EXPERIMENTAL COMPARATIVE STUDY OF SIPHON SPILLWAY AND OVER-FLOW SPILLWAY

Etude expérimentale comparative entre les déversoirs en siphon et a écoulement libre

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ABSTRACT

Two types of spillways in physical models were tested. The first one is a weir considered as an over-flow spillway with Creager profile, the second is a siphon spillway with the same longitudinal profile. Concerning the siphon, the study recognised a clear distinction for no complete prime areas relating to low heads and complete prime areas for the remainder of the values of heads applied to the level upstream.

The field of convenience of the siphon spillway compared to the weir was defined.

The experimentation allowed also proposing two relationships between flow over a weir and the siphon for the same range of measured heads.

KEYWORDS: Coefficient of discharge, Creager profile, model, priming, siphon spillway, weir.

RESUME

Deux types de modèles physiques de déversoirs ont été testés. Le premier est à écoulement libre de profil Creager, tandis que le second est un siphon de même profil que le premier. En ce qui concerne le siphon, l'étude a pu montrer une nette distinction entre les sections de l'écoulement à amorçage partielle liées aux faibles charges et les sections à amorçage plein ou complet les autres valeurs de charges appliquées à l'aval. Comparé au déversoir, les conditions les plus avantageuses pour le siphon ont été définies. L'étude expérimentale a pu conduire à l'établissement de deux relations empiriques liant l'écoulement franchissant le déversoir et celui du siphon pour la même gamme de charges.

MOTS CLES : Coefficient de debit, Profil Creager, modèle, amorçage, déversoir, déversoir en siphon.

1 INTRODUCTION

Siphon spillways are often used in low-head small capacity installations, where it is desirable to keep the reservoir level within a modest range of fluctuation, or in larger installations, where it is used as a service spillway and large floods are carried by an auxiliary spillway (Roberson, and al. 1998).The siphon spillway is a structure in closed duct, generally with rectangular section in a typical width to height ratio b/a of 1.5 to 2.5 and an aeration cross-section at 3 to 5 % of the siphon crest section. Siphon spillway works under increasing discharge like a weir. At a certain discharge priming occurs and the flow is pressurized for larger discharges, (Vischer, and Hager, 1997).

Practically siphon spillways have the advantage of a great sensitivity at the rise of the water upstream level and the great discharge per linear meter of sill. Several realizations of spillways siphon were described by (Rousselier, and Blanchet, 1951). A rare Algerian case is the full-scale siphon constructed in Fergoug Dam located at about thirty kilometer upstream of Bou-Hanfia Dam (Drouhin, Mallet, and Pacquant, 1951). The descriptive details on these works concerning the theoretical base of calculation of flow, cavitations and head loss were presented by (Govinda, 1962). The comparison between different types of spillways in order to optimise the evacuation facilities is treated by several researchers like the investigation of (Ouamane, and Lempérière, 2006), or the analysis through a numerical example which is given by (Bollrich, 2000); this example treats the comparison of the siphon with its similar weir. Comparison of the automatic flap gate spillways and siphon spillways is given by (Bessonneau, and Theret, 1979). In the same context of optimisation, a study concerning the rapid evacuation over steeply sloping overflow is presented by (Houichi, and Achour, 2007).

The present contribution consists in making an experimental hydraulic study of the siphon Creager profile spillway, in order to determine its capacity of discharge compared to weir Creager (1929) profile also, this profile is frequently used in evacuation facilities in almost all Algerian's dams; In overflow spillways form such as Koudiat-Medouar Dam, Ain Zada Dam, Zit Emba Dam… or in sill of spillways such as Ghrib Dam, Sarno Dam, Fodda Dam, Foum-el-Gherza Dam… This comparison is appeared under the effect of the same heads applied at the level upstream. The siphon model is defined by a ratio b/a equal to 4 which corresponds to the maximum coefficient of discharge with value equal to 0.79 (Houichi, and al., 2006).This model is selected from four models examined in the range ratio (1≤b/a≤4) (Houichi, 2007). The weir with free surface and Creager profile is designed for head Hd = 10cm. This head produces generally a lower nappe of flow that agrees closely with spillway profile (Chow, 1981).The study seeks the limits of possibility of replacement of the weir largely used, by their similar siphon spillway which are not much used. The experimental values are consigned in tables 1 and 2 in the appendix.

2 THEORETICAL RECALL OF THE RELATIONS OF DISCHARGE CALCULATIONWeir type Creager

The discharge over the weir with Creager profile according to the schema of the figure 1 is given by a well-known theoretical relation:

$$Q_{weir} = mb\sqrt{2g}\,H^{3/2} \tag{1}$$

Where:

Q_{weir}: discharge of weir (m^3/s)

m: coefficient of discharge of weir

b: width of crest (m)

g: gravity acceleration (m/s^2)

H: head above the crest (m.)

E: the vertical distance from the crest of sill to the floor at the downstream apron (m).

Figure 1: **Weir with Creager profile**

2.2 Siphon spillway

The discharge over the siphon considered as a pressurized conduct is given by the following relation according to the schema of the figure 2:

$$Q_s = \mu A\sqrt{2gH_{act}} \tag{2}$$

Where:

Q_s: Discharge of siphon spillway (m^3/s)

μ: Coefficient of discharge for siphon

A: cross-section at crest of siphon equal to b×a (m^2)

a: vertical dimension of cross-section at crest and exit section of siphon (m)

b: horizontal dimension of cross-section of siphon (m)

g: gravity acceleration (m/s^2)

E**:** the vertical distance from the crest of sill to the floor at the downstream apron (m).

H_{act}: actual head according conditions of flow at exit of siphon according to the schema on figure 2.

$$H_{act} = E + H - a' \tag{3}$$

With:

a': flow depth on downstream.

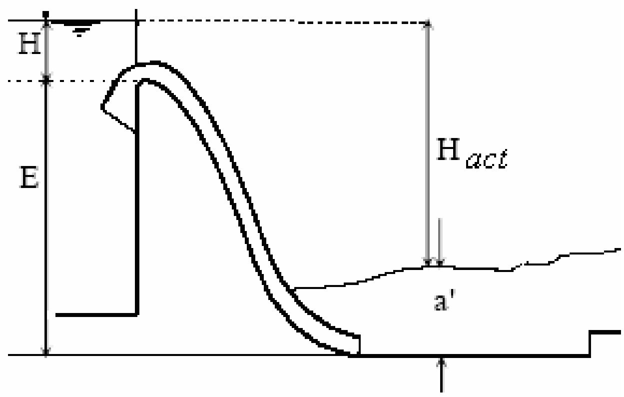
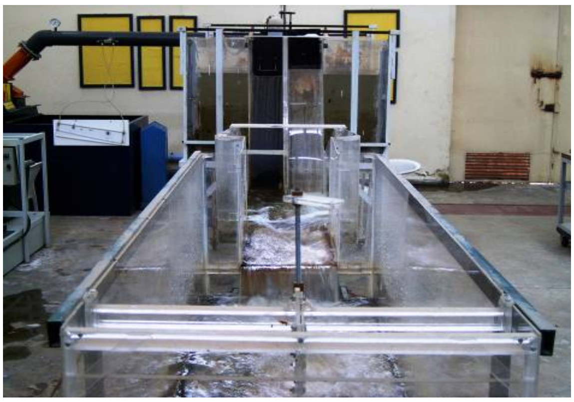


Figure 2: **Siphon with Creager profile; Siphon-exit drowned**

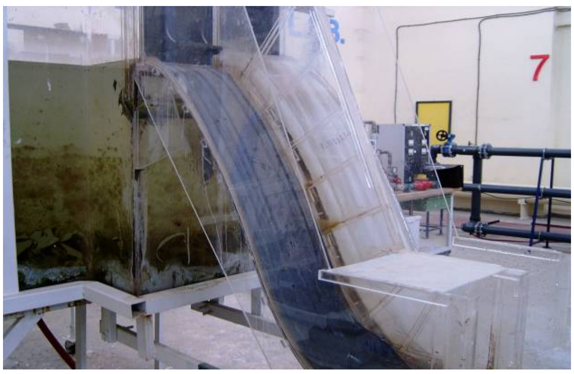
3 EXPERIMENTAL STUDY

3.1 Installation

The experimental station (photography 1) is a hydraulic system formed by a physical spillway model at overflow crest divided into two parts of width b = 17.2 cm each. The first one is used as a weir with free surface Creager profile for design head Hd = 10cm and the broad range of head above the crest from 2 to 18 cm (photography 2 on the left); the second one is used as a siphon spillway (photography 2 on the right) with rectangular opening (Figures 3) for a longitudinal section also with Creager profile, owning a vertical dimension a = 4.3 cm of the cross section and horizontal dimension b = 17.2 cm , the ratio b/a = 4, and a total surface A = 73.96 cm^2. The vertical distance from the crest of sill to the floor at the downstream apron is E = 70.3 cm. The siphon is equipped with area orifices equal to 5 % of the surface of the section of the siphon measured at the crest (photography 3, figure 4); these orifices ensure the automatic stop of the siphon operation when water reaches the crest of sill at the level upstream. The siphon functions at the beginning as weir then it prime when the openings are drowned, being transformed thus as pressurized ducted with length equal to 1.10 m which leads to a stilling basin for 5 cm of depth. The model is constructed in clear Perspex; it is fed in closed loop, starting from an elevated tank supplied by pumping from a second underground tank. The flows are measured by an ultra sonic flow meter, type (1010WP Ultrasonic).



Photography 1. Experimental station



Photography 2. Left: Weir Creager profile;Right: Siphon Spillway

Photography 3. Entrance and aeration orifices

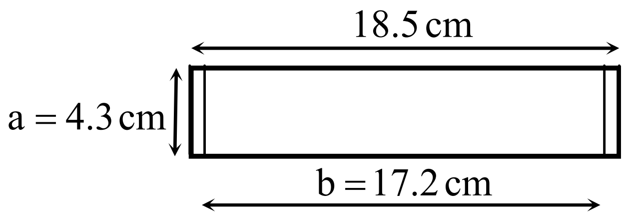


Figure 3: **Siphon with rectangular opening (b×a) = (17.2×4.3 cm); b/a = 4**

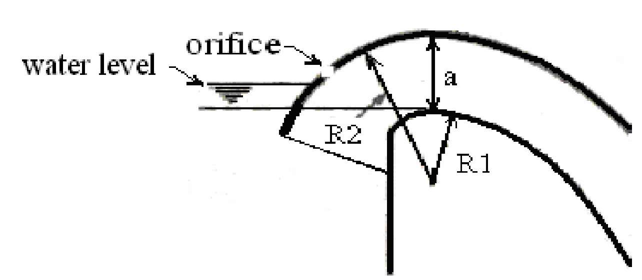


Figure 4: **Entrance and crest of siphon; a = 4.3cm; R_1 = 3.45 cm; R_2 = 7.75 cm**

3.2 Discussions of Results

3.2.1 Complete priming of siphon

When the rectangular siphon duct operates with full section without of air bubbles, the work is considered in complete priming; thus it is possible to conclude:

A clear distinction of the no complete priming areas, for low head values applied to the level upstream of the siphon, as well as a complete priming area beginning at the operation point characterized by a head H equal to (a = 4.3 cm).

The value of the priming flow $Qs_{priming}$ at head H is 20.20l/s when the siphon operates with total section A = 73.96cm^2.

The variation of Q_S (H) is shown in figure 5.

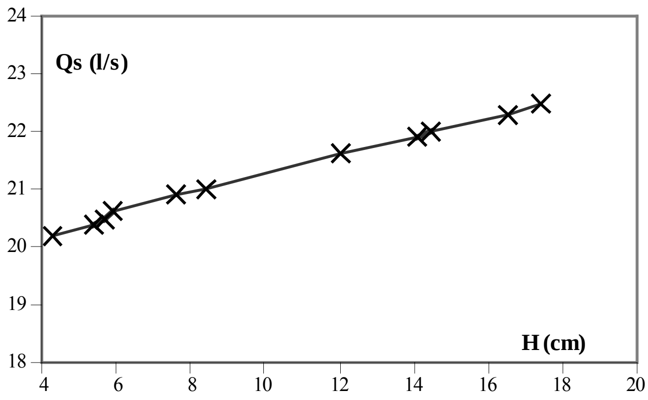


Figure 5: **Variation of Q_s (H) with total cross-section A = 73.96cm^2**

3.2.2 Cavitation control by the vortex theory

As shown in figure 4 let R_1 be the radius of the crest and R_2 be the radius of the crown of the siphon. If h_0 is the negative head at the crest; according to Modi (2000, p671) the discharge Q_S is given from the condition of free vortex flow as:

$$Q_s = bR_1\sqrt{2gh_0}\,\ln(\frac{R_2}{R_1}) \qquad (4)$$

If cavitation is to be avoided, the maximum negative head (vacuum) at the crest may be 7.92 m; it is the difference between the atmospheric pressure at height above the sea level and the vapour pressure.

Thus substituting h_0 = 7.92 m in equation 4, we get

$$Q_{s\,\max} = 12.47bR_1\ln(\frac{R_2}{R_1}) \qquad (5)$$

The numerical value is obtained for present case as:

b=17.2cm; R_1=3.45 cm; R_2=7.75 cm

Qs_{max} = 0.0599 m^3/s or $Qs_{max} \approx$ 60 l/s

Whence, in range of discharge used (Qs≤ 22.5 l/s), no cavitation problems should arise in the siphon.

3.2.3 Expression for the head loss in the entire siphon

After the siphon spillway get primed and is running full, consider V_1, V_2 and V_3 the velocities of flow at entrance, crest and exit end respectively. Let h_L be the head loss in the entire siphon between entrance and the exit end. The details of the entrance conditions are given in (figure 4 and photography 3).

Since the cross-section areas at the crest and the exit end of the siphon duct are equal we can write

$$Q_S = AV_2 = AV_3 \qquad (6)$$

and

$$Q_S = A\sqrt{2g(H_{act} - h_L)} \qquad (7)$$

Thus equating both the values of Qs from equation 2 and 7, we get

$$h_L = (1-\mu^2)H_{act} \qquad (8)$$

The values of head loss in the entire siphon can be calculated according equation 8.

3.2.4 Capacity of evacuation of the siphon compared to weir

For limiting the fields where the capacity of evacuation of the siphon with Creager's profile, having Qs flows is better when it's compared to its similar weir which has Q_{weir} flows under the same operating conditions and the same head applied at the upstream level, we have represented ,on figure 6, the variation of Qs/Q_{dev} versus H/a ratio for siphon with total section and weir characterized by a width of the sill b = 17.2 cm. This representation makes possible to prove that the capacity of evacuation of siphon is better than weir if the value of the ratio H/a is lower than 3.50.

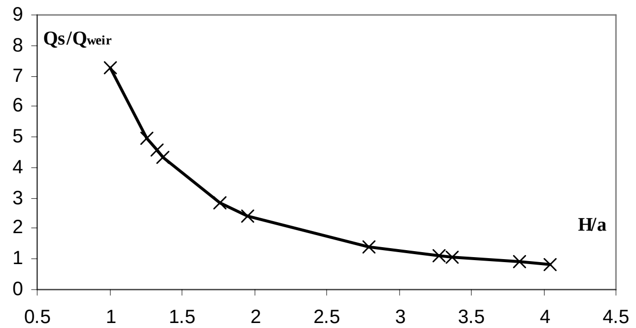


Figure 6: **Variation of Qs/Q_{weir} vs. H/a with total cross-section A = 73.96 cm^2**

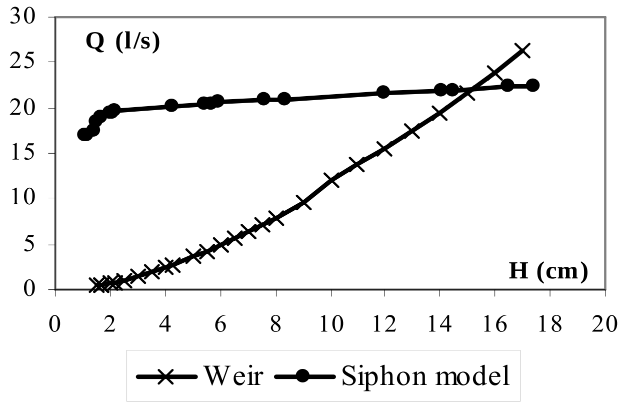


Figure 7: **Variation of Q_S (H) vs. Q_{weir} (H).**

Referring to figure 7 and considering the siphon model compared to weir for the low heads which do not ensure priming, we can announce that the average coefficient of discharge has a value $\mu = 0.729$ (table.2) that is lower than 0.791 which corresponds to siphon at its maximum capacity. he average coefficient of discharge of the weir for the same heads is certainly lower than 0.501 which corresponds to the design point. This value is m = 0.356 (table.1).

In these conditions the evacuation over the siphon is much better than the one ensured by the weir what confirms that siphons spillways have a great sensitivity at the rise of the water upstream level and the great discharge per linear meter of sill. The works are then related by the following relationship:

$$q_s = 2.7\,q_w + 0.1 \tag{9}$$

Knowing that:$q_{s:}$ specific flow of the siphon in ($l/s/m^2$), calculated by:

$$q_s = Q_s / b \tag{10}$$

$q_{w:}$ specific flow of the weir in ($l/s/m^2$), calculated by:

$$q_w = Q_w / b \tag{11}$$

Referring to figure 7 also and considering the siphon model at priming estate ($H \geq 4.3$cm) compared to weir for the wide range $1 \leq H/a \leq 4$ .Two types spillways are related by the following relationship:

$$\frac{Q_s}{Q_w} = 7\left(\frac{H}{a}\right)^{-1.57} \tag{12}$$

Equation12 was obtained with correlation coefficient R greater than 0.9999.

The limit inferior for the range of validity of equation 12 is given by the state of priming contrariwise the limit superior is dictated by the experimental laboratory conditions which cannot give beyond this value.

4 CONCLUSIONS

The capacity of discharge of weir and siphon spillway profiled in Creager type was theoretically reminded from and experimentally examined. The comparative study of models siphon spillway and weir made possible to define the fields according to value of the ratio H/a where the siphon is considered to be better in evacuation than the weir under the same conditions of flow and vice versa.

Finally, the study presents linear and non linear relationships between the flow over the weir considered as an over-flow spillway and the siphon spillway.

NOTATION

A — Total cross-section of evacuation (m^2)

a — vertical dimension of cross-section at crest and exit section of siphon (m)

a' — Flow depth on downstream (m)

b — width crest of weir and horizontal dimension of siphon cross-section (m)

E — the vertical distance from the crest of sill to the floor at the downstream apron (m)

g — gravitational acceleration (ms^{-2})

H — head above the crest (m)

H_d — design head (m)

H_{act} — actual head according conditions of flow at exit of siphon (m.)

m — Coefficient of discharge for weir (-)

Q_{weir} — Discharge of weir (m^3s^{-1})

q_{weir} — Specific discharge for weir ($m^3s^{-1}m^{-2}$)

Q_s — Discharge of Siphon spillway (m^3s^{-1})

q_s — Specific discharge for siphon ($m^3s^{-1}m^{-2}$)

μ — Coefficient of discharge for siphon (-)

REFERENCES

[1] Bessonneau, M., Theret, B. (1979). ″Automatic flap gate spillways and siphon spillways- Comparaison and advantages of both systems″, ICOLD, 13th congress, New Delhi, India.

[2] Bollrich, G. (2000). ″Technische Hydromechanik″, Band 1, 4. Auflage, Verlag fur Bauwesen Berlin. Germany.

[3] Chow,V.T. (1981). ″Open-Channel Hydraulics ″, International Student Edition, McGraw-Hill, 17th Printing, Tokyo,China.

[4] Creager, W.P. (1929). ″Engineering of Masonry Dams″. John Wiley & Sons, New York, USA.

[5] Drouhin, G., Mallet, Ch. and Pacquant. J. (1951). ″Contribution to the study of the rate of flow and the determination of flood discharge″. ICOLD, 4th congress, New Delhi, India.

[6] Govinda, Rao,N.S. (1962). ″Hydraulics″, Asia publishing house, India.

[7] Houichi, L., Ghassan, I., Achour, B. (2006).″ Experiments for the discharge capacity of the siphon spillway having the Creager-Ofitserov profile″. International journal of fluid mechanics research, Volume33, Number5, Begell house, Inc.,USA.

[8] Houichi, L., Achour, B. (2007).″ Flow depth computation at the toe of an overflow dam in steeply sloping case″. Dam Engineering, Volume XVII, Issue

4, Wilmington Media, UK.

[9] Houichi, L. (2007). ″ Ouvrages d'évacuation ″. Doctorate Thesis, University of Batna, Algeria.

[10] Ouamane, A. Lempérière, F. (2006). ″Nouvelle conception de déversoir pour l'accroissement de la capacité des retenues des barrages″. Colloque International sur la Protection et la préservation des ressources en eau. Blida. Algérie

[11] Roberson, J.A.,Cassidy, J.J., Chaudhry,M.H.(1998). ″Hydraulic engineering″, Second edition. John Wiley & Sons, New York, USA.

[12] Rousselier,M., Blanchet, P. (1951). ″Some realizations of siphons″, ICOLD, 4th congress, New Delhi, India.

[13] Vischer, D.L., Hager,W.H. (1997). ″Dam hydraulics″, John Wiley and Sons Ltd, England.

APPENDIX 1

Table 1. Experimental measurements: Weir with width sill equal to 17.2 cm

N°	H (cm)	Q_{weir} (l/s)	m (-)
1	1,5	0,46	0,33
2	1,65	0,54	0,34
3	1,7	0,57	0,34
4	2	0,75	0,35
5	2,2	0,82	0,35
6	2,5	1,10	0,366
7	3	1,51	0,380
8	3,5	1,96	0,393
9	4	2,46	0,404
10	4,3	2,78	0,410
11	5	3,60	0,423
12	5,5	4,24	0,431
13	6	4,96	0,443
14	6,5	5,62	0,445
15	7	6,42	0,455
16	7,5	7,13	0,456
17	8	7,91	0,459
18	9	9,59	0,466
19	10	12,04	0,501
20	11	13,68	0,492
21	12	15,46	0,488
22	13	17,48	0,489
23	14	19,50	0,489
24	15	21,63	0,489
25	16	23,87	0,490
26	17	26,22	0,491
27	18	28,67	0,493

APPENDIX 2

Table 2. Experimental measurements: Siphon model

N°	Qs (l/s)	H (cm)	E (cm)	a' (cm)	H_{act})cm(	A (cm^2)	μ (-)	Observation
1	16,90	1,1	70,3	13	58,4	73,96	0,675	No complete priming
2	17 ,00	1,2		13	58,5		0,678	
3	17,50	1,4		13	58,7		0,697	
4	18,50	1,5		13	58,8		0,736	
5	18,85	1,65		13	58,95		0,749	
6	18,90	1,7		13	59		0,751	
7	19,44	2		13	59,3		0,771	
8	19,50	2,1		13	59,4		0,772	
9	19,70	2,2		13	59,5		0,780	
10	20,20	4,3		13	61,6		0,786	Complete priming
11	20,40	5,4		13	62,7		0,786	
12	20,50	5,7		13	63		0,788	
13	20,60	5,9		13	63,2		0,791	
14	20,90	7,6		13	64,9		0,792	
15	21,00	8,4		13	65,7		0,791	
16	21,60	12		13	69,3		0,792	
17	21,90	14,1		13	71,4		0,791	
18	22,00	14,5		13	71,8		0,793	
19	22,30	16,5		13	73,8		0,792	
20	22,50	17,4		13	74,7		0,795	