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# INCREASE OF THE SAFETY OF DAMS
# REHABILITATION OF WEIRS

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**ABSTRACT** With the important data bases of registered floods and the improvement of calculation methods in the domains of hydrology, the probable maximum flood for an existing structure can increase considerably when compared to the initial conception flood. If the weir does not allow passage of flood updated in conditions of suitable safety, the structure requires a modification to increase the spillways capacity.

This paper presents some studies and solutions which can be adopted to increase the spillways capacity and consequently, increase the safety of existing dams. These solutions relate to the rehabilitation of existing weirs by the modification of the weir crest, in labyrinth crest, (P.K.Weir), or fusegate or fuseplugs.

Many studies and tests on hydraulic models were realized worldwide and especially in the Hydraulic Development and environment laboratory -university of Biskra- (Algeria) for the development and optimization of these solutions. These tests have studied the modification of labyrinth weir geometry so that it can be realized on existing structures and have an economic efficiency. Obtained results showed the hydraulic efficiency of these solutions and their economic interest.

These solutions may be also very cost efficient for new dams.

## INTRODUCTION

The statistical study of the causes of failure dams showed that the two main causes of accidents are the floods and the problems related to foundations (J.C. MILLET and Al. 1988). New hydrological knowledge and development of methods of data processing acquired these last decades showed undersize of a large number of the existing spillways.

It is possible to increase the capacity of these works by their rehabilitation to avoid the problem of submersion, so several solutions are conceivable.

Most of the existing dams are equipped with free sill spillways whose hydraulic functioning are governed by the laws of the free flow and represent most simple and effective solutions.

The discharge evacuated with a free sill weir is given by the universal relation:

$$Q = \mu L \sqrt{2g} H^{3/2}$$

(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 length of the crest weir L or the lowering of the sill to increase the head H.

The linear elongation of the crest can not be feasible because of the width limited of weir or the conditions topographic local. However, the rehabilitation of the existing weir by a weir with not 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 head of functioning.

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. This inconvenience can be ruled out by using a fuse system which guarantees an increase of the capacity of the weir for exceptional floods and allows to maintain the same level of storage.

## INCREASE OF THE DISCHARGE BY THE INCREASE OF THE EFFICIENCY OF THE EXISTING WEIR

The increase of the length crest of a linear weir with free sill can be obtained by the adoption of a discontinuous crest in plan which allows to have a length discharge bigger than the width of the weir. Objective is to increase discharge by unity of width for a given head of functioning. So, the labyrinth weir is the ideal structure to discharge a larger flood at a comparatively low head.

### Labyrinth Weir of classic shape

The labyrinth weir is made by several cycles of the same geometrical configuration often trapezoidal repeated periodically. Obviously this increases greatly the crest length. Walls are thin and vertical.

The cost of this type of weir is relatively low with regard to weirs equipped with gates, this leads to its use simultaneously to increase the storage and the spillage capacity (Tullis and Al. 1995).
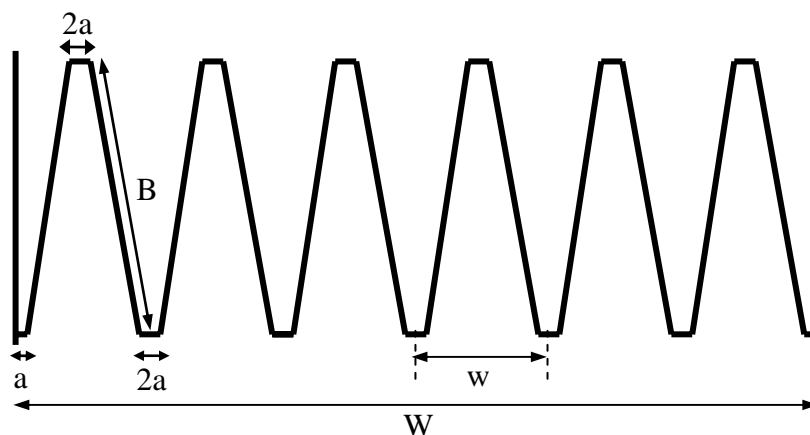


**Fig.1 labyrinth weir of trapezoidal shape**

a: Half width of the frontal wall        B: Length of the lateral wall
w: Width of a cycle        W: total Width of the weir

Most of the labyrinth weirs realized have a trapezoidal shape. However, it is possible that other shapes can be more efficient than trapezoidal shape.

One solution for the improvement of the hydraulic performance and the cost of the labyrinth weir corresponds to the adoption of a rectangular shape with a profiled entrance.
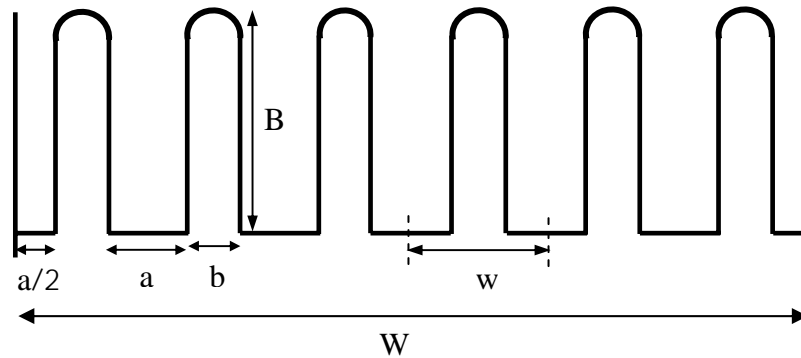


**Fig.2 Labyrinth weir of rectangular shape with profiled entrance**

a: Half width of the frontal wall    B: Length the lateral wall    P: walls height
w: Width of a cycle    W: total Width of the weir    H: nape depth

This new geometry of labyrinth weir was studied by several model tests in the Hydraulic Development and Environment laboratory of Biskra's university (Algeria). Four models of labyrinth weir were tested, three of rectangular shape with a profiled entrance (fig.2) and one of trapezoidal shape in plan (fig.1).

Table 1

Geometrical characteristic of models

| Shape | Entrance shape | P (cm) | a (cm) | b (cm) | w (cm) | r (cm) | L (cm) | L/W | w/P | Wt (cm) |
|-------|----------------|--------|--------|--------|--------|--------|--------|-----|-----|---------|
| Rectangular | Profiled | 15 | 9 | 6 | 15 | 3 | 60 | 4 | 1 | 90 |
| Rectangular | Profiled | 15 | 7,5 | 7,5 | 15 | 3,75 | 60 | 4 | 1 | 90 |
| Rectangular | Profiled | 15 | 6 | 9 | 15 | 4,5 | 60 | 4 | 1 | 90 |
| Trapezoidal | Flat | 15 | / | / | 15 | a'=1,5 | 60 | 4 | 1 | 90 |

Figures (3 and 4) show that rectangular shape with a profiled entrance is more effective than trapezoidal shape for values of head h/P< 0,7. These results are valid for a rectangular shape with a width of inlets wider than the outlet (a>b).

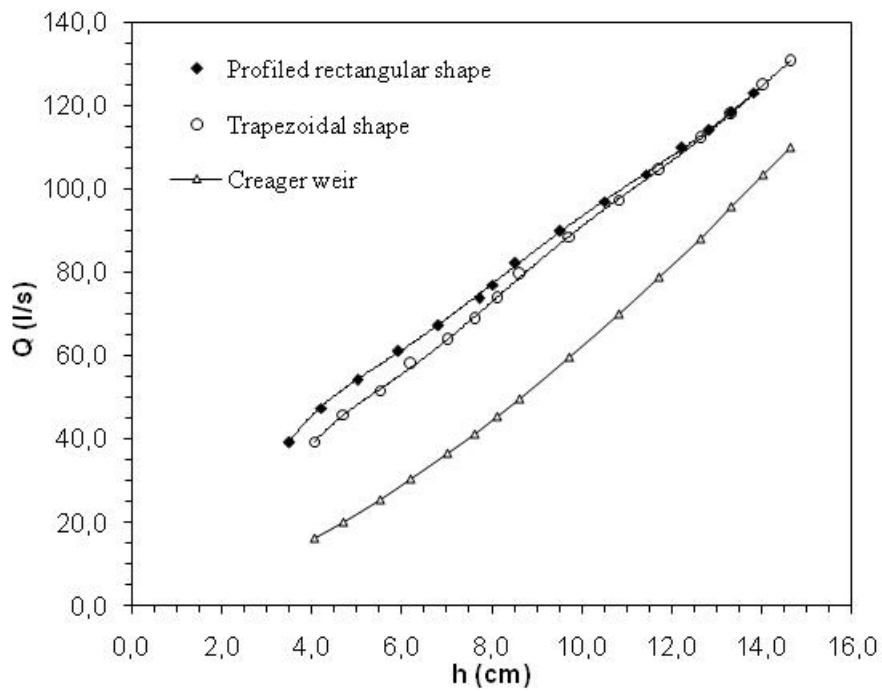**Fig.3 Discharge curve according to the shape in plan L/W=4**
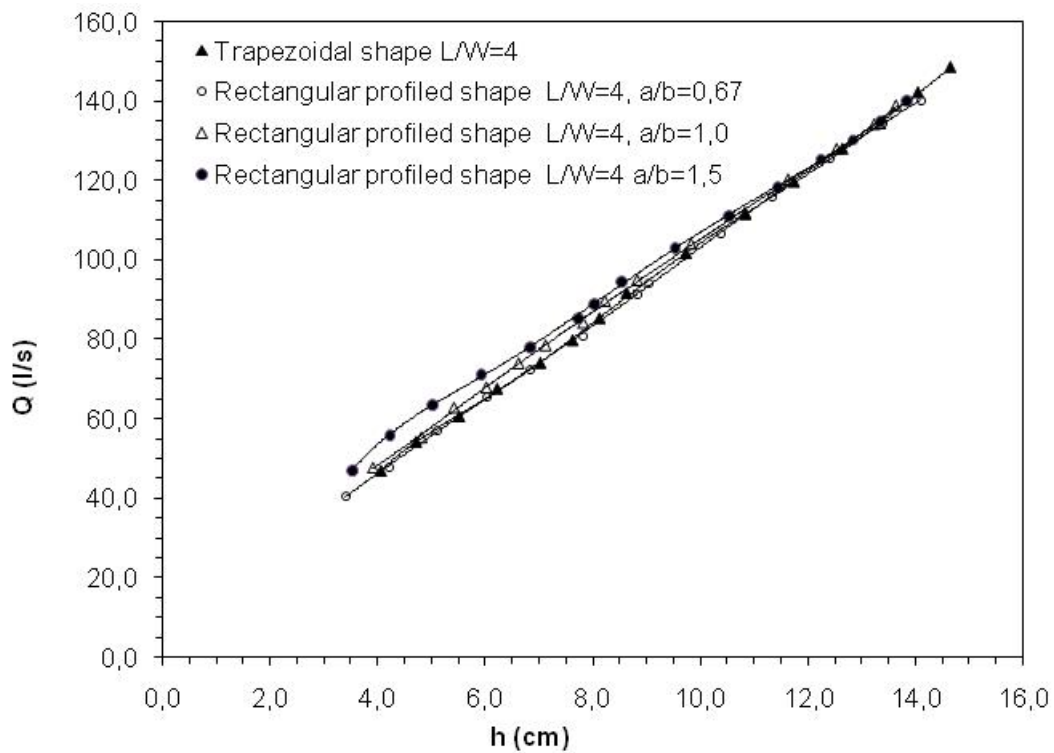


**Fig.4 Discharge curve according to the shape in plan and the ratio a/b**

The labyrinth weir represents an appropriate solution to increase the capacity of the existing weirs, its application was recommended for several earth dams worldwide, however, its application for many concrete dams is not possible for traditional trapezoidal shapes because the length of the side walls are generally superior to the width of the cross-section of the top of dams in concrete. However, a new configuration of labyrinth weir which can be used for earth dams and concrete dams was developed in 2003 by Hydrocoop-France in association with Biskra's university (Algeria). This new type is characterized by a rectangular disposal a little similar to the forms of Keys of Piano, what explains the name of Piano Keys Weir (P.K.Weir).

**Piano Keys Weirs (PKWeir)**

The Piano Keys Weir or P.K.Weir can be considered as an improved shape of the labyrinth weir. It can be used for the new dams or for 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 h = 4 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. 5 and fig. 6)

The P.K. Weir multiplies the discharge of a Creager weir by 3,5 or 4 for h = 0,3 H and by about 2 for h = H. The saving in depth of reservoir (or in height of the dam) is close to 0,5 H, or the saving of specific discharge close to 2 H$^{1,5}$.

The specific discharge of the P.K.Weir (model A) in m³/s/m can be estimated by the following relation:

$$q = 4h\sqrt{H}$$
(2)

q: Specific discharge                    h: total head on the P.K.Weir

H: Maximal height of walls

The comparison of the two models PKWeir (A and B) shows that the discharge of the model B is higher by about 10% than for the model A for h = 0,5H and 3 % for a total head h= H. (Fig.7)

The optimum value of a/b for model A seems close to 1,2.

The P.K.Weir can be prefabricated steel elements for specific discharges lower than 10 $m^3$/s/m and reinforced concrete elements of average thickness (0,15 to 0,40 m) according to the height for specific discharges greater than 10 $m^3$/s/m.

In practice, the height of walls can be from 1 to 6 m, with elements completely prefabricated until 2 m. The necessary reinforced concrete by m of weir is (in m3) in the range of 0,5 H² (H height of elements in m).

It is possible to increase the safety, i.e. discharge of the existing weirs without changing maximum level of the reservoir or the level of the sill if lowering the sill by a depth H and placing a P.K.Weir of the same height. The saving of the discharge is close to 2 $H^{1.5}$ for a volume of reinforced concrete of 0,5 $H^2$ by linear meter of width.
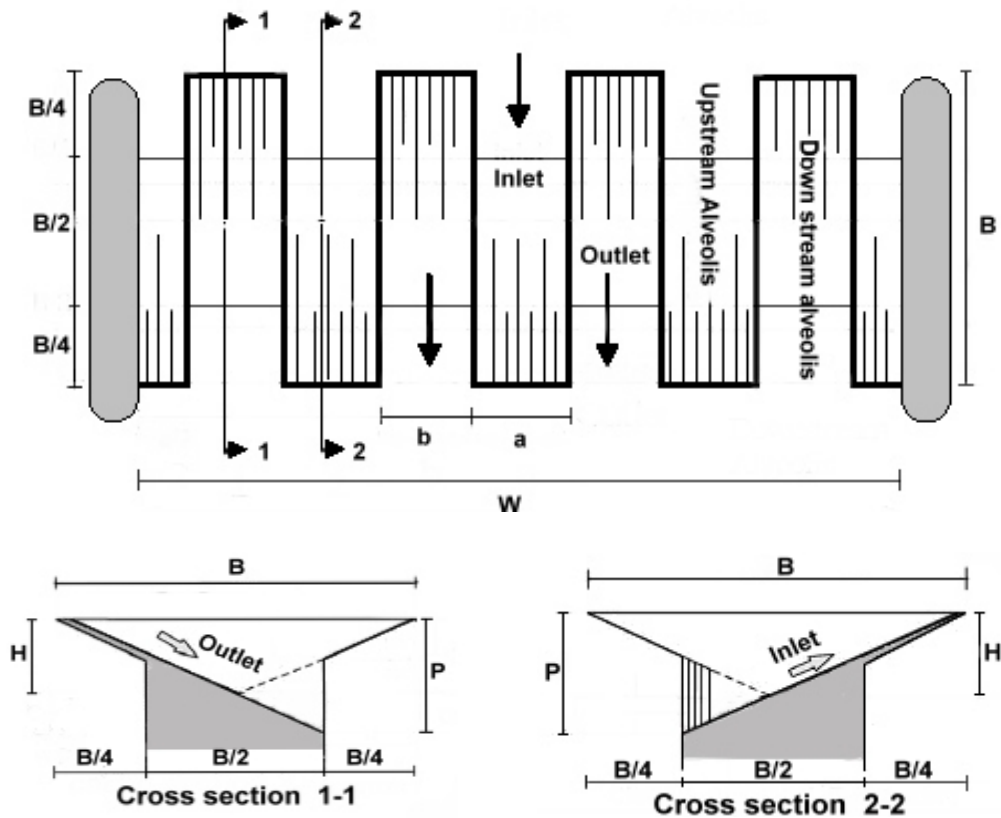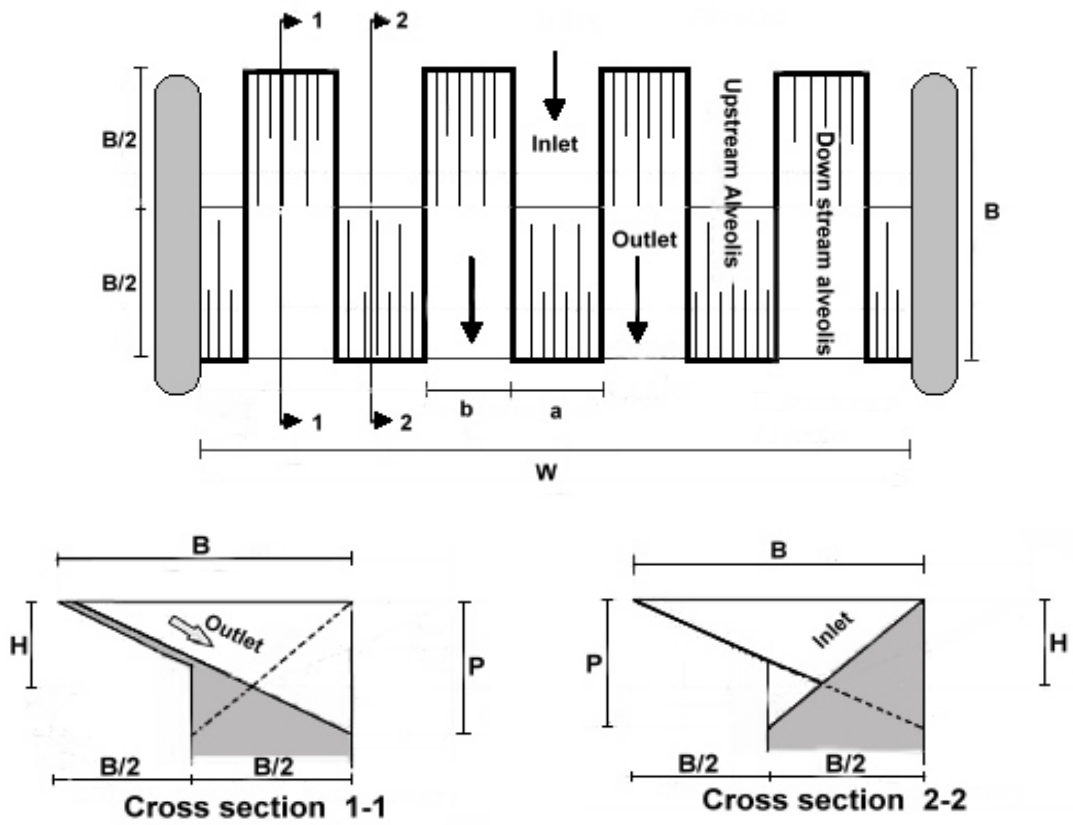


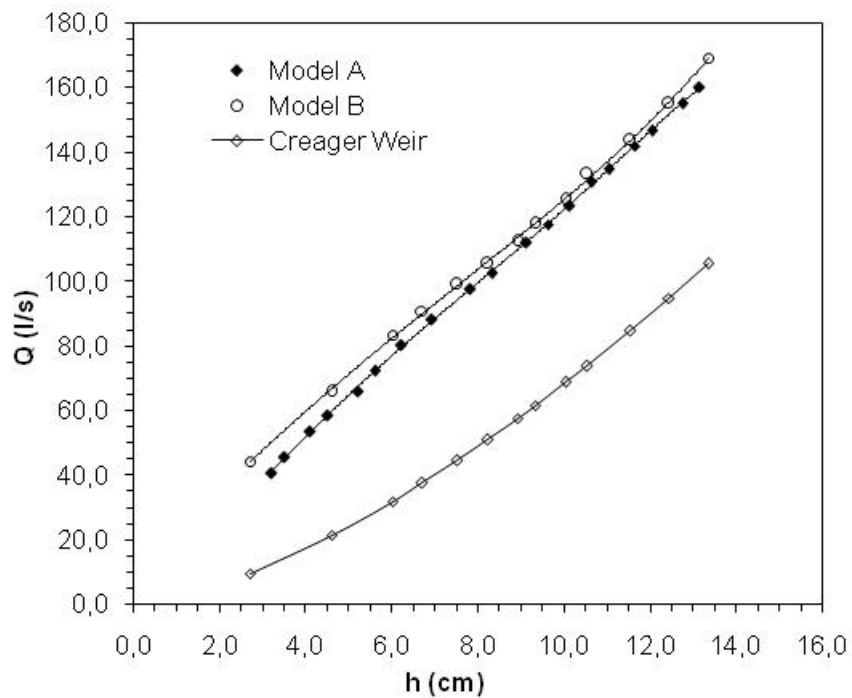**Fig.5 Piano Keys Weir model A**

**Fig.6 Piano Keys Weir model B**



**Fig.7 Discharge curves of PKWeir models A and B (L/W = 6)**
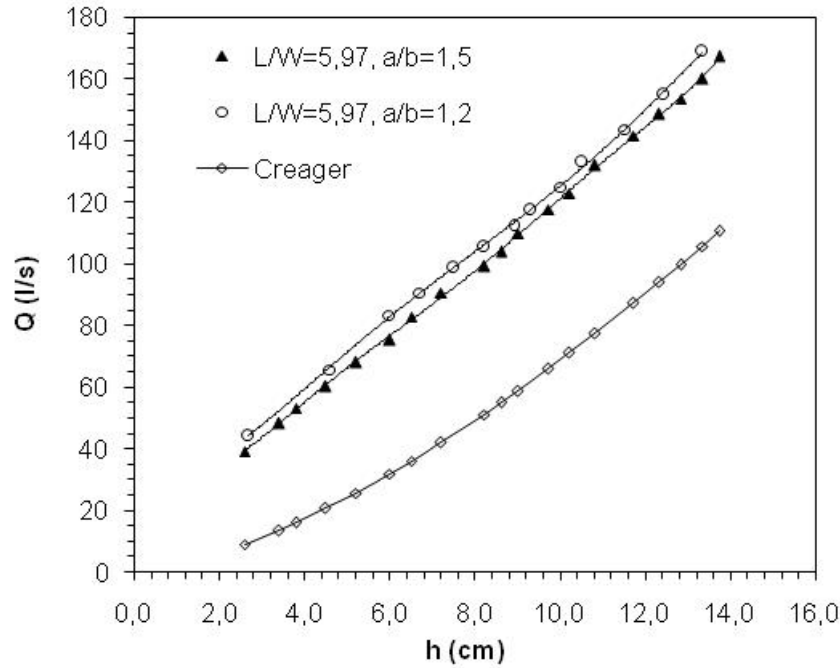
**compared with the Creager weir**

**Fig.8 Curves of discharge according to the variation of the width of alveoli**

## INCREASE OF THE DISCHARGE BY INCREASING THE NAPPE DEPTH

The increase of the nappe depth of an existing weir can be obtained if lowering the existing sill what allows to increase the discharge. However the reduction in the sill engenders a considerable loss of the useful volume. It is possible to maintain the same level of storage without changing the maximum level of the reservoir by using a fusible system.

The principle is to lower the sill of the existing weir by a depth of 1 to 7m and setting up fusible elements of the same height which allow the plugging of the gap created by the reduction in the sill level.

The fusible elements are auto-stable until a certain level of reservoir. When the upstream level of water exceeds this level during the floods, the elements tilt automatically allowing so the passage of the flood through the breach created by the reduction in the sill level. The elements which tilt are not recoverable and must be replaced after the passage of flood to restore initial functioning in its integrity.

Fuse devices are made with steel elements or in reinforced concrete and may be designed and operate as various labyrinth weir until a certain level of the nappe depth. Beyond this level the elements tilt to allow the discharge of the flood.
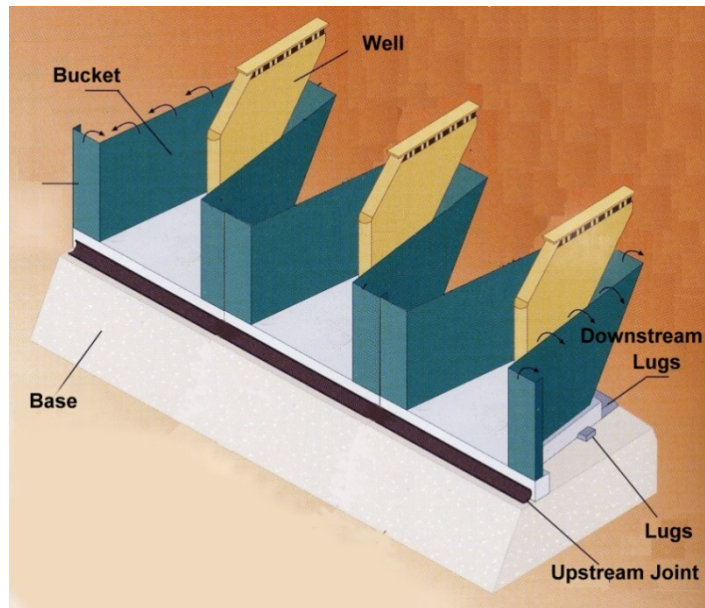
**Fig.9 Labyrinth fusegate**

About 40 existing dams were heightened with fusegates to increase storage or capacity of spillways.

For ordinary floods, fusegates are submerged by a nappe depth which can be from 50 to 100 % of the height of the labyrinth. The length walls is of the order of 3 times the width of the weir.

With fuse gates, uplift is created under the fuse elements by a well for a precise reservoir level, thus causing tilting of the element.

**Fuseplugs**

To increase the capacity of evacuation of the ungated weirs, it is possible to lower the sill by 1 or 2 m and to place blocks in concrete of simple geometry. These blocks are auto-stable until the upstream water level reaches a certain level for which they tilt.
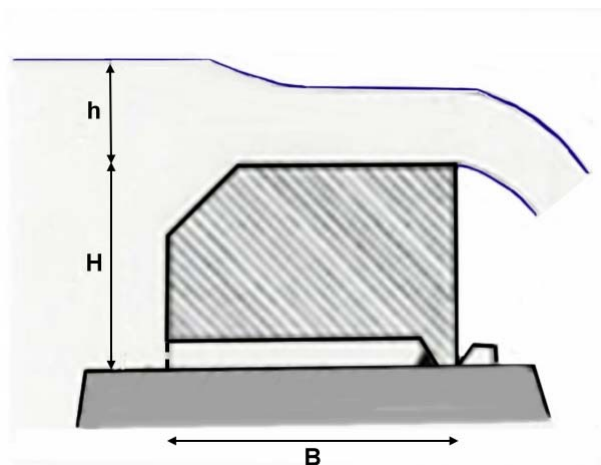


**Fig.10 Fuseplug**

Fuseplugs on the same sill have the same height H but can have different thicknesses B, so that they tilt for different heights of water. This level can be foreseen exactly if the value of the uplift under blocks is known well. A way simple to resolve this problem is to make sure that uplift is total. This can be make by the creation of a space under every block, which is closed in the downstream with a joint and communicating with the upstream. (fig. 10)


**CONCLUSION**

It is possible to increase the safety of many existing dams by upgrading their spillways. This can be made at low cost by using simple and economic solutions. Among these, the labyrinth weir, the P.K.Weir and the fuseplugs.
The labyrinth weir can be improved in order to increase its efficiency by using for example a rectangular shape with a profiled entrance.
The P.K.Weir represents an economic and reliable solution for the increase of the discharge of the existing weirs.
Concrete fuseplugs are a simple and economic way for increasing safety.
Various tests realized on several models showed the interest of each of these weirs.

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