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Study of optimization of labyrinth weir

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ABSTRACT: The spillway represents a fundamental importance for the safety of dams; however, its cost represents a significant part of the global cost of dam. The labyrinth weir represents an effective alternative for the control of floods with a low realization cost. It is characterized by length crest longer than that of a rectilinear weir for a same width of influence; this allows to increase the discharge significantly. The labyrinth weir is conceived using several geometrical simple and repetitive forms. The two concepts, simplicity and repetition, makes the conception and construction easy and economic. However, the variety of forms of the labyrinth and the complexity of the flow did not allow the determination of an optimal shape for this type of weir. This paper is interested in the study of optimization of the labyrinth weir by an experimental way. The study showed that the flow on the labyrinth weir is dependent of various geometrical parameters which characterize this particular type of weir.

1 INTRODUCTION

Dams are of great importance for country socio-economic development. However, these works represent a major risk for persons and material security. Consequently, it is worthy understanding problems related to dams, especially the submersion risk during exceptional floods. It is essential to make a conception allowing the flood evacuation without prejudice to dams and downstream territories.

Therefore the labyrinth weir plays a key role for floods to be passed with low upstream head and to increase the reservoir capacity in a significant manner. The labyrinth weir conception also helps economically thanks to the reduction of structural expense.

This kind of weir is often used in the case of limited width or reduction of maximal upstream head conditions. Generally, it is characterized by no linear plan shapes, represented by a repetition of trapezoidal, triangular or rectangular shapes. Of course, this disposition increases the weir length and consequently the discharge on the labyrinth will be increased by comparison to a linear creager weir of same width and upstream head.

The variables which will be taken into consideration in the labyrinth weir conception include (Fig. 1) the length L, width W, height P, the angle α, the cycle number n and additional parameters of secondary importance as the thickness of walls, crest shape and the flow approach condition.

The improvement of weir hydraulic performance generally requires physical model experimentation; due to the important number of dimensional parameters that govern the flow over this weir type.

The objective of the present research is to assess the impact of various geometrical parameters of the labyrinth weir by an experimental way. The assessment is linked to three dimensionless factors;

- The ratio between the widths of upstream and downstream alveoli a/b.
- The increasing length ratio L/W.
- The ratio between the width of the intake channel to the width of the spillway W_c/Wt.

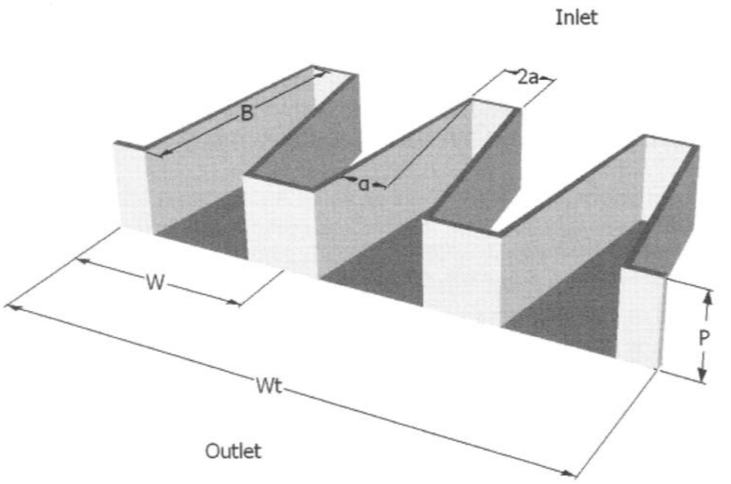


Figure 1. Labyrinth weir with trapezoidal shape.

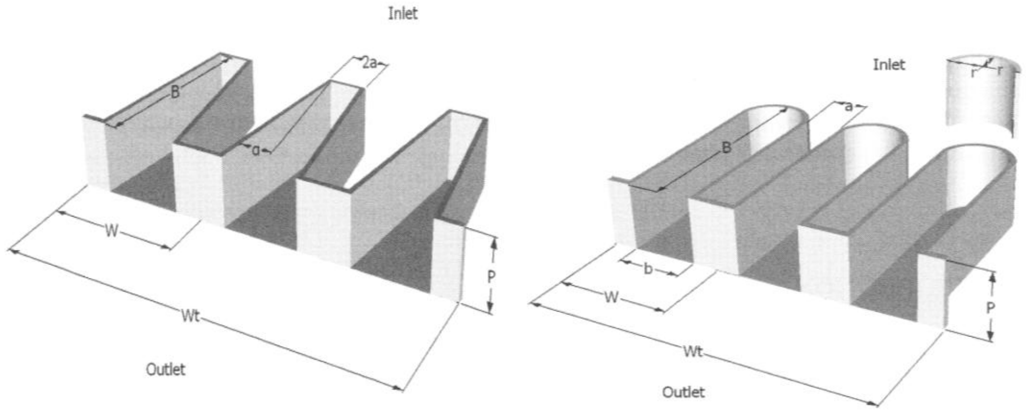


Figure 2. Labyrinth weirs, with round shape (left) and trapezoidal shape (right).

2 EXPERIMENTAL PROGRAM

2.1 *Definition of the experimental models*

The examination of the Impact of these dimensionless parameters on the design capacity requires the design of six models of labyrinth weir. The models were made with 2 mm thickness walls, allowing to consider the crest of the various models as thin-wall. The characteristics of each model are listed in Table 1.

2.2 *Description of the test facility*

The experimental work was conducted in the laboratory facility comprising a supply channel with 0.75 × 0.75 m cross section and 4.30 m length (Fig. 3). This channel is connected to the simulation basin, with a square shape 3 × 3 m and 1.1 m height. The labyrinth model is inserted at the outlet of the simulation basin. The so-called return channel is 2 m long and 1 m wide, connected to outlet. The labyrinth models were constructed with 2 mm thickness steel walls.

Table 1. Geometrical characteristic of the experimental models

Models	n°	n	L cm	Wt cm	P cm	B cm	W cm	a cm	b cm	r cm	L/Wt	W/P	a/b	B/P
Round	01	6	353	90.3	15	25	15	6	9	5	3.91	1	0.66	1.66
Round	02	6	355	90.8	15	25	15	9	6	5	3.91	1	1.5	1.66
Round	03	6	351	90	15	25	15	7.5	7.5	5	3.91	1	1	1.66
Trapézoïdal	04	6	358	90.5	15	27	15	–	–	–	3.96	1	–	1.8
Round	05	6	538.5	90.2	15	39	15	9	6	3	5.97	1	1.5	2.6
Trapezoidal	06	6	606.6	102.3	15	48	15	–	–	–	5.93	1	–	3.2

a: half frontal wall length.
B: length of lateral wall.
P: height of labyrinth weir.
Wt: width of labyrinth weir.
L: length of crest development labyrinth weir.
r: radius of round shape.
a & b: width of the upstream and downstream alveoli for round shape.
α: angle between the side wall of labyrinth weir and the flow direction for trapezoidal shape .

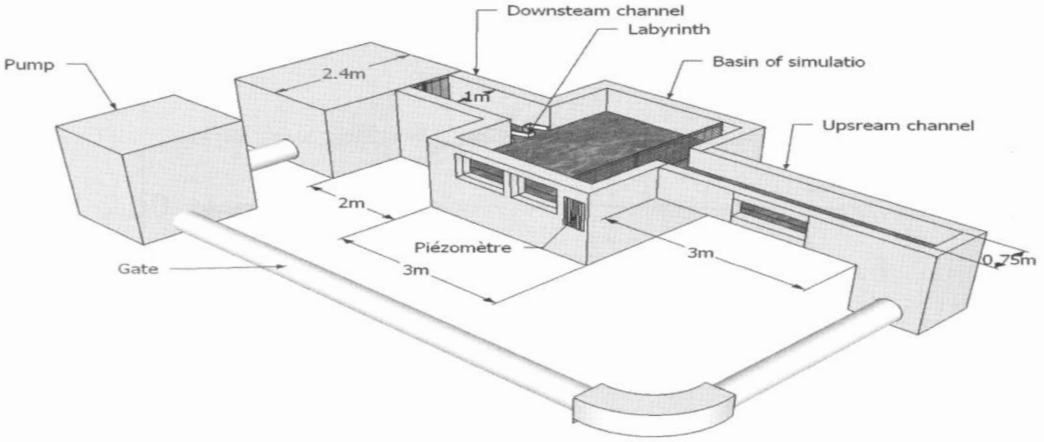


Figure 3. The experimental facility.

3 EXPERIMENTAL RESULTS

3.1 *Introduction*

This chapter proposes to present the tests results of different models. These results are expressed by the relation between the discharge coefficient and the dimensionless upstream head

$$CW = f\,(h^*/P). \tag{1}$$

where C_W is the discharge coefficient and h^* the upstream head

3.2 *Influence of the ratio a/b*

In order to verify the ratio a/b impact on the labyrinth weir performance, three models of rectangular shape with rounded upstream, with ratios $a/b = 0.67$, 1 and 1.5 and $L/W = 4$ were performed.

The tests clearly illustrate the effect of varying the width of the input and output alveoli. The increase of the ratio a/b let automatically grow the labyrinth weir performance. The discharge coefficient for ratio $a/b = 1.5$ is clearly superior to the one with a ratio $a/b = 1$ and the latter is higher than that of ratio $a/b = 0.67$. This result does not warrant that the optimum will be reached with a ratio $a/b = 1.5$ but this one is the best among the tested value.

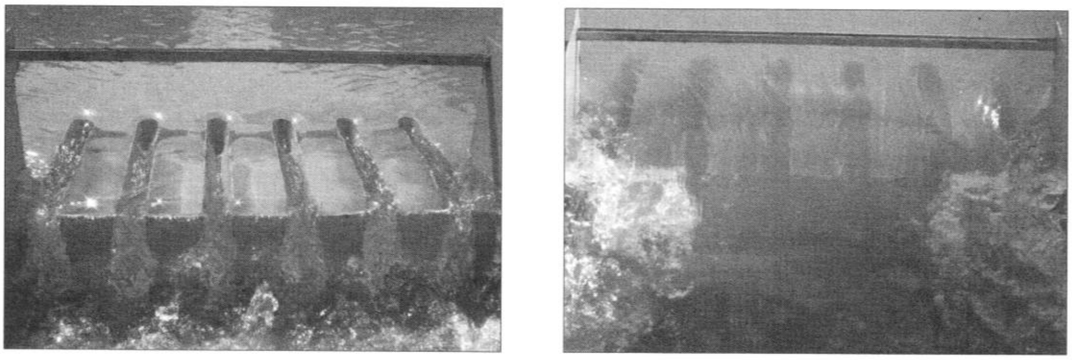


Figure 4. Labyrinth weir during the test, low upstream head (left) and high upstream head (right).

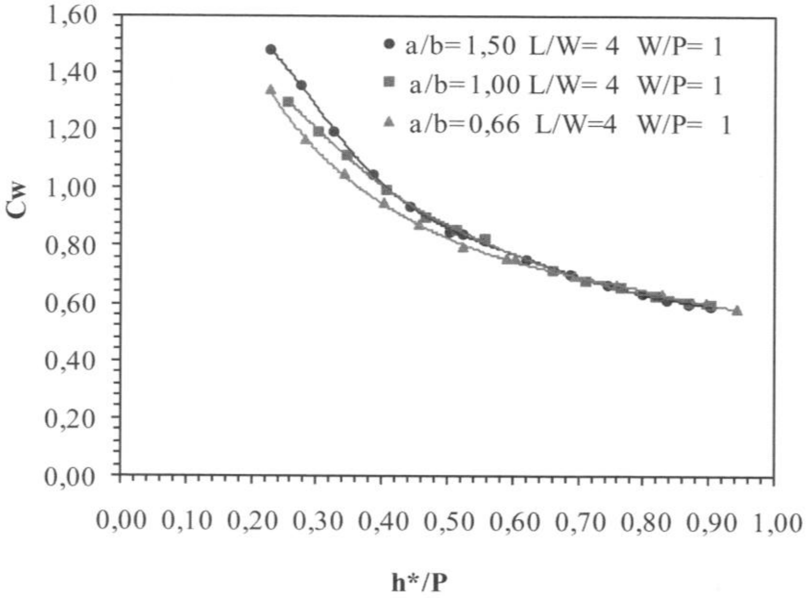


Figure 5. Variation of the discharge coefficient *Cw* for different a/b ratios and $L/W = 4$.

The difference between the various configurations is reduced with increasing upstream head. This can be explained by the fact that for low and medium upstream head the downstream alveoli are not entirely filled with water (Fig. 4 left).

3.3 *Influence of the ratio L/W*

To check the influence of the ratio L/W on labyrinth performance, four models have been tested: two models of rectangular shape with rounded upstream with ratio $L/W = 4$ and 6 and two models of classic trapezoidal shape with ratio $L/W = 4$ and 6.

The graphs of Figure 6 illustrate clearly that, in the case of the labyrinth weir with rectangular shape and rounded upstream, the increase of L/W from 4 to 6 can improve the performance by 10% for a upstream head of $h^*/P = 0.3$ and 5% for an upstream head on $h^*/P = 0.7$, although the length of the walls was increased by 50 %. An increase of ratio $L/W = 4$ to 6 for the labyrinth weir with trapezoidal shape produces an efficiency gain of 30% for upstream head for $h^*/P = 0.3$ and 17% for $h^*/P = 0.7$ (Fig. 7).

This shows that the transition of ratio $L/W = 4$ to 6 permit a higher efficiency increase of the labyrinth weir with trapezoidal shape than rectangular rounded shape.

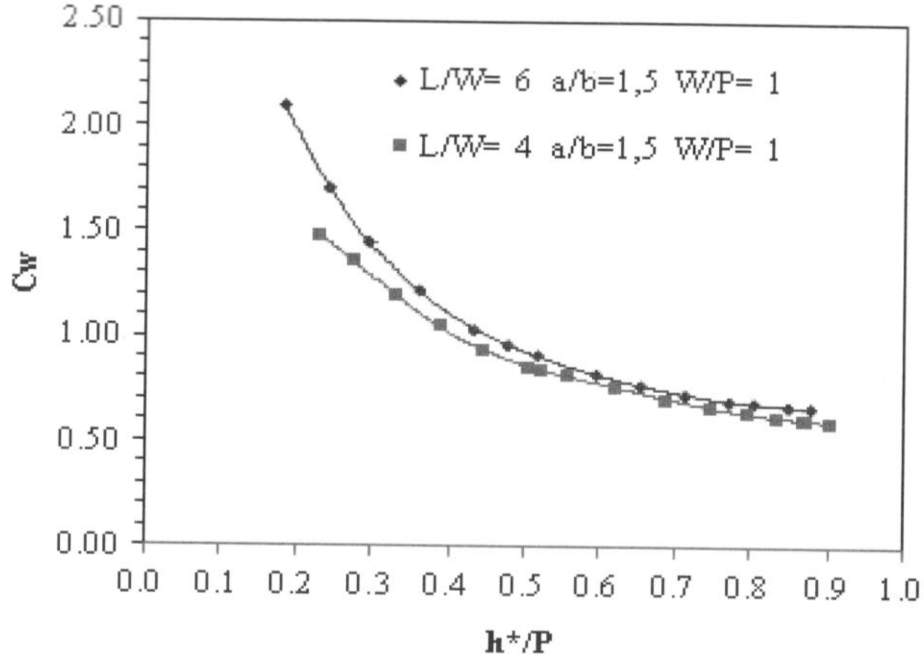


Figure 6. Variation of discharge coefficient *Cw* with *L*/*W* for rectangular shape rounded upstream.

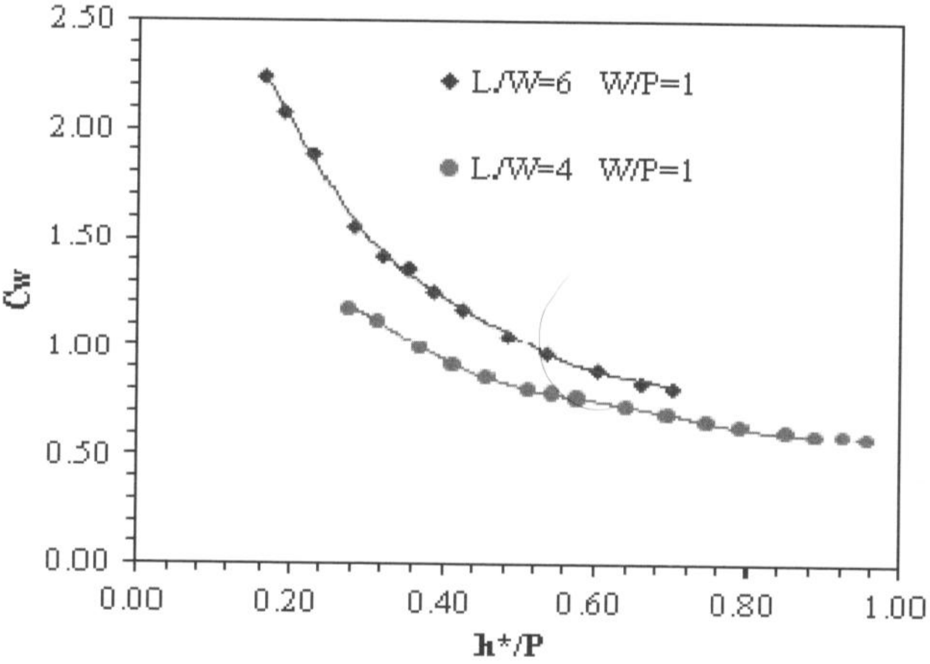
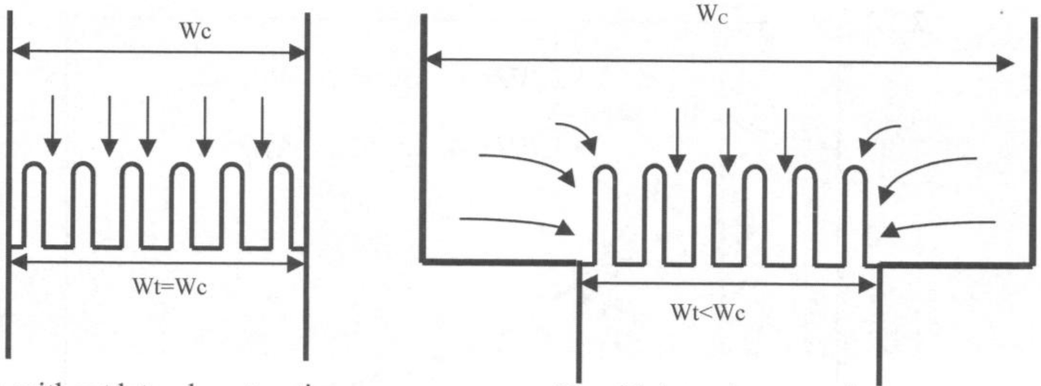


Figure 7. Variation of discharge coefficient *Cw* with *L*/*W* for trapezoidal shape.

3.4 *Impact of lateral contraction Wc/Wt*

To test the effect of the lateral contraction on the hydraulic performance of labyrinth weir two types of implementation were experienced (Fig. 8). The first arrangement corresponds to a width of inlet channel equal to the width of the labyrinth weir $Wc = Wt$. The second disposition corresponds to a width of inlet channel equal four times the width of the spillway $Wc = 4Wt$.

The graphs of Figure 9 clearly show the effect of the lateral contraction on the discharge coefficient. Comparing the discharge coefficient of both installations shows that the discharge coefficient values corresponding to the weir without contraction are much higher than the values obtained for



A-without lateral contraction

B- with lateral contraction

Figure 8. Labyrinth weir with and without lateral contraction.

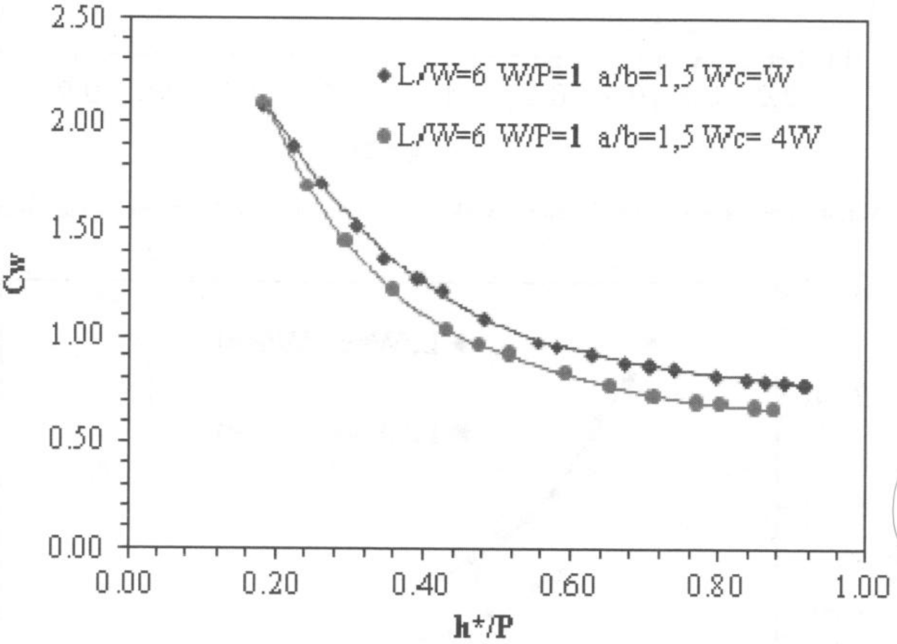


Figure 9. Variation of the discharge coefficient *Cw* with model implementation.

the spillway with contraction. The difference between the values of the two dispositions increases with h^*. For $h^*/P = 0.3$ the difference is 11% for $h^*/P = 0.5$, the difference increases to 17% and for $h^*/P = 0.7$ the difference between the two curves is 22%.

3.5 *Impact of filling alveoli*

Partial filling of the labyrinth alveoli can reduce the construction cost of the work (Fig. 10). However, this solution may have effects on the hydraulic performance. To determine the degree of filling under which the hydraulic performance will not be affected, several height and length filling ratios have been tested.

A- Filling 1/4 the length upstream and downstream, with filling heights 1/3, 1/2 and 2/3P.
B- Filling half the length upstream and downstream, with filling heights 1/3, 1/2 and 2/3P.

The results showed that:

1) Filling a quarter of the length has none effect on the discharge coefficient, whatever the height filling (Fig. 11).

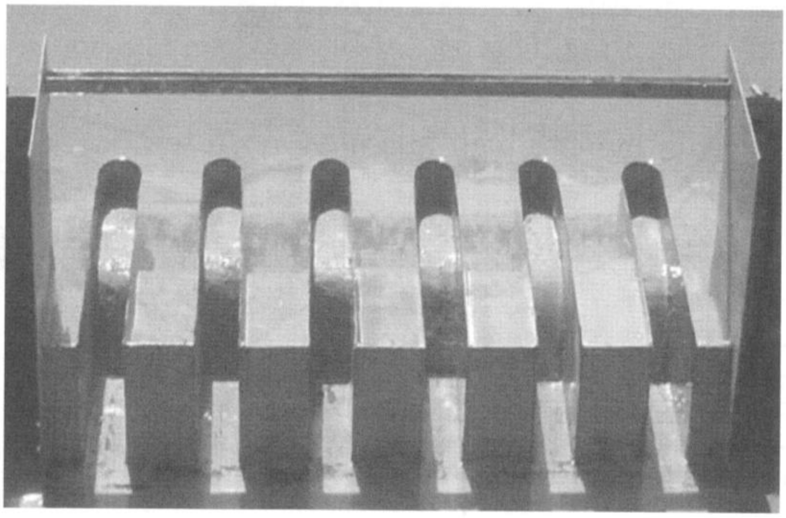


Figure 10. Labyrinth weir with filling.

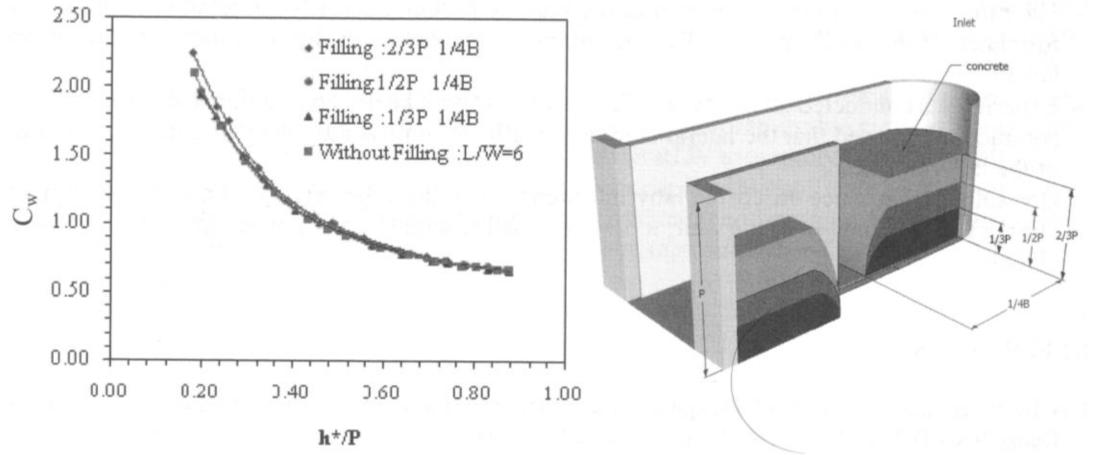


Figure 11. Variation of the discharge coefficient *Cw* with ¼ B filling.

2) With half length filling, the discharge begins to be affected if the height filling is greater than P/3 (Fig. 12).

4 CONCLUSION

Following the analysis of the hydraulic behavior of labyrinth weirs, the number of dimensionless parameters governing the flow over the labyrinth weir upstream with rounded rectangular shape has been fixed at three.

These order parameters and secondary parameters (filling) have been experiments on six types of labyrinth weir, allowing to determine the impact of different dimensionless parameters on the hydraulic performance and to contribute to the optimization of this type of spillway. The tests concerned the ratio between the input and output a/b, the influence of the ratio L/W, the impact on the flow of lateral contraction of the channel *Wc/W* and the impact of alveoli filling.

The results showed that:

- The ratio 1.5 is the best among the tested values. The evidence of these tests is that the hydraulic performance increases with the ratio a/b for low and medium heads ($h^*/P < 0,5$).

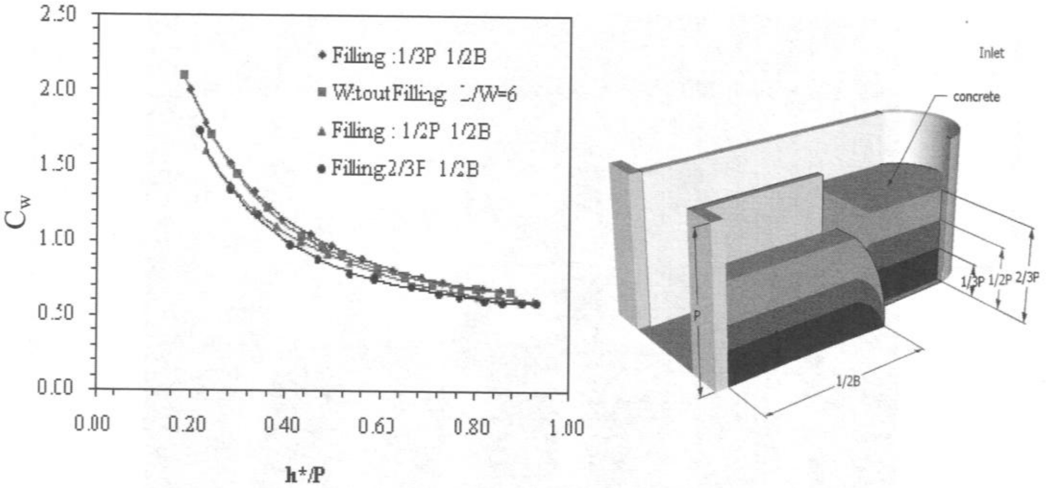


Figure 12. Variation of the discharge coefficient *Cw* with ½ B filling.

- The ratio L/W has to be considered as the most important parameter in relation with the performance of this spillway type. This performance decreases rapidly with increasing upstream head.
- Experiments conducted on two types of dispositions (with lateral contraction and without lateral contraction) showed that the lateral contraction affects significantly the hydraulic performance of the labyrinth weir.
- One solution to reduce the cost of labyrinth weirs is to reduce the height of the walls while maintaining the same height of the weir; it may be possible with filling of upstream and downstream alveoli.

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