THEORETICAL AND EXPERIMENTAL STUDY OF THE HYDRAULIC JUMP IN U-SHAPED CHANNEL WITH POSITIVE SLOPE

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RESUME

Le présent article propose une étude théorique du ressaut hydraulique dans un canal profilé en «U » à pente positive. Une relation fonctionnelle exprimant le nombre de Froude de l'écoulement incident en fonction des hauteurs relatives amont et aval, la longueur relative du ressaut et l'angle d'inclinaison du canal par rapport à l'horizontal. Une analyse expérimentale est également proposée afin de corriger la relation théorique proposée. A cet effet, six pentes positives sont testées.

MOTS CLES: Ressaut hydraulique, canal profilé en "U", pente positive, canaux ouverts.

ABSTRACT

This paper presents both theoretical and experimental study of the hydraulic jump in a sloped U–shaped channel. A theoretical relation expressing the inflow Froude number as function of the upstream and downstream relative heights, the relative length of the jump and the channel slope. An experimental analysis is also proposed in order to correct the proposed relationship. For this purpose, six positive slopes are tested.

KEYWORDS: Hydraulic jump, U–shaped channel, positive slope, opens channels.

1 INTRODUCTION

Hydraulic jump is the most convenient and least expensive uses in a few hydraulic works to dissipate the energy. This jump is formed during the abrupt transition from a torrential flow to a river flow. During this transition a standing wave is formed and the energy is then dissipated by turbulence. The hydraulic jump has been studied by a large number of researchers, including Bradley and Peterka (1957), Hager and Bretz (1987), Hager (1992) and Ead and Rajaratnam (2002) who have studied the hydraulic jump in horizontal rectangular channel. Also, the hydraulic jump controlled by sill in U- shaped channel has been studied by Achour and Debabache. However, the first detailed study on the hydraulic jump in a rectangular channel to positive slope was that of Bakhmeteff and Matzke (1938) who have examined the surface profile, the length of the jump and the distribution of speeds. Kindsvater (1944) classifies the sloped hydraulic jump according to the position of the upstream of the jump in relation to the end of the slope, into four types: A-jump for which the toe of the jump coincides with the downstream extremity of the slope, B-jump for which the toe of the jump is between the A-jump and the C-jump ;C-jump for which the end of the jump roller coincides with the downstream extremity of the slope, and D-jump for which the jump roller appears completely in the sloped portion. The D-jump was analyzed by Wilson (1970), Ohatsi and al (1973), Rajaratnam and Murahari (1974), Mikhalev and Hoang (1976). Debabeche et al. (2009) have studied the hydraulic jump with positive slope in triangular channel. Cherhabil (2010) subsequently developed, in his doctoral thesis, the hydraulic jump with positive slope in two profiles of prismatic channels: the triangular channel and the U-shaped channel.

This paper offers a theoretical and experimental study of the hydraulic jump evolving in U-shaped channel with positive slope. The main objective is to show that the latter is governed by five parameters that can be express in the form of a functional relations $f(F1,y1,y2,\lambda j,\alpha)= 0$, F1 is the inflow Froude number, (y1,y2) are respectively the relating upstream and downstream sequent depht of jump, λj the relative length of jump and α is the slope of the channel.

The configuration of the jump adopted for this paper corresponds to the D-jump (according to the classification of Kindsvater, 1944). A wide range of values of the Froude number of incident F1 (practice range) has been considered in order to validate the proposed relations (F1 between 1 and 28).

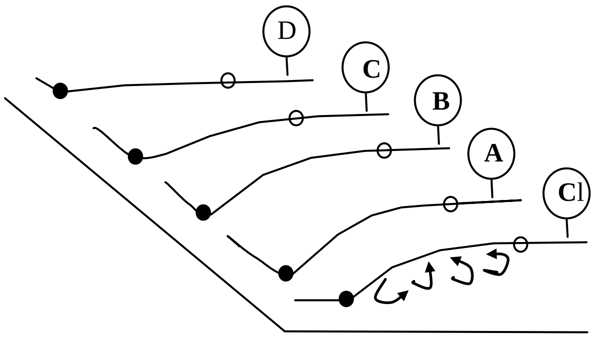

Figure 01: Classification of ledges slanted according to Kindsvater (1944)

A-jump for which the toe of the jump coincides with the downstream extremity of the slope, B-jump for which the toe of the jump is between the A-jump and the C-jump ;C-jump for which the end of the jump roller coincides with the downstream extremity of the slope, and D-jump for which the jump roller appears completely in the sloped portion.type Cl: horizontal hydraulic jump. (●) the beginning of the hydraulic jump; (○) position of the end of the roller.

The k coefficient represents the ratio between the actual volume and the approached volume of jump. In order to estimate the value of this correction factor "k" of the volume of jump, we had recourse to testing hydraulic jump in a reduced model to U-shaped channel with positive slope. An experimental analysis of the theoretical relationship obtained will be in a second time the subject of this study. Several generalized relations were obtained expressing the relating downstream sequent depht y2 as a function of the Froude number of incident F1 and of the inclinaison (α) with regard to the horizontal channel. To do this, six positive slopes are tested: α = 0.000 ; 0.5729, 1.1457, 1.7183, 2.2906, 2.8624 ; respectively corresponding to the values of tang (α) = 0.00; 0.01; 0.02; 0.03; 0.04 and 0.05 .

2 THEORY

The hydraulic jump is governed by the momentum equation applied between its initial and final sections.

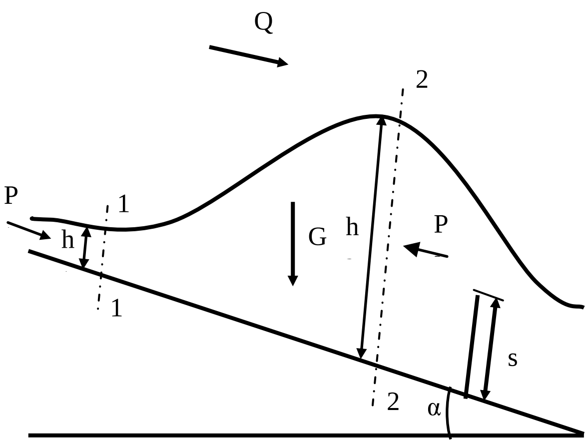

Figure 02: Hydraulic jump in a U-shaped channel to positive slope

The momentum equation between the sections 1 and 2 is written:

$$\rho Q\, v_1 + P_1 + G \sin\alpha = \rho Q\, v_2 + P_2 \qquad (1)$$

where ρ is the density of water, Q is the discharge, P1 is the force of pressure applied to the section1-1 it is calculated in the circular part of the channel, P2 is the force of pressure applied to the section 2-2, it is calculated in the U-profile part , ν1 and ν2 are the average speeds of the flow, G (G = $\overline{\omega}$ V) is the weight of the water applied to the center of gravity of the water volume of the jump ,V is the volume of water between the sections 1 and 2, And $\overline{\omega}$ is the specific weight of the water. α is the positive tilt of the channel in relation to the horizontal. The following assumptions must be taken into account in the sections (1) and (2) : The distribution of the pressure in the initial and final sections of the jump, is hydrostatic and the losses of loads by friction are negligible. The weight G of the jump and the forces of pressures P1 and P2 are expressed in applying the laws of the hydrostatic as follows:

$$P_1 = \left(\varpi\left[\left(\frac{D^3}{12A_1}\right)\sin^3\theta_1 - \left(\frac{D}{2}\right)\cos\theta_1\right]\cos\alpha \right).\left(\frac{D^2}{4}\left(\theta_1 - \sin\theta_1\cos\theta_1\right)\right) \qquad (2)$$

$$P_2 = \left[\frac{D}{2}\left[\left(y_2 - \frac{1}{2}\right)\left(y_2 + \frac{1}{2} - 2C_0\right) + \frac{1}{6}\right] / \left(y_2 - C_0\right)\right]\cos\alpha.\left(h_2 D + \frac{D^2}{8}(\pi - 4)\right) \qquad (3)$$

Where: A1and A2 are respectively the areas of the wet sections initial and final:

$$A_1 = \frac{D^2}{4}(\theta_1 - \sin\theta_1 \cos\theta_1) \quad (4);$$

$$A_2 = h_2 D + \frac{D^2}{8}(\pi - 4) \quad (5)$$

$\overline{h}_1$, $\overline{h}_2$ respectively, represent the distance between the centers of gravity of the cross-sections 1 and 2 and the upper face of the flow (free surface of the flow) :

$$\overline{h_1} = \left[\left(\frac{D^3}{12A_1}\right)\sin^3\theta_1 - \left(\frac{D}{2}\right)\cos\theta_1\right]\cos\alpha \qquad (6)$$

$$\overline{h_2} = \left[\frac{D}{2}\left[\left(y_2 - \frac{1}{2}\right)\left(y_2 + \frac{1}{2} - 2C_0\right) + \frac{1}{6}\right] / (y_2 - C_0)\right]\cos\alpha \qquad (7)$$

h1 and h2 are upstream and downstream relating sequent depht, D is the width of the channel, it is the diameter of the half circular part of the channel. The volume V representing the hydraulic jump is not straight because of turbulence at the surface and:

$$C_0 = \left(1 - \frac{\pi}{4}\right)/2$$

In order to find the value of the actual volume, it is necessary to multiply this volume by a coefficient "K" representing the ratio between the real volume and the approached volume according to the figure (4). This coefficient is determined by experimental data follows:

The first case:, Y2≥1/2:

$$V = \frac{D^2 L_j}{2}\left(\frac{\overline{\theta_1}}{4} + (y_2 - C_0)\right) \qquad (8)$$

L_j : Represents the length of the jump;

$\overline{\theta_1}$ =($\theta_1 - \sin\theta_1 \cos\theta_1$)

avec:

$$\theta_1 = \cos^{-1}\left(1 - \frac{2h_1}{D}\right)$$

by considering the equations: (2) and (3), the equation (1) becomes as follows:

$$\frac{Q^2}{g\frac{D^2}{4}\overline{\theta_1}} + \left(\frac{D^3}{12\frac{D^2}{4}\overline{\theta_1}}\sin^3\theta_1 - \frac{D}{2}\cos\theta_1\right)\cos\frac{D^2}{4}\overline{\theta_1} + k\frac{D^2 Lj}{2}\left(\frac{\overline{\theta_1}}{4} + y_2 - C_0\right)Sin\alpha =$$

$$\frac{Q^2}{gD^2(y_2 - C_0)} + \left[\frac{\left[\frac{D}{2}\left(y_2 - \frac{1}{2}\right)\left(y_2 + \frac{1}{2} - 2C_0\right) + \frac{1}{6}\right]}{y_2 - C_0}\right]\cos\alpha D^2(y_2 - C_0) \qquad (9)$$

The relative discharge in a U-shaped section with positive slope for the case: y2≥ 1/2 is written:

$$q=\left[\frac{\left[\frac{2}{3}\left(1-Sin^{3}\theta_{1}\right)+\overline{\theta_{1}}Cos\theta_{1}+\left(2y_{2}-1\right)\left(2y_{2}+1-4C_{0}\right)\right]\cos\alpha-4k\,\frac{Lj}{D}\left(\frac{\overline{\theta_{1}}}{4}+y_{2}-C_{0}\right)Sin\alpha}{\left(\frac{32}{\overline{\theta}1}-\frac{8}{y_{2}-C_{0}}\right)}\right]^{1/2} \quad (10)$$

The inflow Froude number F1 of U-shaped section is written:

$$IF_{1}^{2}=q^{2}\,\frac{64Sin\theta_{1}}{\overline{\theta}_{1}^{3}} \quad (8)$$

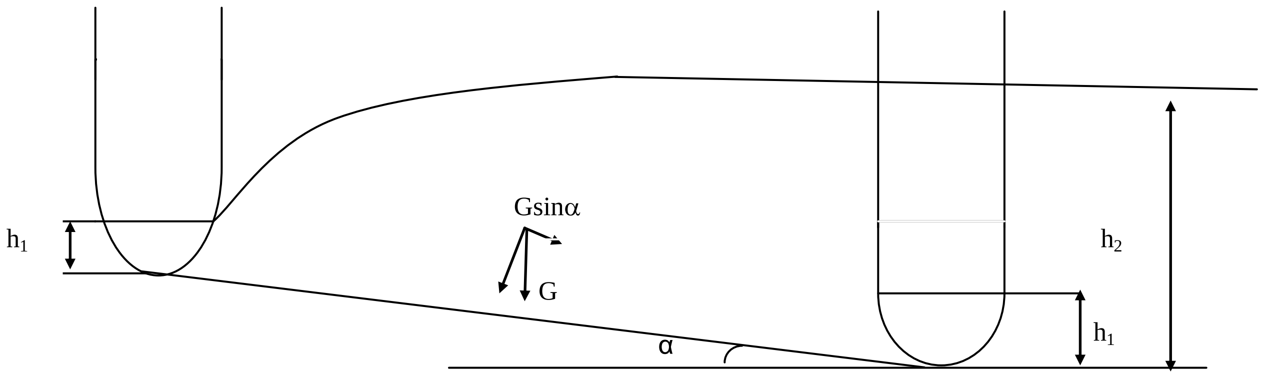

Figure 03: Geometric representation of the hydraulic jump moving in U-shaped channel with positive slope

Figure 04: geometric representation of the flow depths $\overline{h}_1, \overline{h}_2$

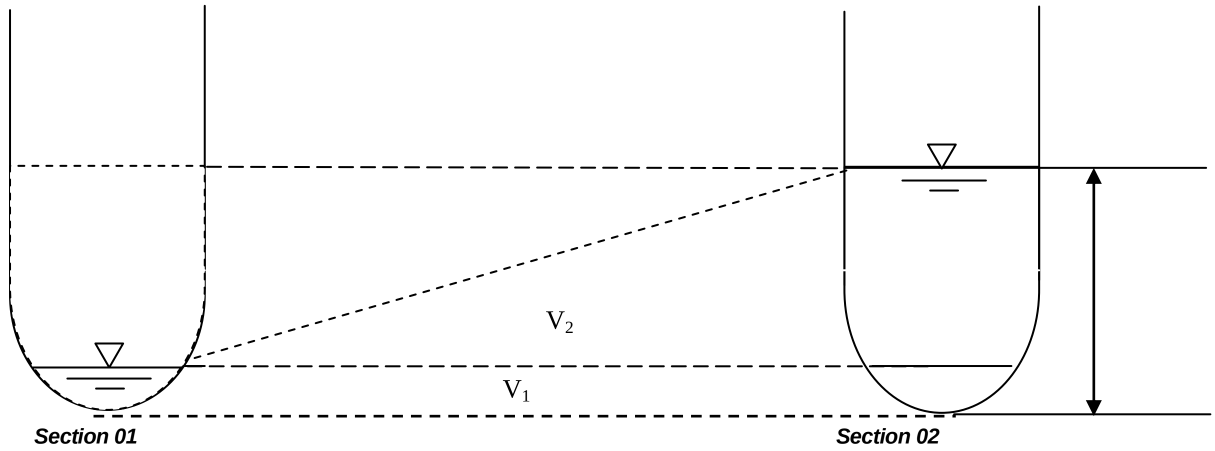

Figure 04: The geometrical shape of volume V of the jump

by considering equation (10) and

$$IF_1^2 = q^2 \frac{64 Sin\theta_1}{\overline{\theta_1^3}},$$

The inflow Froude number in U-shaped section with positive slope for the case $Y_2 \geq 1/2$ is written as follows:

$$IF_1 = \left[\left(\frac{64 Sin\theta_1}{\overline{\theta_1^3}} \right) \left(\frac{\left[\frac{2}{3}\left(1 - Sin^3\theta_1\right) + \overline{\theta_1} Cos\theta_1 + (2y_2 - 1)(2y_2 + 1 - 4C_0) \right] \cos\alpha - 4k \frac{Lj}{D} \left(\frac{\overline{\theta_1}}{4} + y_2 - C_0 \right) Sin\alpha}{\frac{32}{\overline{\theta 1}} - \frac{8}{y_2 - C_0}} \right) \right]^{\frac{1}{2}} \quad (12)$$

The second case:,Y2< 1/2:

$$V = \frac{D^2 \, L_j \, (\overline{\theta}_1 + \overline{\theta}_2)}{8} \quad (13)$$

With:

$$\overline{\theta_2} = (\theta_2 - Sin\theta_2 Cos\theta_2) \quad (14)$$

$$\theta_2 = cos^{-1}\left(1 - \frac{2h_2}{D}\right)$$

We have for this second case:

$$P_1 = \left(\varpi \left[\left(\frac{D^3}{12A_1} \right) \sin^3\theta_1 - \left(\frac{D}{2} \right) \cos\theta_1 \right] \cos\alpha \right) . \frac{D^2}{4} \left(\overline{\theta_1} \right) \quad (15)$$

$$P_2 = \left(\varpi \left[\left(\frac{D^3}{12A_2} \right) \sin^3\theta_1 - \left(\frac{D}{2} \right) \cos\theta_1 \right] \cos\alpha \right) . \frac{D^2}{4} \left(\overline{\theta_2} \right) \quad (16)$$

By considering eq: (15) and (16), the equation (1) can be written as:

$$32q^2\left(\frac{1}{\overline{\theta}_1}-\frac{1}{\overline{\theta}_2}\right)=$$
$$\left[\frac{2}{3}\left(Sin^3\theta_2-Sin^3\theta_1\right)+\left(\overline{\theta}_1 Cos\theta_1-\overline{\theta}_2 Cos\theta_2\right)\right]\cos\alpha-\frac{kLj}{D}\left(\overline{\theta}_1+\overline{\theta}_2\right)Sin\alpha \qquad (17)$$

The relative discharge in a U-shaped section with positive slope for the case: Y2< ½, is written as :

$$q=\left[\frac{\left[\frac{2}{3}\left(Sin^3\theta_2-Sin^3\theta_1\right)+\left(\overline{\theta}_1 Cos\theta_1-\overline{\theta}_2 Cos\theta_2\right)\right]\cos\alpha-\frac{kLj}{D}\left(\overline{\theta}_1+\overline{\theta}_2\right)Sin\alpha}{32\left(\frac{1}{\overline{\theta}_1}-\frac{1}{\overline{\theta}_2}\right)}\right]^{\frac{1}{2}} \qquad (18)$$

By considering (18) and, the inflow Froude number in a U-shaped section with positive slope for the case,Y2 < 1/2 is written as follows:

$$IF_1=$$
$$\left[\left(\frac{\left[-\frac{2}{3}\left(Sin^3\theta_1-Sin^3\theta_2\right)+\left(\overline{\theta}_1 Cos\theta_1-\overline{\theta}_2 Cos\theta_2\right)\right]\cos\alpha-\frac{kLj}{D}\left(\overline{\theta}_1+\overline{\theta}_2\right)Sin\alpha}{32\left(\frac{1}{\overline{\theta}_1}-\frac{1}{\overline{\theta}_2}\right)}\right)\times\frac{64Sin\theta_1}{\overline{\theta}_1^3}\right]^{\frac{1}{2}} \qquad (19)$$

For the determination of the relation of the correction factor k in equations (12) and (19), the proposed theoretical approach will be analyzed using experimental data.

3 EXPERIMENTAL STUDY

The experiment was conducted in a U-shaped channel of 6m long, with a diameter D = 0.245 m at the laboratory LARGHYDE of civil and hydraulic department of university of Biskra. Incidental flow is caused by a series of five converging (fig.5) their heights show the initial heights h1 (cm): 1.1 ; 2.0 ; 3.4 ; 4.4 and 6 ; corresponding to the values of the upstream relating sequent depht y1 =h1/D equal respectively to: 0.0449 ; 0.0816 ; 0.1388 ; 0.1796 ; 0.2449 . For every height h1 chosen, six positions of the slope are tested, so that the tangent of the inclinaison α with regard to the horizontal, takes the flowing values: 0,000; 0,5729; 1,1457; 1,7183; 2,2906; 2,8624; corresponding respectively to the flowing values of tg (α): 0, 1%, 2%, 3%, 4% and 5%. Sills with a thickness of 2 mm and of different heights s have been manufactured in sheet and tested, in order to observe their influence on the control of the jump, their heights are in the interval: 3< s(cm) < 40. A large range of the inflow Froude number was obtained (1< IF1 < 28).

Figure 05: a) box support ***b) series of five converging***

4 DETERMATION OF THE CORRECTION FACTOR K

From the equations (10) and (12), we can obtain the following expressions of the correction factor k:

For, Y2 ≥1/2

$$k = \frac{\left[\frac{2}{3}\left(1 - Sin^3\theta_1\right) + \overline{\theta_1} Cos\theta_1 + (2y_2 - 1)(2y_2 + 1 - 4C_0)\right]\cos\alpha - \frac{IF_1^2}{64Sin\theta_1}\left(32\overline{\theta_1^2} - \frac{8\overline{\theta_1^3}}{y_2 - C_0}\right)}{4\frac{Lj}{D}\left(\frac{\overline{\theta_1}}{4} + y_2 - C_0\right)Sin\alpha} \quad (20)$$

From the equations (18) and (19), we can obtain the following expressions of the correction factor k:

For, Y2 >1/2

$$k = \frac{\left[\frac{2}{3}\left(Sin^3\theta_2 + Sin^3\theta_1\right) + \left(\overline{\theta_1} Cos\theta_1 - \overline{\theta_2} Cos\theta_2\right)\right]\cos\alpha - \frac{IF_1^2}{2Sin\theta_1}\left(\overline{\theta_1^2} - \frac{\overline{\theta_1^3}}{\overline{\theta_2}}\right)}{\frac{Lj}{D}\left(\overline{\theta_1} + \overline{\theta_2}\right)Sin\alpha} \quad (21)$$

The value of the correction factor k, given as the ratio of the real volume and the approached volume of the jump is determined by regression, using the experimental data, and its value is k=1,13 ±0.5 ; using this average value we correcte the theoretical equation of the Froude number. This coefficient is a constant and does not depend on the slope of the channel.By knowing the value of k, equations (12) and (19) become:

$$F_1 = \left[\left(\frac{64Sin\theta_1}{\overline{\theta_1^3}}\right) \times \left(\frac{\left[\frac{2}{3}\left(1 - Sin^3\theta_1\right) + \overline{\theta_1} Cos\theta_1 + (2y_2 - 1)(2y_2 + 1 - 4C_0)\right]\cos\alpha - 4.52\frac{L_j}{D}\left(\frac{\overline{\theta_1}}{4} + y_2 - C_0\right)\sin\alpha}{\frac{32}{\overline{\theta 1}} - \frac{8}{y_2 - C_0}}\right)\right]^{1/2} \quad (22)$$

5 EXPERIMENTAL VARIATION OF THE SEQUENT DEPTHS RATIO

The values of the inflow Froude number $F1_{thcor}$ are those calculated by the equations (22) and (23).

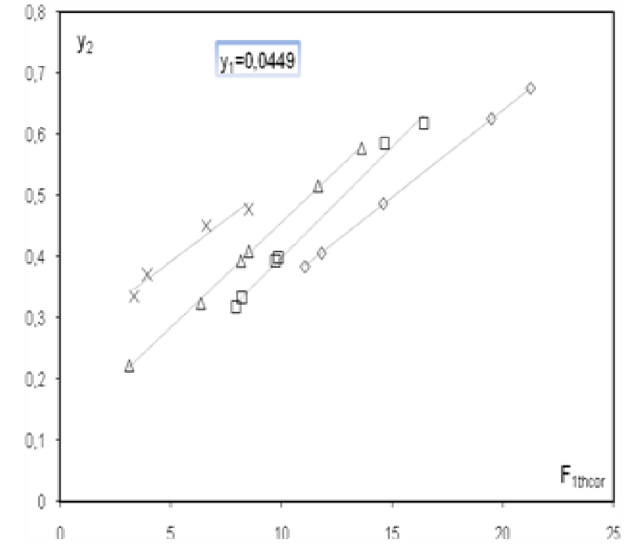

Figure 06: ***Variation in the final relating height y2 as a function of the inflow Froude number F1 for the hydraulic jump with positive slope according to the relations (22) and (23) for the initial relating height y1 =0,0449, for four positive slopes (%): (◊) 0 ; (□) 1 ; (∆) 2 ; (x) 3***

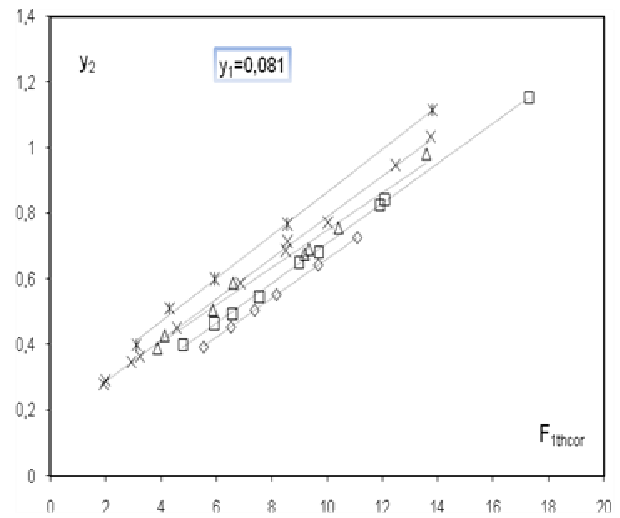

Figure 07: ***Variation of the final relating height y2 as a function of the inflow Froude number F1 for the hydraulic jump with positive slope, according to the equations (22) and (23) for the initial relating height y1 = 0.081 ,for five positive slopes (%): (◊) 0 ; (□) 1 ; (∆) 2 ;(x) 3; (*) 4***

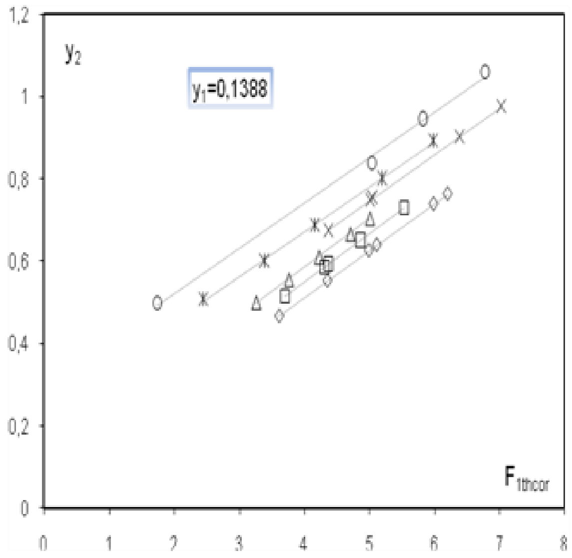

Figure 08: ***Variation of the final relating height y2 as a function of the inflow Froude number F1 for the hydraulic jump with positive slope according to the relations (22) and (23) for the initial relating height y1 = 0.1388 , for six positive slopes (%) : (◊) 0 ; (□) 1 ; (∆) 2 ;(x) 3; (*) 4 ; (○)5***

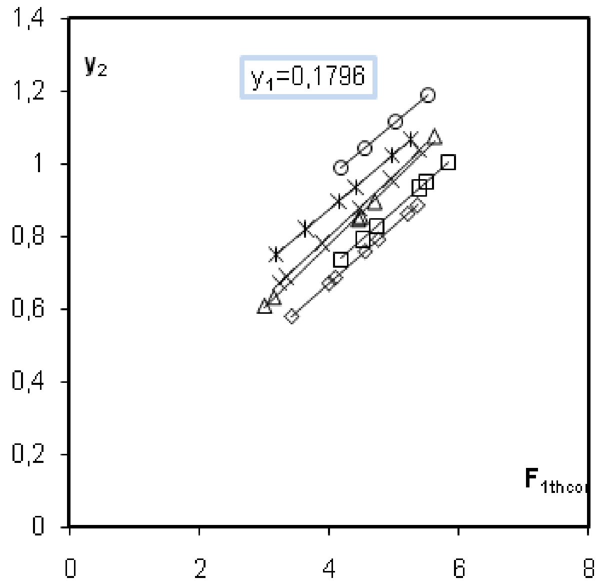

Figure 09: ***Variation of the final relating height y2 as a function of the inflow Froude number F1 for the hydraulic jump with positive slope according to the relations (22) and (23) for the initial relating height y1 = 0.1796 , for six positive slopes (%): (◊) 0 ; (□) 1 ; (∆) 2 and (x) 3; (*) 4 ; (○)5***

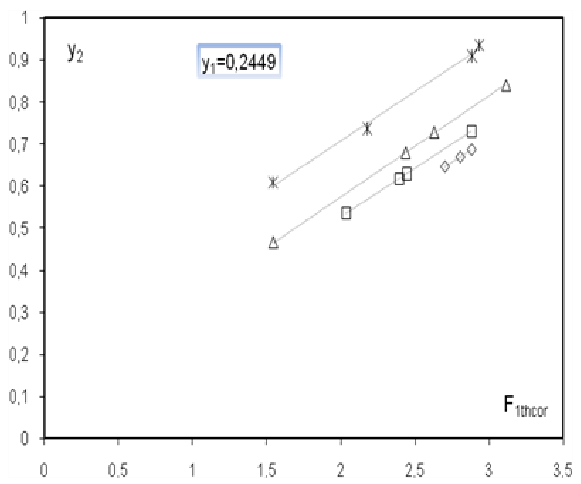

Figure10: Variation of the final relating height y2 as a function of the inflow Froude number F1 for the hydraulic jump with positive slope according to the equations (22) and (23) for the initial relating height y1 = 0.2449 ,for six positive slopes distinct (%) : (◊) 0 ; (□)1; (Δ) 2 and (x) 3

Because of small difference between every two successive slope, they acquired in some cases, graphs which almost become confused. One notices for all the figures, which for the same inflow Froude number F1, y_2 the final relating height augments proportionately with the growth of the slope.

5.1 Explicit relation of the final relating height y_2(F_1, i)

In addition, the general relations (22) and (23) are in a form implicit screw to screw of the final relating height y_2; and their application need therefore the use of an iterative process. The adjustment of the graphs shown in the figures (5, 6, 7, 8, 9) will make these relations, explicit concerning y_2.

Figures (5, 6, 7, 8 and 9) show that for the same inflow Froude number F1, the final height h2 increases with the growth of the inclination of the channel "i". Using the experimental data, the regression analyzes lead us to obtain the adjustment equations:

y_2 = 0,0319F_1+ 0,0132 e103,05i , pour $0 \leq i=tg(\alpha) \leq 0{,}05$; $2 < F_1 < 21$; y_1 =0 ;0449 (24)

y_2= 0,05802 F_1+ 0,0734 e33, 465i , pour $0 \leq i=tg(\alpha) \leq 0{,}05$; $1 < F_1 < 7$; y_1 =0,081 (25)

y_2 = 0,11318 F_1+ 0,0575 e35,996 i pour $0 \leq i=tg(\alpha) \leq 0{,}05$; $1{,}6<F_1 <7$; y1 =0,1388 (26)

y_2 = 0,1587 F_1 + 0,0418 e42,733i, pour $0 \leq i=tg(\alpha) \leq 0{,}05$; $3 < F_1< 6$; y_1 =0,1796 (27)

y_2 = 0,1886 F_1 + 0,043 e44,13i , pour $0 \leq i=tg(\alpha) \leq 0{,}05$; $1{,}5< F_1<3{,}2$;y_1 =0,2449 (28)

The equations (24) , (25) , (26) , (27) , (28) give us a simple means for the determination of the relative height final y_2 using the Froude number F_1 and the inclination of the channel i.

this consideration has led us to propose to replace the relations (22) and (23) by the explicit relations approximations (24),) , (25) , (26) , (27) , (28) allowing the easy determination of the relative height final y_2 as a function of the inflow Froude number F_1 and of the angle of slope of channel α, and this for each corresponding relative height y_1.

6 CONCLUSION

The hydraulic jump evolving in a U-shaped channel with positive slope has been theoretically and experimentally studied. The configuration of the jump adopted in this study corresponds to the D-jump. Functional relations $F_1= f(y_1,y_2, \lambda_j,\alpha)= 0$, expressing the inflow Froude number F_1 as a function to the relating upstream and downstream sequent depht, the relative height of jump and the slope of the channel, have been obtained. The k coefficient representing the report between the actual volume and the approached volume of the jump is determined by regression using the experimental data and its value is k= 1.13± 0.5. However the approached relations a obtained appear under implicit form screw-to-bolt of the downstream relating sequent depht y_2, and explicit relation are proposed. These relations allow particularly to determine the downstream relating sequent depht l y2, by knowing the inflow Froude number F_1 and the slope of the channel.

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LIST OF SYMBOLS

D Diameter of the channel [m]

F_1 inflow Froude number [-]

P_1 Force of pressure on the wet section to the upstream of the jump [N]

P_2 Force of pressure on the wet section downstream of the jump [N]

g acceleration of gravity [$m.s^{-2}$]

h_1 upstream sequent depht [m]

h_2 downstream sequent depht [m]

i channel slope (i=tg(α))

k correction coefficient of jump volume [-]

Lj Length of jump [m]

Q flow discharge [$m^3.s^{-1}$]

V volume of water between the initial and final sections [m^3]

v_1 average speed in the wet section initial [$m.s^{-1}$]

v_2 average speed in the wet section final [$m.s^{-1}$]

α angle of inclinaison of the channel with regard to the horizontal [rad]

λ_j relative length of jump (λj = Lj / h1) [-]

$\overline{\omega}$ specific weight of the liquid [$N. m^{-3}$]

ρ density of the liquid [$kg.m^{-3}$]

EXPERIMENTAL MEASUREMENTS HAVING BEEN USED FOR THE TRACING OF THE GRAPH OF Y_2 ACCORDING TO $F1_{TH}$

$y_1 = 0.0449$: 1^{st} *opning*

Table 01:

slope 0%		slope 1%		slope 2%		slope 3%	
F_{th}	y_2	F_{th}	y_2	F_{th}	y_2	F_{th}	y_2
11,060	*0.383*	*7,932*	*0,317*	*2,959*	*0.221*		*0,242*
11,809	*0.405*	*8,158*	*0,332*	*6,221*	*0.323*	*5,943*	*0,380*
14,598	*0.486*	*9,663*	*0,391*	*8,003*	*0.393*	*2,788*	*0,334*
19,478	*0.624*	*9,778*	*0,397*	*8,344*	*0.408*	*3,334*	*0,370*
21,252	*0.674*	*14,490*	*0,584*	*11,447*	*0.515*	*6,129*	*0,451*
		16,285	*0,616*	*13,396*	*0.577*	*8,169*	*0,477*

$y_1 = 0.0816 \quad 2^{rd}\ opning$

Table0 2:

slope 0%		slope 1%		slope 2%		slope 3%		slope 4%		slope 5%	
$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2
5,536	*0,393*		*0,400*	*3,779*	*0,390*	*1,825*	*0,281*		*0,204*		*0,291*
6,527	*0,453*		*0,463*	*4,023*	*0,428*	*1,876*	*0,292*	*2,964*	*0,398*		*0,493*
7,370	*0,504*		*0,493*	*5,801*	*0,506*	*2,824*	*0,346*		*0,508*		*0,541*
8,167	*0,552*		*0,546*	*6,500*	*0,588*	*3,136*	*0,365*	*5,765*	*0,598*	*4,421*	*0,672*
9,686	*0,642*		*0,649*	*9,136*	*0,675*	*4,481*	*0,451*	*8,393*	*0,765*	*6,282*	*0,803*
11,104	*0,762*		*0,681*	*9,293*	*0,690*	*6,788*	*0,586*	*13,591*	*1,112*	*11,246*	*0,978*
			0,824	*10,363*	*0,755*	*8,423*	*0,687*				
			0,842	*13,502*	*0,979*	*8,465*	*0,715*				
			1,151			*9,948*	*0,771*				
						12,371	*0,946*				
						13,623	*1,032*				

$y_1 = 0.1388 \quad 3^{rd}\ opning$

Table 03:

slope 0%		slope 1%		slope 2%		slope 3%		slope 4%		slope 5%	
$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2
3,614	*0,466*	*1,904*	*0,300*	*3,105*	*0,484*	*2,205*	*0,441*		*0,263*		*0,254*
4,353	*0,552*	*3,270*	*0,466*	*3,231*	*0,501*	*4,314*	*0,675*	*2,358*	*0,507*		*0,307*
4,990	*0,625*	*3,691*	*0,515*	*3,732*	*0,556*	*4,952*	*0,748*	*3,306*	*0,600*	*1,582*	*0,500*
5,112	*0,639*	*4,295*	*0,585*	*4,193*	*0,611*	*4,986*	*0,754*	*4,084*	*0,687*	*4,940*	*0,839*
5,983	*0,738*	*4,351*	*0,593*	*4,671*	*0,667*	*6,329*	*0,902*	*5,124*	*0,800*	*5,721*	*0,946*
6,199	*0,763*	*4,842*	*0,651*	*4,967*	*0,705*	*6,967*	*0,975*	*5,908*	*0,891*	*6,670*	*1,06*

		5,508	*0,729*								

$y_1 = 0.1795$ 4^{th} *opning*

Table 04:

slope 0%		slope 1%		slope 2%		slope 3%		slope 4%		slope 5%	
$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2
5,220	*0,862*	*4,184*	*0,738*	*3,009*	*0,609*	*3,238*	*0,674*	*3,180*	*0,748*	*4,181*	*0,987*
4,557	*0,759*	*4,519*	*0,793*	*3,154*	*0,633*	*3,340*	*0,691*	*3,635*	*0,818*	*4,541*	*1,042*
4,764	*0,791*	*4,737*	*0,830*	*4,496*	*0,854*	*3,894*	*0,782*	*4,135*	*0,894*	*5,018*	*1,116*
4,095	*0,687*	*5,395*	*0,932*	*4,709*	*0,895*	*4,475*	*0,877*	*4,400*	*0,934*	*5,515*	*1,189*
3,993	*0,671*	*5,493*	*0,948*	*5,631*	*1,074*	*4,968*	*0,955*	*4,970*	*1,022*		
3,416	*0,580*	*5,835*	*1,001*	*4,459*	*0,847*	*5,402*	*1,034*	*5,248*	*1,064*		
5,370	*0,886*										

$y_1 = 0.2449$ 5^{th} *opning*

Tableau 05:

slope 1%		slope 2%		slope 3%		slope 4%	
$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2	$F_{1thé}$	y_2
2,871	*0,729*	*1,529*	*0,466*	*2,911*	*0,854*	*1,487*	*0,608*
2,385	*0,615*	*2,418*	*0,68*	*2,802*	*0,843*	*2,132*	*0,736*
2,437	*0,628*	*2,609*	*0,728*	*3,172*	*0,928*	*2,838*	*0,910*
2,028	*0,535*	*3,092*	*0,840*			*2,882*	*0,935*