyrinth weir is an economical solution as the specific discharge is less than 50 m^3/s/m. Beyond this value the labyrinth weir requires great height walls which implies a greater wall thickness and greater reinforcement. For higher specific discharge (50 m^3/s/m) the walls require an important quantity of steel (up to 200 kg/m^3/s) (Blanc & Lempérière, 2001).

A solution which helps to reduce the additional cost consists in filling the lower portion of the alveoli of the labyrinth by an ordinary concrete. This results in a reduction of the free height of walls, which allows to have hydrostatic pressure forces which act only moderately on the upper portion of the wall. This allows to have a smaller wall thicknesses and therefore a low reinforcement of the structure.

However, the partial filling of the alveoli can result in a reduction in the performance of labyrinth weir. To compensate for this loss of performance it would useful to choose a form of a labyrinth which has a high performance.

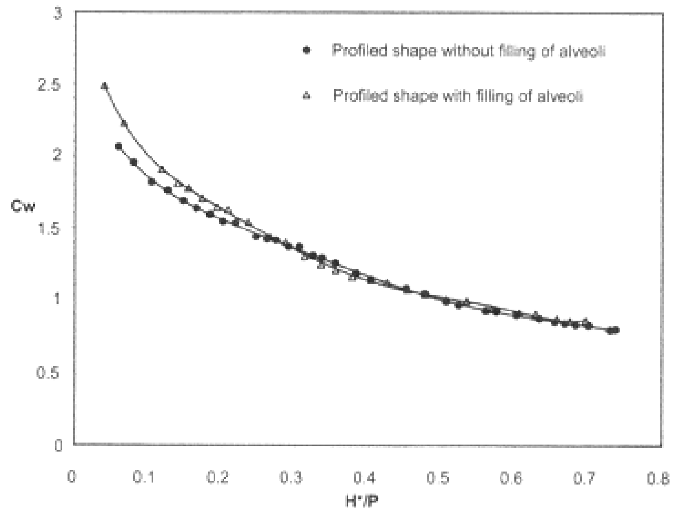

Figure 5. Discharge coefficient of labyrinth weir with profiled shape L/W = 3.9 W/P = 1.

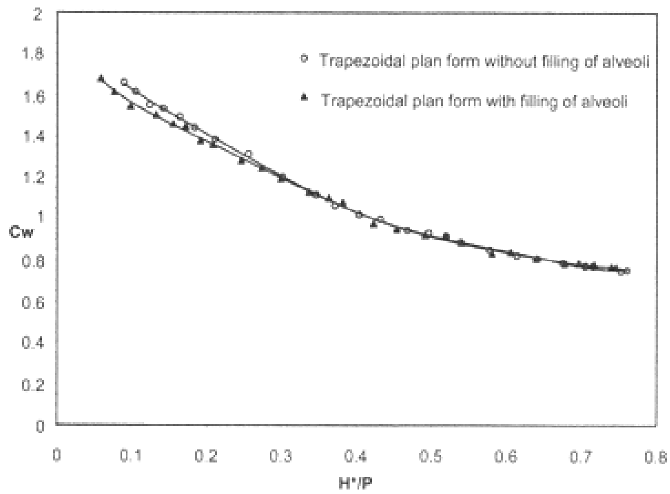

Figure 6. Discharge coefficient of labyrinth weir trapezoidal L/W = 3.9 W/P = 1.

To check the effect of partial filling of the alveoli on the hydraulic performance, two models of labyrinth weir are tested. The first with a classic trapezoidal plan form and the second with a profiled shape of entrance. The tests are carried out under conditions with and without filling of the alveoli.

The observation of the flow during the experiment showed that the flow on the weir with partially filled alveoli and rather airy and stable for low charge, which is not the case for weirs without filling alveoli. This justifies the offset between the two curves of discharge coefficient for the range of values of the relative head $H^*/P < 0.25$ (Fig. 5 and 6).

The comparison of curves discharge coefficient for both cases of functioning with and without filling (Fig. 5 and 6) shows that alveoli filling has no effect than for the low heads. For the range of values of $H^*/P > 2.5$, the two weirs have the same hydraulic performance. So, the partial filling of the alveoli has no effect on the performance of labyrinth weir and helps to avoid the problem of aeration for low heads on the weir.

As well, it's recommended for the greater specific discharges than $50\,m^3/s/ml$ to design the labyrinth weir with the alveoli partially filled in ordinary concrete this gives an economic structure while maintaining hydraulic performance similar to that of classical labyrinth weir.

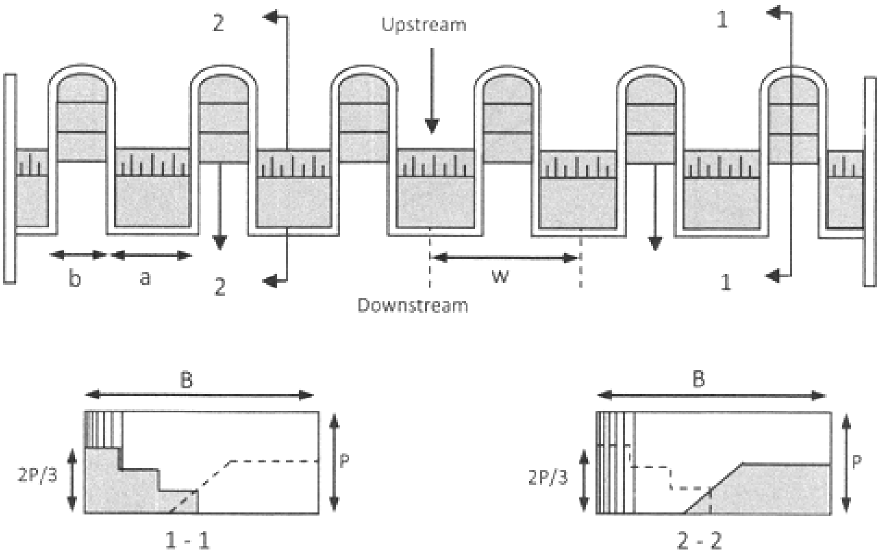

Figure 7. Rectangular labyrinth weir with shaped entrance and the alveoli partially filled with: a the width of upstream alveolus, b the width of downstream alveolus, B the length of the side wall and w the width of cycle of labyrinth.

4 IMPROVEMENT OF THE PLAN FORM

It is possible that other plan form can be effective as the trapezoidal and triangular shapes often used in existing dams. Thus, for practical, economic and hydraulic performance reasons, we may adopt a rectangular plan form with a profiled entrance and the apron of the downstream alveoli as a stairs and that of the upstream alveoli partially inclined. These structural particularities can improve the performance of labyrinth spillway and reduce the cost of construction (Fig. 7).

The choice of the rectangular shape allows vary the widths of the upstream and downstream cells to obtain a ratio of width which allows for better hydraulic efficiency and reduced cost (Ouamane & Ben Said, 2010).

The profiled shape of the entrance and the inclination of part of the apron of the upstream alveoli can improve the flow conditions at the entrance of the labyrinth; therefore the weir becomes more efficient. The partial filling of alveoli upstream and downstream of ordinary concrete can reduce the thickness of the walls and the quantity of steel, because the free part of the walls is reduced. The design of the apron of the downstream alveoli as stair step, also help to dispel some of the energy.

4.1 *Comparative study with the trapezoidal shape*

Often the labyrinth weir is designed with a trapezoidal shape in plan that is repeated periodically (Hinchliff & Houston, 1984). This is not justified; it is possible that the labyrinth weir take another geometric shape that can be as effective as the trapezoidal shape. The choice of a rectangular shape can be as effective of viewpoint, hydraulic and economic performance and is easy for construction, especially when it is used as a dam weir of low height in the rivers. The experiment of two models of labyrinth weirs of the same dimensions, successively, trapezoidal and rectangular rounded upstream showed that the rectangular shape can be as effective as the trapezoidal shape and even more effective for the relative heads lower than 0.5, corresponding to the practical range for the design of the labyrinth weirs (Fig. 8).

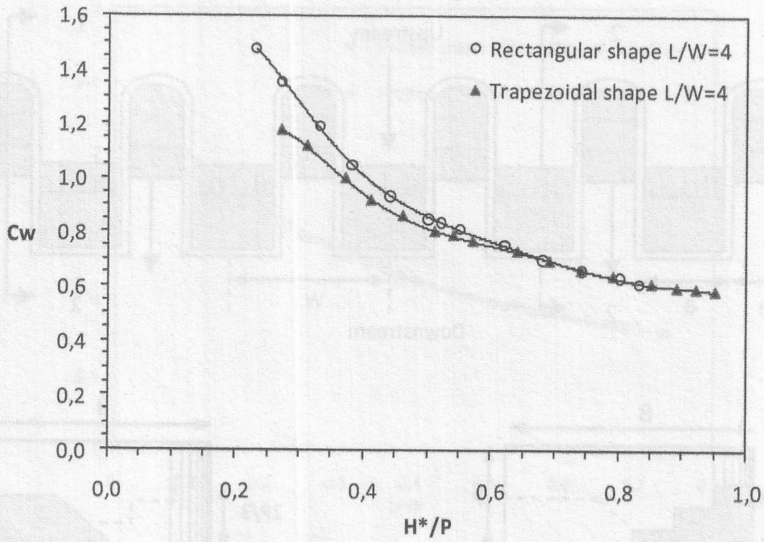

Figure 8. Coefficient of discharge according to the shape of the labyrinth weir.

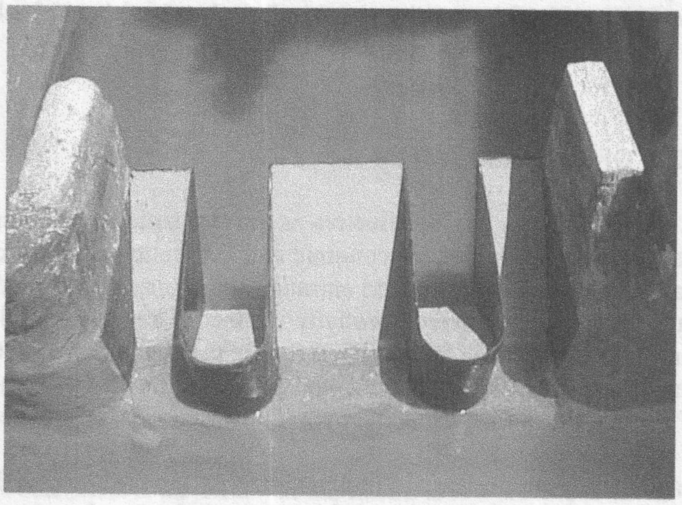

Figure 9. Model of the labyrinth weir with a downstream overhang.

5 IMPROVING THE SHAPE CROSS

Usually the labyrinth weirs are designed with vertical walls disposed frontally or laterally to the flow direction. This arrangement requires a substantial length of the side walls to achieve effective performance. This limits the application of the labyrinth weir and does not allow its installation on most crests of concrete dams. It is possible to reduce the length of the base of the side walls without affecting the length of the sill of labyrinth weir, therefore, maintain or even increase the efficiency of this type of weir. This is feasible by using a part of the length of the side walls in overhang upstream and downstream or only on one side. In this case the front walls become inclined and the upstream and downstream apron of alveoli can also be tilted.

This provision has been the subject of a test model labyrinth weir with downstream overhang and an inclined apron of the upstream and downstream alveoli. The results showed that this weir configuration provides a better performance which can be three times that the linear weir for medium heads on weir (Fig. 10).

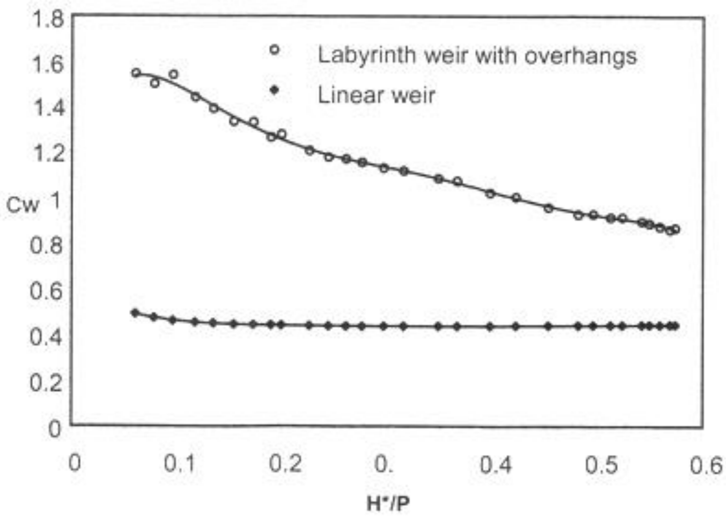

Figure 10. Curves of discharge coefficients of labyrinth weir with a downstream overhang and linear weir.

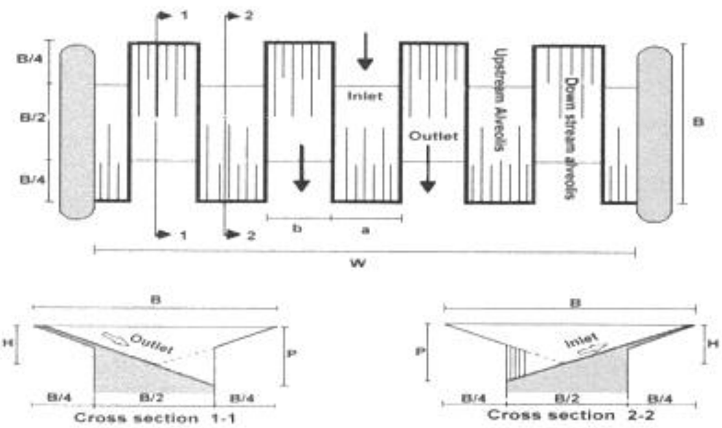

Figure 11. Piano Keys Weir model A.

6 CONCLUSION

So this shows that this type of weir is a similar alternative of the viewpoint hydraulic efficiency to that of the labyrinth weir with vertical walls. The disposition of the inclined apron between the side walls leads to reduction in the average height of the weir. Thus, the walls of the weir become less thick than the weir with horizontal apron due to the reduction of forces applied to the walls, which reduces the quantity of steel reinforcement. However, the volume of the concrete of the apron becomes larger. The use of inclined apron minimizes the effect of turbulence at the weir crest, producing a flow of the threads of liquid which are more or less regular.

The application of the previously mentioned improvements to the labyrinth weir can lead to a form of economic weir and of a better hydraulic performance. The piano keys weir (PK-Weir) brings all these advantages, it can be used for new dams or existing dams that require increase in the spillway capacity and/or storage capacity. It can be placed on small sections of existing or new concrete dams and allows discharging of specific flows up to 100 $m^3/s/m$ and multiply by at least three the discharge weir Creager (Lempérière & Ouamane, 2003).

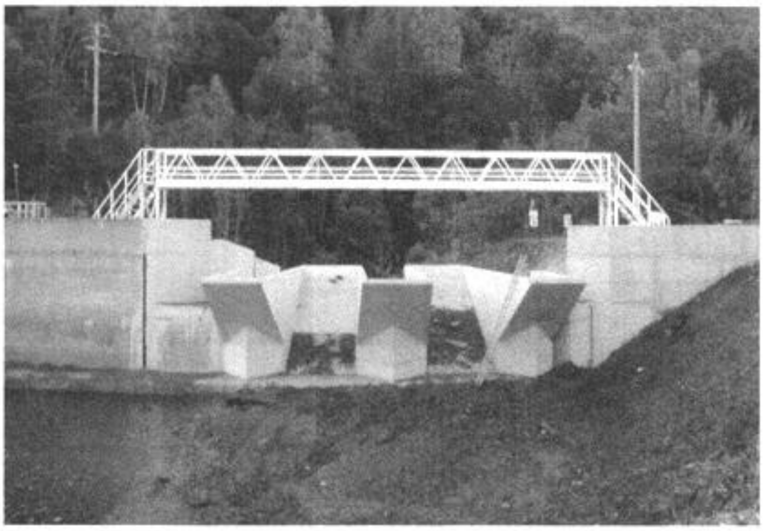

Figure 12. The piano keys weir (PK-Weir) carried out in 2006 to the Goulours dam (France).

The final configuration of the PK-Weir was determined following tests on physical models, which permit to define the geometry of the PK-Weir (Ouamane & Lempérière, 2006), which is based on:

- A rectangular layout.
- An inclined apron of the upstream and downstream alveoli.
- A base length reduced through the use of overhang.
- A reduced width of rectangular elements.

The first application of PK Weir carried out at Goulours dam near Toulouse (France) (Fig. 12).

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