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Hydraulic and Costs data for various Labyrinth Weirs

Données Hydrauliques et du Coût pour divers Déversoirs de Labyrinthe

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Summary: The Algerian dams are characterized by a rate of important silting which has as consequence a reduction of the storage capacity. Partial solution of this problem consists in increasing the capacity of reservoirs by heightening the sills of weirs. This operation is practicable by the adoption of various types of labyrinth weirs. Several forms of labyrinth were used in Algeria such as: the Keddara dam, Harreza, Bakhada, and the Fountain de Gazelles dam.
Exceptionally, the spillway of Beni Bahdel dam is characterized by a capacity which is of fifteen times that of a Creager weir. It takes the shape of labyrinth with downstream overhangs pressed on piers.
Since five years the hydraulics laboratory of Biskra University (Algeria) proceeded to study of optimization and comparison of three types of labyrinth weir (with the cooperation of Hydrocoop-France).
These studies have for objectives:

- To improve (for the same cost) shape and hydraulic performance of traditional conceptions with vertical walls.
- To optimize through several tests on models the shape of a new conception which can also improve efficiency on several existing spillways: Piano Key Weir (P.K.Weir).
- To conceive a new shape which favors the evacuation of a large specific discharge.

This optimization does not take into account only the hydraulic performance, but also the structural conception and opportunities of construction.
This presentation of performance includes the discharge coefficient, but also the save depth of water in comparison with the Creager weir and the quantity of reinforced concrete by m3/s of discharge or by m3 of storage.
Appropriate possibilities to improve the capacity of several Algerian reservoirs were recapitulated.

Résumé : Les barrages Algériens sont caractérisés par un taux d'envasement important qui a comme conséquence une réduction de la capacité de stockage. La solution partielle à ce problème consiste à faire augmenter la capacité des réservoirs par la surélévation des seuils des déversoirs. Cette opération est réalisable par l'adoption des divers types de déversoirs en labyrinthe. Plusieurs formes de labyrinthe ont fait l'objet d'application en Algérie tels que : le barrage Keddara, Harreza, Bakhada, et le barrage Fontaine des Gazelles.
Exceptionnellement, l'évacuateur de crues du barrage Beni Bahdel se caractérise par une capacité d'évacuation qui est de quinze fois celle d'un déversoir Creager. Il prend la forme du labyrinthe avec des porte-à-faux aval appuyés sur des piles.

Depuis cinq années le laboratoire d'hydraulique de l'université de Biskra (Algérie) a procédé à l'étude d'optimisation et de comparaison de trois formes de déversoir en labyrinthe (avec la collaboration d'Hydrocoop-France).
Ces études ont pour objectifs :

- Améliorer (pour le même coût) la forme et la performance hydraulique des conceptions traditionnelles avec des parois verticales.
- Optimiser à travers plusieurs essais sur modèles la forme d'une nouvelle conception qui peut également améliorer le rendement de plusieurs évacuateurs de crues existants : Piano Key Weir (P.K.Weir).
- Concevoir une nouvelle forme qui favorise l'évacuation d'un grand débit spécifique.

Cette optimisation ne tient pas compte seulement de la performance hydraulique, mais aussi de la conception de point de vue structure et des facilités de construction.
Cette présentation de la performance inclura le coefficient de débit, mais aussi le gain de profondeur d'eau en comparaison avec le déversoir de type Creager et la quantité de béton armé par m^3/s de débit du déversoir ou par m^3 de stockage.
Les possibilités appropriées pour améliorer la capacité de plusieurs réservoirs Algériens ont été récapitulées.

1-Dams and requirements of supplementary storage in Algeria

The silting of Algerian dams reservoirs constitutes the most grave phenomenon for the water reserve, in a region where the lack of water constitutes a factor limiting the economic development.
Storage capacity lost by silting is estimated at 600 Mm3 about 10 % of the total capacity of Algerian dams. This reduction engendered a decrease of the regulate volumes which compromises the satisfaction of requirements.

A summary study of the Algerian dams shows that almost the third of the capacity lost by silting can be recuperate by the heightening of weirs sill for some existing dams.
The most appropriate structure to the heightening corresponds to the labyrinth weirs. Consequently, three different configurations of labyrinth can be presented.
Algeria knew the application of this type of weir since the 30s; the following table gives some labyrinth weirs realized in Algeria.

Table-1- Existing Labyrinth Weirs in Algeria

Dam	Year of completion	Total capacity of reservoir ($10^6 m^3$)	Capacity of spillway (m^3/s)
Bakhadda	**1936/S. 1959**	**56**	**2000**
Beni Bahdel	**1952**	**63**	**1000**
Harreza	**1984**	**70**	**350**
Kheddara	**1985**	**145.6**	**380**
Fontaine des Gazelles	**2000**	**55.5**	**3000**

There are now worldwide about hundred spillways using the principle of labyrinth. Relevant reports refer mainly to hydraulic coefficient values according to nappe depth. The report below refers also to structural data and tries to compare the economic efficiency of various solutions: for instance:

"Which is the cost (or the volume of reinforced concrete) for increasing the discharge by 1 m^3/s as compared with a usual Creager Weir?"

and "Which existing or new dams may use various labyrinth weirs?"

and "Which maximum specific flow may withstand such structures?"

2- Traditional labyrinth weirs

Usually they are made by vertical reinforced concrete walls built with a trapezoidal layout upon a flat area. The total length of walls is most often in the range of 4 times the length of the spillway, the maximum nappe depth in the range of half of the wall height and the discharge is about twice the discharge of a traditional Creager Weir for a same nappe depth. The nappe depth saving is thus in the range of one third of the walls height or the increase of specific flow for a same nappe depth, (in $m^3/s/m)H^{1,5}$, H being in m the walls height.
Walls height is most often 3 or 4 m and specific flows between 5 and 15 $m^3/s/m$. However the Ute spillway in U.S. had a 9 m high walls and a specific flow of 60 m3/s/m for a total flow of 15,000 m^3/s.

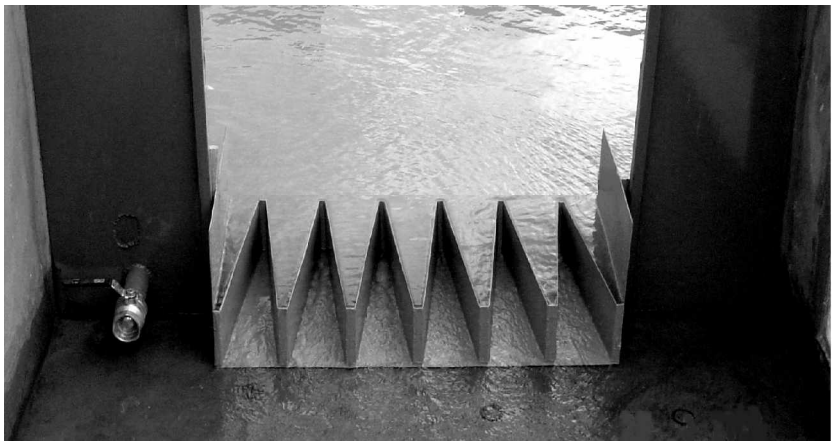

Fig. 1 Traditional labyrinth weir of trapezoidal shape

Increasing the discharge by 1 m^3/s required about 1 m^3 of reinforced concrete for small walls height. It required 2 m^3 in Ute Dam (with 400 K of reinforced steel); 15,000 m^3 of reinforced concrete increased the discharge from 7,000 to 15,000 m^3/s.
A main drawback of this solution is the length of the structure which cannot thus be placed on top of a gravity dam section, i.e. on usual spill ways structures.

2-1-possible Improvements of traditional labyrinth weir

The improvement of a labyrinth efficiency is possible.
1) Usually, the inlets and outlets alveoli have the same shape; this is not justified a hydraulic point of view and a structure, so, some optimizations seem possible to increase discharge in the same cost, by choosing for example a shape of profiled entrance (Fig. 2).

Fig. 2 Labyrinth weir

2) It is possible to avoid very costly high walls by using more ordinary concrete inside the inlets and outlets alveoli, this favors the reduction of the thickness of walls and consequently the volume of reinforced concrete (Fig. 3).

For more than five years, the Hydraulic developments and environment laboratory of Biskra university has made in cooperation with Hydrocoop several studies and hydraulic model tests for various shapes of labyrinth weirs in order to optimize this type of weir.

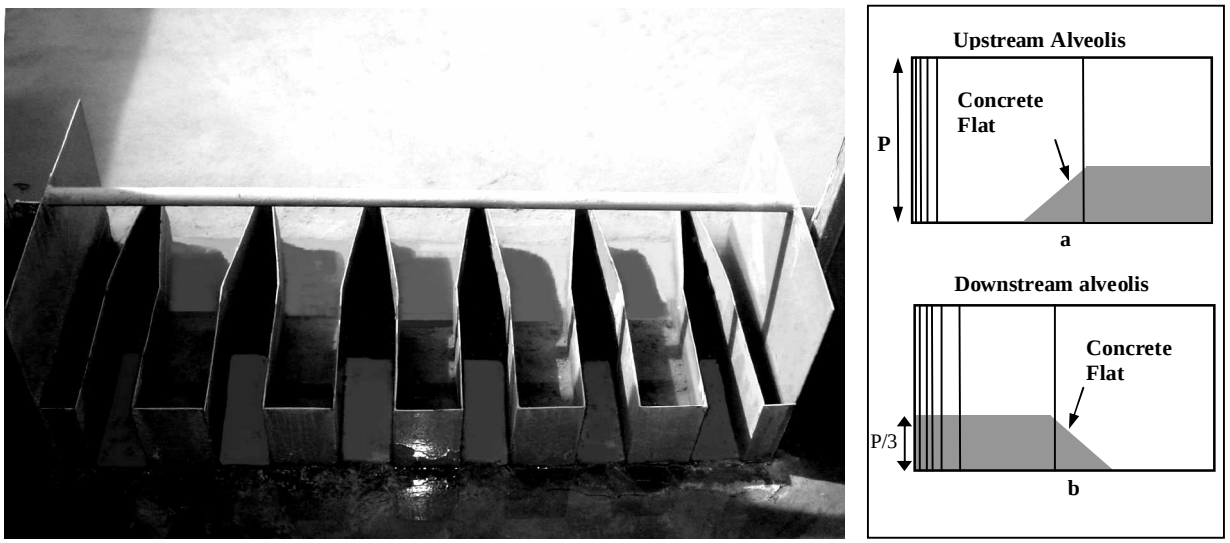

Fig. 3 Labyrinth weir with profiled entrance and partial filling in ordinary concrete inside the inlets and outlets alveoli

Tests made on a labyrinth weir showed that the partial filling in ordinary concrete inside the inlets and outlets alveoli until a height equal to the third of the height of walls doesn't influence the hydraulic performance of weir.

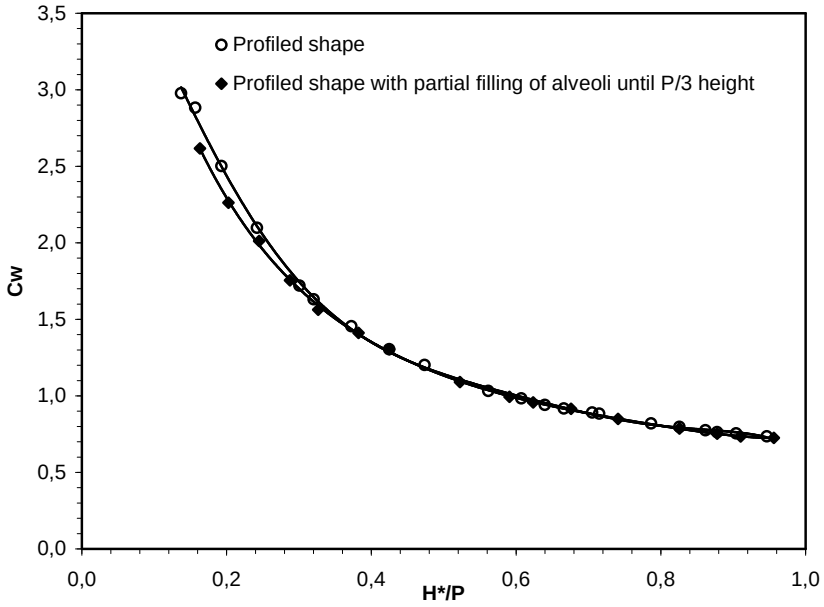

Figure 4 - Coefficient of debit according to filling of alveoli P/3 (L/W=6)

3- Labyrinth fusegates (Hydroplus)

About 30 existing dams have been upgraded with labyrinth fusegates for extra storage or extra discharge capacity.
For ordinary floods the fusegates are overtopped by a nappe depth which may be 50 to 100% of the labyrinth height. The length of walls is in the range of 3 times the spillway length.
In order to place the fusegates on top of existing spillways and to favour tilting for high floods, the cross section includes a downstream hangover.
Labyrinth fusegates have been built for specific flows up to about 60 $m^3/s/m$.

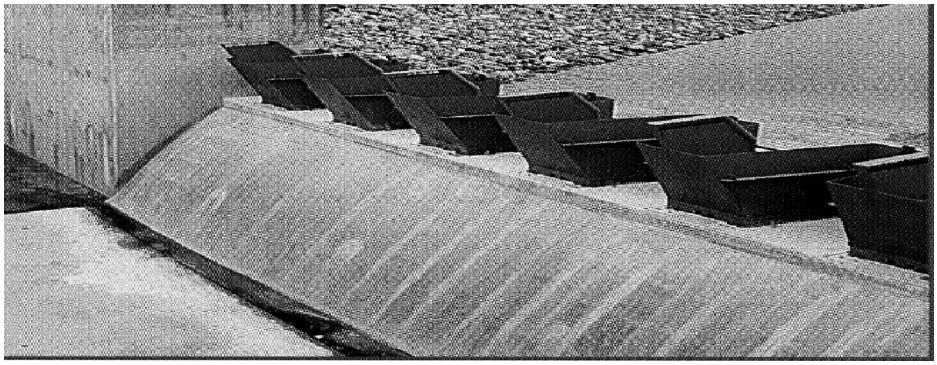

Fig.5 Labyrinth Fusegates

4- Piano Keys Weirs (P .K. Weirs)

Since over 5 years, studies and model tests have been made in 5 countries (Algeria, China, France, India and Vietnam) and coordinated by Hydrocoop for selecting and optimizing new shapes of Labyrinth Weirs which could be placed on top of usual dams cross sections, i.e. on existing or new spillways. The studies took in account hydraulics and also structural optimization and construction facilities.

A large part of studies and tests for comparing various shapes and selecting optimized solutions were made along 4 years in Biskra University in Algeria. The final choice was based upon using partly inclined walls and a simple rectangular lay out shape, quite similar to Piano Keys, justifying the chosen name.

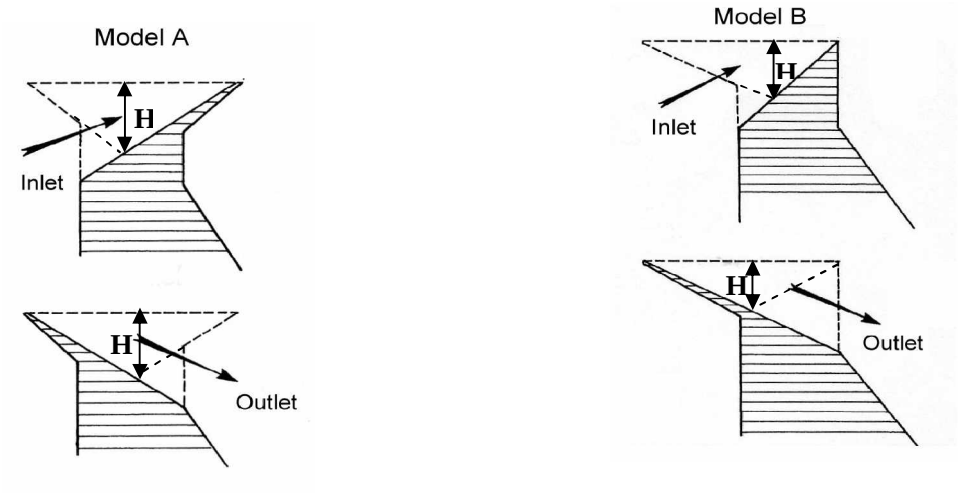

Fig. 6- P.K.WEIR Models A and B

4-1 Shape of P. K. Weirs

The studies made in Biskra have analysed many options, the obtained results showed that:
- An upstream hangover gives a higher discharge than a downstream hangover and even higher than 2 smaller symmetrical ones.
- It is better to have inlets wider than outlets, except for very high discharges.
- The hydraulic shape of the entrance is important.
- The slopes may be optimized between 2/1 and 3/2.
- For moderate flows the depth of the downstream part of the outlet may be reduced.
- The best cost efficiency seems reached for a ratio of full length of walls to spillway length between 4 and 6.

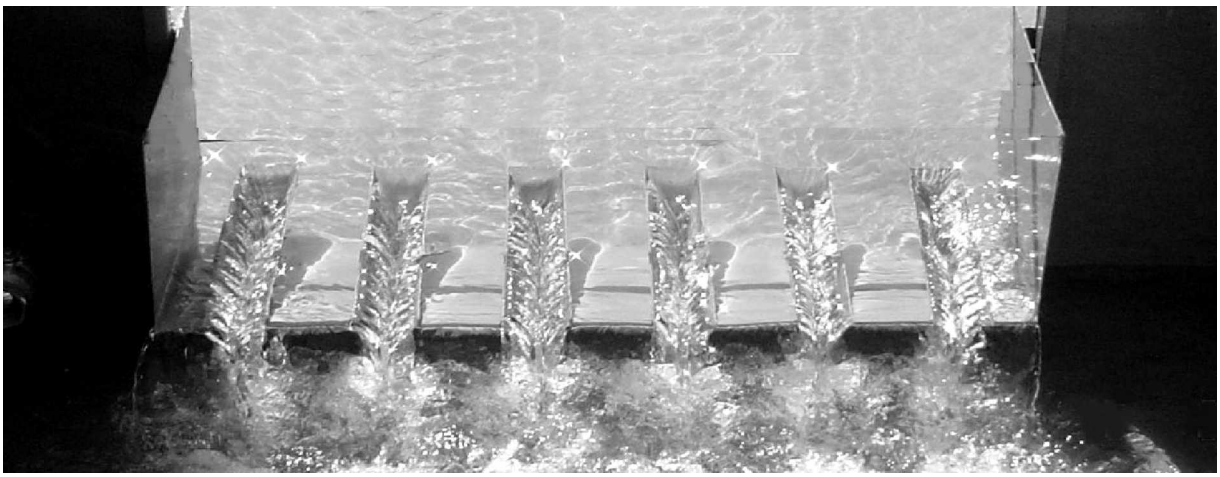

Fig. 7 Flow on the P.K.WEIR

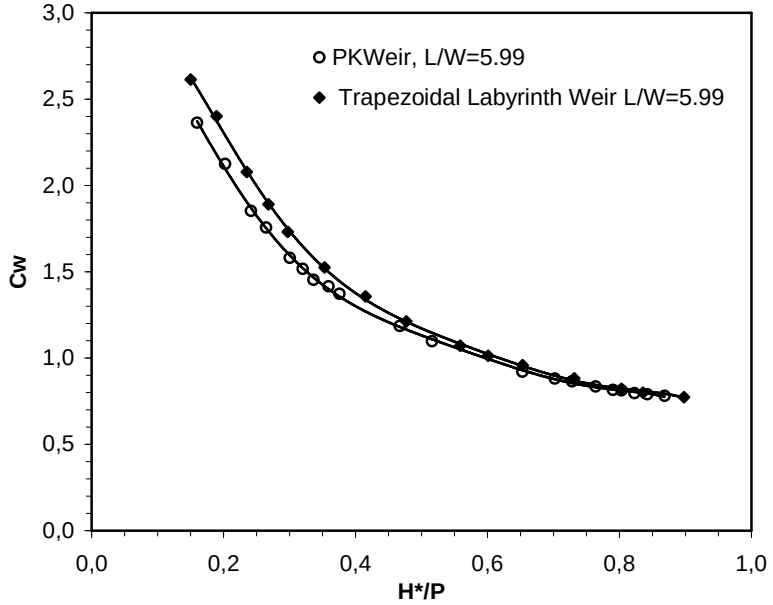

Fig. 8 Comparison of the coefficient of discharge of the P.K.WEIR with the trapezoidal labyrinth weir

4-2 Some cost data for P.K. Weirs

- H being the maximum walls height, the extra specific discharge as compared with a Creager Weir is between 1,5 and 2 $H^{1,5}$ for various models and the volume of reinforced concrete is in the range of 0,5 H^2. Increasing the discharge by 1 m^3/s requires thus about 0,5 $H^2/1,8$ $H^{1,5}$ or about $0{,}3\sqrt{H}$, i.e. 0,4 to 0,7 m^3 for usual values of H between 2 and 6 m. These quantities are about half of those of traditional labyrinth weirs. The cost is specially low in developing countries where the labour cost is low.

- The nappe depth saving is about 0,5 H, i.e. a storage increase of 0,5 HS (if S is in m^2 the reservoir area). If L is the spillway length, the volume of reinforced concrete is about 0,5 H^2L and the storage increase by each m^3 of reinforced concrete : $\frac{0.5HS}{0{,}5H^2L}$ or $\frac{S}{HL}$

For usual values of $\frac{S}{L}$ between 5,000 and 20,000 and H = 2 to 4 m, 1 m^3 of reinforced concrete increases the water storage by several thousand m^3.

The discharge and efficiency of P.K. Weirs are about the same on top of a dam or on a flat area such as used for traditional labyrinth weirs.

The efficiency of P.K. Weirs remains high for huge overtopping and downstream high level; it may thus be used for low head falls in large rivers.

Some examples of possible application for Algerian dams are summarized in the following table.

Table 2- possible Utilisation PKWeir in Algeria

Dam	H	L	Vs	Vc	Vs/Vc
	m	m	Mm^3	Mm^3	
Ain Zada	6	75	41	1350	30370
Babar	2.22	160	10	394	25380
Zit Amba	3	50	22	225	97777

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H : Maximal height of walls
L: Width of the weir
Vs: Supplementary storage
Vc: Volume of reinforced concrete

Conclusion

Labyrinth weirs represent a profitable economic solution for the increase of the reservoirs capacity and\or the spillways capacity of the existing or new dams. The application of one or the other type of labyrinth weir (traditional Labyrinth, Fusegate or PKWEIR), depends on local conditions of each dam and the cost of the work. The PKWEIR represents the type of the most suitable weir for the most part of the existing dams which require the increase of storage capacity or the capacity of the spillway. It can be also an economic alternative for the new dams. The improvement of the hydraulic performance and the efficiency of investment remain always possible.

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