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Research Article

STUDY OF THE EXPERIMENTAL APPROACH OF PROFITABILITY AND THE GENERALIZED PROFILE OF THE HYDRAULIC SPRING Evolving IN A RECTANGULAR CHANNEL OF COMPOSITE SECTION WITH A ROUGH MINOR BED

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ABSTRACT

The objective of this study is to carry out an experimental analysis of the phenomenon of hydraulic jump occurring in a canal of rectangular section composed of a rough minor bed. Its main goal is to study how the roughness of the channel bottom influences the characteristics of the hydraulic jump, in particular its efficiency and its generalized profile. . To better illustrate this impact, the experimental results are presented in the form of graphs. These graphs highlight the variation in efficiency as a function of the Froude number of the incident flow for the two bed configurations (minor and major). Likewise, they show the variation of the Y ratio as a function of the X ratio, where Y and X are dimensionless variables.

Key words: hydraulic jump; compound rectangular channel; rough minor bed; jump yield; generalized profile of the jump.

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1. INTRODUCTION

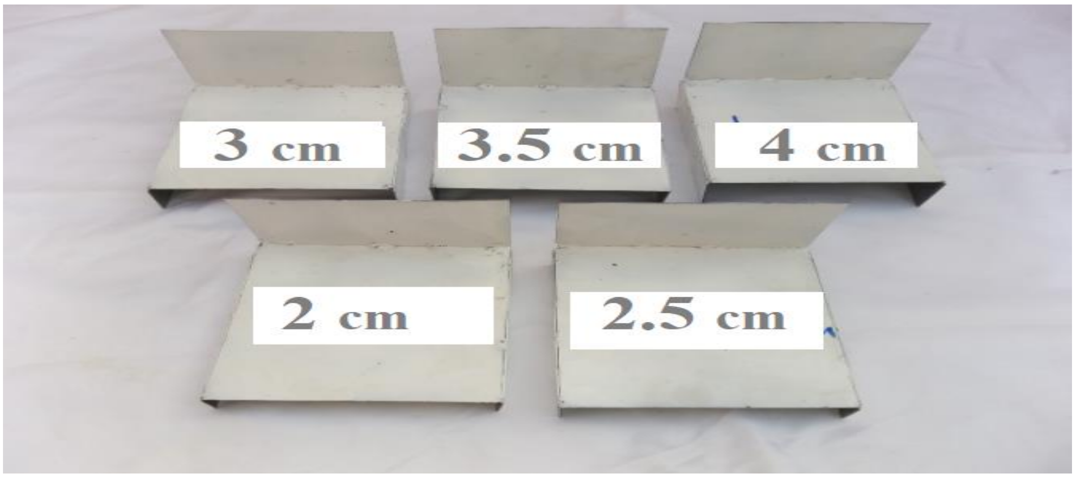
The phenomenon of hydraulic jump is common in free surface flows, occurring in natural watercourses as well as in artificial channels and industrial applications [11; 18]. The hydraulic jump is characterized by intense turbulent flow accompanied by the formation of large-scale turbulence, surface ridges, sprays, as well as energy dissipation [7,5]. Hydraulic jump occurs when the flow regime changes from supercritical to subcritical, leading to a noticeable dissipation of energy and an increase in flow depth. Its main role is to dissipate excess energy from the water downstream of hydraulic structures such as weirs and sluice gates. Left unchecked, this excess energy can cause damage to the banks and river bed [21,9]. Other authors [12,26,23,20], [16,1,13,24] studied the hydraulic jump on rough beds for the first time. Further research was carried out by [18,9,14], who examined the properties of average turbulent motion in a channel with an artificially rough surface. Other researchers [15,19,12,6] examined the impacts of uniform artificial roughness on the hydraulic jump phenomenon. Little research has focused on the phenomenon of the jump which forms in a horizontal compound rectangular channel with a smooth bed, but it has been analyzed by [17,5,25]. Our study mainly aims to propose theoretical approaches and to conduct experiments to examine the hydraulic jump. This manifests itself in a rectangular channel composed of a rough minor bed. We introduced roughness by using plastic pellets uniformly and evenly. The experiments were carried out using five different roughness values (ε = 06 mm; ε = 08 mm; ε = 10 mm and ε = 12 mm). The results demonstrated that roughness has a notable effect on energy loss as well as depth h2.

1.1. Problem position

Changing the parameters upstream (flow, heights, Froude number, etc.) and downstream (the type of obstacle, its position, its height, etc.) [8], can lead to the creation of various forms of jump. The term "classic jump" refers to the formation of a specific configuration in a rectangular channel having little or no slope with an absence of downstream obstruction [2]. It is also called "controlled" when its creation depends on the presence of an obstacle installed downstream of the flow [4]. It is called "forced" when it develops on both sides of the obstacle [8]. The phenomenon of hydraulic jump can manifest itself in channels of prismatic or non-prismatic shape, whether their bottom is smooth [3] or rough [22]. Our study concerns a hydraulic jump controlled by a thin-walled threshold which develops in a rectangular channel of compound section with a rough minor bed, and which includes different openings h1 (as illustrated in photograph 01). We carried out several experimental measurements for a fixed initial height h1, by varying the threshold heights and the relative roughnesses ε/b.

The hydraulic and geometric parameters studied in our experiment include the relative flow Q*, the initial Froude number F1, the initial height h1 of the flow, the final height h2 of the jump, as well as the relative roughness ε/b. Consequently, the resulting dimensionless parameter is the following:

The Froude number F1 is expressed by the following relationship:: $F_1 = Q / (g\ b^2\ h_1^3)$ [10].



Photograph 1. the five initial heights (h_1 (cm) = 02 ; 02.5 ; 03 ; 03.5 et 04)

1.2. Description of the tests

1.2.1. Experimental procedure of the experiments

We carried out an experimental study on the hydraulic jump controlled by a thin-walled sill, developing in a rectangular channel with a composite section with a rough minor bed within the Laboratory for the exploitation and valorization of natural resources in arid zones (EVRNZA) from the Department of Civil and Hydraulic Engineering of the University of Ouargla [10]. The experiment was carried out using five different values for the initial height of the flow: h1 (cm) = 2; 2.5; 3; 3.5 and 4 have been tested. Four levels of roughness were evaluated with the following absolute values: ε (mm) = 06; 08; 10 and 12mm. The establishment of a threshold downstream of the flow is necessary for the development of the controlled jump. To form and control the jump, several thresholds of varying heights, ranging from 2.5 cm to 21 cm, were examined (Photograph 02).

Photograph 2. Thin-walled sills vary from 2.5 to 21 cm

Once the configuration of the controlled jump has been obtained, we proceed as follows for a determined initial height h1 and a threshold position x:

1/ Measurement of the discharge height (hdev) of the rectangular spillway (Photograph 03).

2/ Determination of the corresponding volumetric flow using the rectangular flow meter formula according to Hachemi and Rachedi (2006):

$$Q= 0{,}3794(2g)^{(1/2)}\,\beta(1+0{,}16496\,\beta^{2{,}0716})^{3/2}\,h_{dev}^{3/2} \qquad (1)$$

Taking into account:

Q: The flow rate (m3/s).

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β= b/B: Enlargement report.

b: Width of the notch (m).

B: Channel width (m).

g: The acceleration of gravity (m/s2).

hdev: The height of the overhanging blade (m).

3/ Determination of the Froude number F1 of the initial flow using relation (1).

4/ Determination of the final height (h2) of the jump.= b/B: Enlargement report.

b: Width of the notch (m).

B: Channel width (m).

g: The acceleration of gravity (m/s2).

hdev: The height of the overhanging blade (m).

3/ Determination of the Froude number F1 of the initial flow using relation (1).

4/ Determination of the final height (h2) of the jump.

Photograph 3. Rectangular weir used to measure spill blades

1.2.2. Method of preparing the roughness used

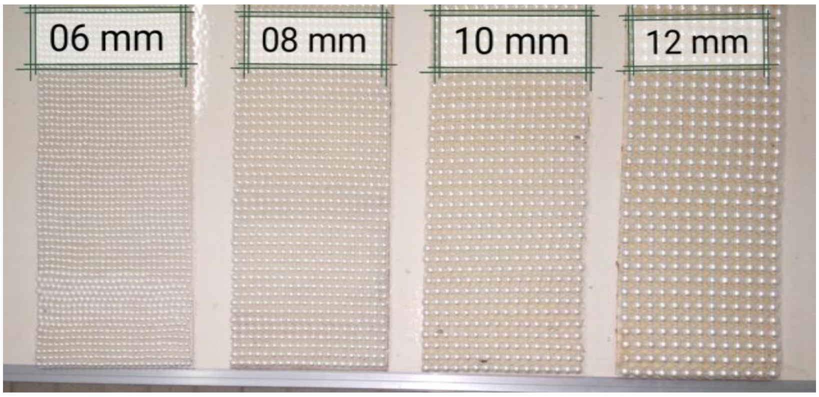
To achieve a rough minor bed with a uniform roughness distribution, we followed the following steps:

1/ Opt for plastic mercury balls with diameters between 6 and 12 mm.

2/ We arranged the plastic balls in a linear and uniform manner on a mat extended over a length of four meters along the test channel.

3/ Subsequently, the rough mat obtained is meticulously fixed on the minor bed of the rectangular channel with composite section.

4/ The roughnesses obtained are as follows: ε = 06 mm, ε = 08 mm, ε = 10 mm and ε = 12 mm.



Photograph 4. Mats for different roughness diameters

2. RESULTS AND DISCUSSION

2.1. Jump yield

The hydraulic jump is of major technical interest because of its ability to effectively dissipate kinetic energy. Bernoulli's equation, applied between the upstream and downstream sections of the jump, imposes a fundamental constraint

$$:H_1 = h_1 + Q^2/(2.g.A_1^2) = h_2 + Q^2/(2.g.A_2^2) + \Delta H \quad (2)$$

The efficiency, noted η, of the hydraulic jump is determined by

$$\eta = \Delta H/H_1 \; \Delta H = H_1 - H_2 \quad (3)$$

With:

H1: represents the upstream load

H2: represents the downstream load

The yield fluctuates in a range from 0 à 1 ($0<\eta<1$) :

$$H_1 = \alpha_1 (V_1^2/2g) + h_1; \qquad H_2 = \alpha_2 (V_2^2/2g) + h_2$$

In equation (2), we substitute the variables H1 and H2 with their values:

$$\eta = 1 - [(\alpha_2 (V_2^2/2.g) + h_2) / (\alpha_1 (V_1^2/2.g) + h_1)] \quad (4)$$

By replacing V1 = Q/A1 and V2 = Q/A2 in equation (4), it transforms

$$\text{into:} \eta = 1 - [(\alpha_2 (Q^2/2.g.A_2^2) + h_2) / (\alpha_1 (Q^2/2.g.A_1^2) + h_1)] \quad (5)$$

With :

The area of the upstream section: A1= bh1

The area of the downstream section: A2= B (h2 − h) + bh

α1 = α2 = 1

The Froude number !F1: $F_1 = Q/\sqrt{b^2 h_1^3 g}$

In this case, the expression for yield can be expressed as follows

$$\eta = 1 - \frac{Y + \dfrac{F_1^2}{2[Y/\beta \ - (1/\beta - 1)/\tau]^2}}{1 + F_1^2/2} \tag{6}$$

The variation in the yield of the jump as a function of the incident Froude number for the two configurations, that is to say the minor bed and the major bed, is illustrated in figures 01 and 02 below.

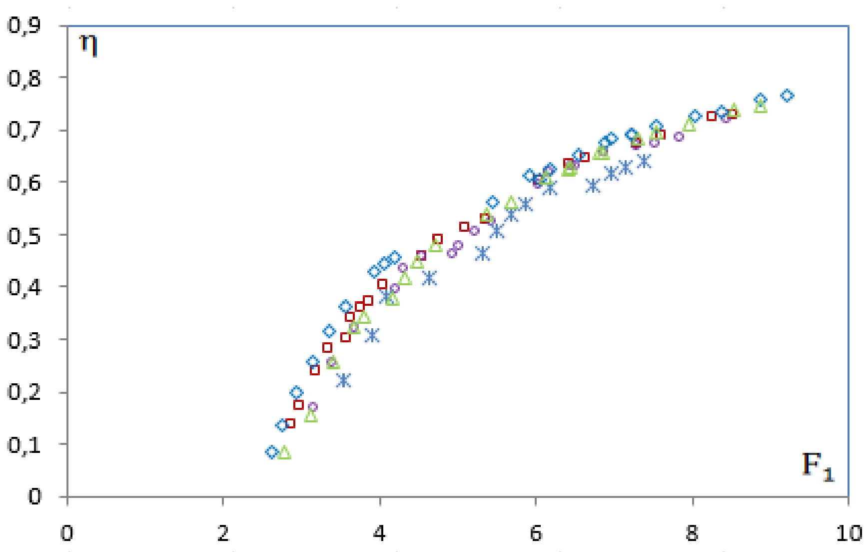


Fig. 1. variation of efficiency η as a function of Froude number F1

The symbols used indicate the experimental points of the rectangular channel jump, where the section is composed of a rough bottom with different relative roughnesses ε/b in minor bed : (◊) = 12 mm ; (□)= 10 mm ; (Δ)= 08 mm ; (0) = 06 mm et (*) =00 mm

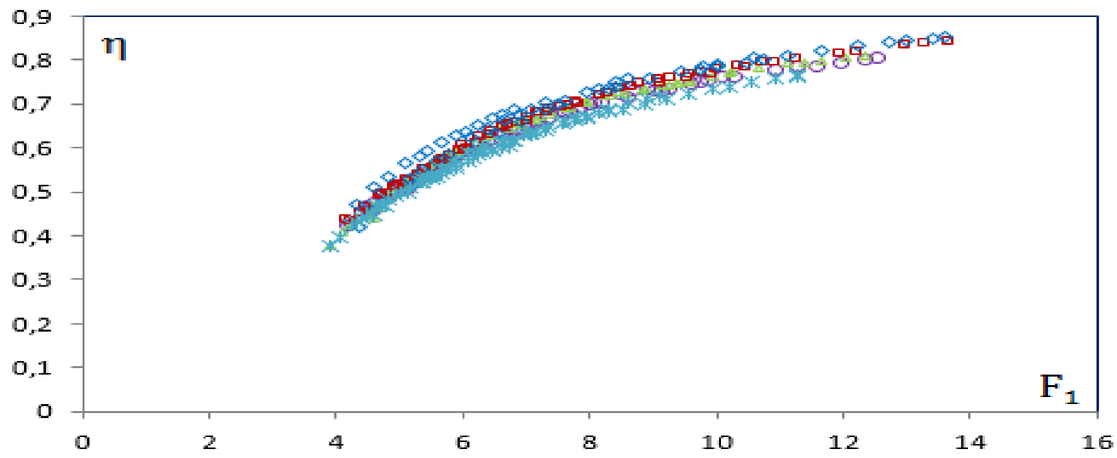


Fig.2. the variation of the efficiency η as a function of the Froude number F1

The colored symbols used illustrate the experimental points of the jump observed in a rectangular channel where the section consists of a rough bottom, presenting different relative roughnesses ε/b in the major bed:(◊) = 12 mm ; (□)= 10 mm ; (Δ)= 08 mm ; (0) = 06 mm and (*) =00 mm

Figures (01) and (02) demonstrate that increasing the incident Froude number leads to an increase in efficiency. Furthermore, for the same incident Froude number, the efficiency increases with the increase in roughness in both cases. Thus, an increase in equivalent roughness leads to increased energy dissipation.

1.1. Generalized surface profile of the jump

The experimentation allowed us to characterize the profile of the free surface of the jump from its initiation to its final configuration in a rectangular channel of compound section presenting a rough bottom geometry.

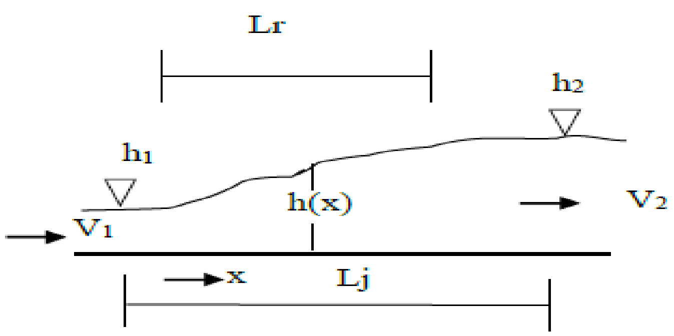


Fig.3. Surface profile of the jump

The simplified diagram presented in Figure (03) concerns both the minor bed and the major bed, the longitudinal coordinate x varies from $0 \leqslant x \leqslant Lj$, while the depth h(x) lies in the range of $h1 \leqslant h(x) \leqslant h2$, where h1 and h2 represent respectively the upstream and downstream heights of the jump.

We can use the parameters x and h(x) to create the dimensionless variables Y and X by applying the formula:$Y= (h(x) - h_1) / (h_2 - h_1)$

$X = x / Lj$

The dimensionless variables Y and X are restricted such that: $0 \leqslant X \leqslant 1$ and $0 \leqslant Y \leqslant 1$.

The relationship between the variation of the Y ratio as a function of the X ratio is illustrated in Figures (04) and (05), these graphs present the experimental measurement points for different roughnesses.

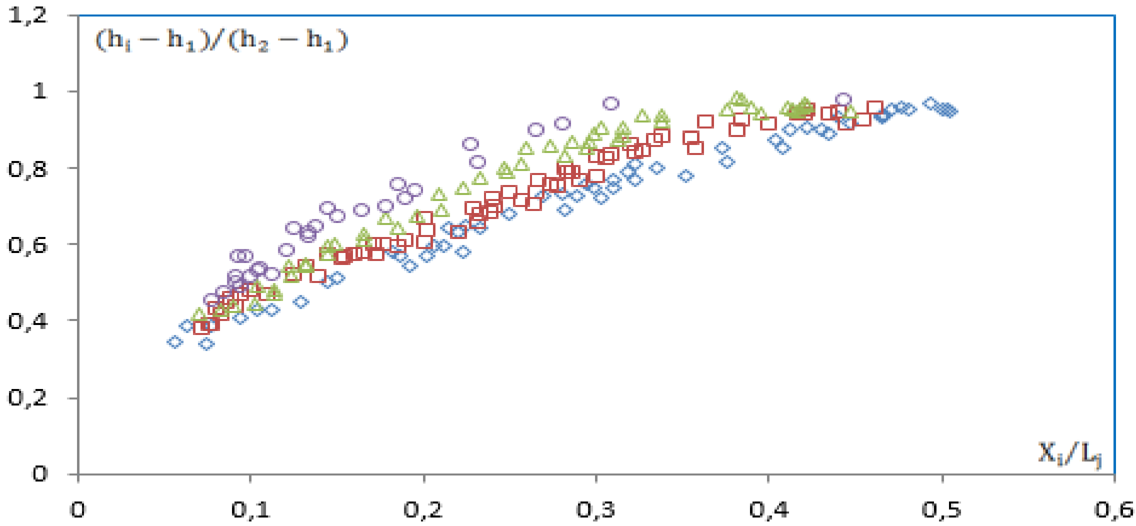


Fig.4. presents the profile of the generalized surface of the minor bed of the hydraulic jump in a rectangular channel of composite shape with rough bottom, for four different roughness levels **in minor bed**: (◊) 06 mm; (□) 08mm; (Δ) 10mm and (○) 12mm.

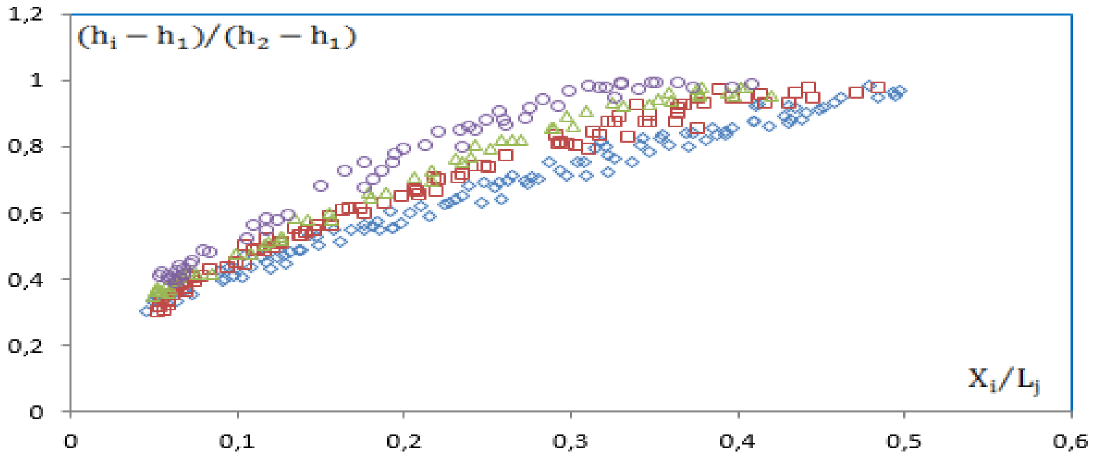


Fig.5. shows the profile of the generalized surface of the major bed of the hydraulic jump in a rectangular channel of composite shape with rough bottom, for four different roughness levels **in the main bed** : (◊) 06 mm; (□) 08mm; (Δ) 10 mm and (○) 12 mm

Figures (04) and (05): clearly illustrate four distinct point clouds, each corresponding to one of the four roughnesses evaluated. It is observed that, for a given x/Lj ratio, the value of y increases proportionally to the increase in absolute roughness. this trend highlights the impact of roughness on the reduction of depth h2

3. CONCLUSION

The experiment focused its attention on the dissipation of kinetic energy. The latter was expressed by yield. Indeed, the analysis of the variation in the yield of the hydraulic jump as a function of the incident Froude number for the two cases (minor and major bed) indicates that the hydraulic jump in a rectangular channel of composite section with a rough minor bed dissipates the energy more efficiently than its smooth bottom counterpart.

The experimental analysis also examined the generalized profile of the jump for the two cases, namely the minor bed and the major bed. Indeed, for four equivalent values of roughness (ε=12mm, ε=10mm, ε=08mm and ε=06mm), the evolution of the non-dimensional vertical ratio Y as a function of the non-dimensional horizontal ratio X, Y increases with increasing absolute roughness. Furthermore, the effect of depth reduction is correlated with the magnitude of roughness.

4. MAIN RATINGS

A_1	The area of the initial wetted section	[m]
A_2	The area of the final wetted section	[m]
b	Width of minor channel bed	[m]
B	Width of main bed	[m]
F_1	Froude number upstream of the jump	[ ]
g	Gravity acceleration	[m/s^2]
h_1	Initial height of the jump	[m]
h_2	Final height of the jump	[m]
h	Height of full edge of minor bed	[m]
H_1 et H_2	Total loads at the foot and at the end of the jump	[m]
ΔH	Load losses due to jump	[m]
H_{dev}	Height of the dumping blade	[m]
L_j	Length of the jump	[m]
Q	Volume flow	[m^3 /s]
V_1 et V_2	Average speeds at the base and at the end of the jump	[m/s]
X	Longitudinal coordinate	[m]
β	Enlargement report	[ ]
$\tau = h_1/ h$	Form ratio	[ ]
η	Jump yield	[ ]
ε	Absolute roughness	[m]
ε/b	Relative roughness	[ ]

5. REFERENCES

[1] Abbaspour A, Hosseinzadeh Dalir A, Farsadizadeh D, and Sadraddini A.A. (2009). Effect of sinusoidal corrugated bed on hydraulic jump characteristics. J. Hydro-Environ. Res. 3, 109–117.

[2] Achour, B., Dissipation d'énergie par ressaut, thèse d'état. Université de Tizi Ouzou,

Institut de Génie Civil, 1998.

[3] Achour, B., (2000). Ressaut hydraulique dans une galerie circulaire brusquement élargie. JHR 2000 ; 38(4) : 307 311.

[4] Achour, B., Debabeche, M., Ressaut contrôlé par seuil dans un canal profile en U. Journal of hydraulic research, Vol. 41 (02), pp. 97 103, 2003.

[5] Benabdesselam A. (2020). Approches theoriques et expéimentale du ressaut hydraulique dans un profil de canal composes (Doctorat dissertation, Université Mohamed Khider-Biskra).

[6] Carollo F. G, Ferro V, Pampalone V. (2007). Hydraulic jumps on rough beds. Journal of Hydraulic Engineering. 133(9), 989-999.

[7] Chanson H. (2011). Hydraulic jumps: turbulence and air bubble entrainment. J. La Houille Blanche. 1, 5-16.

[8] Debabeche, M., Ressaut hydraulique dans les canaux prismatiques. Thèse de doctorat d'état, Département d'Hydraulique, Université de Biskra, Algérie, 2003.

[9] Debabeche M, Kateb S, & Ghomri A. (2006). Etude expérimentale du ressaut hydraulique dans un canal triangulaire à parois rugueuses. Larhyss Journal P-ISSN 1112-3680/E-ISSN. (5), 2521-9782.

[10] Djamaa.W., Ghomri. A., (2020). Study of experimental approach of the relative length of the surface role of the hydraulic jump evolving in a rectangular channel of section composed with rough bottom; Journal of Fundamental and Applied Sciences ISSN 1112 9867.

[11] De Leo, Annalisa, et al. (2020). The effects of hydraulic jumps instability on a natural river confluence: The case study of the Chiaravagna River (Italy). Water 12.7: 2027.

[12] Ead S.A, and Rajaratnam, N. (2002). Hydraulic jump on corrugated bed. J. Hydraul. Eng. ASCE, 128(7), 656-663.

[13] Esfahani M J. (2017). Characteristics of hydraulic jump on rough bed with adverse slope. ISH Journal of Hydraulic Engineering, 23(3), 301-307.

[14] Ghomri A. (2012). Le ressaut hydraulique dans les canaux prismatique à parois rugueuses (Doctoral dissertation, Université Mohamed Khider-Biskra).

[15] Hughes W C, Flack J E. 1984. Hydraulic jump properties over a rough bed. Journal of Hydraulic Engineering. 110 (12), 1755-1771.

[16] Izadjoo F, and Shafai Bejestan M. (2007). "Corrugated bed hydraulic jump stilling basin." J. Appl.Sci. 7, 1164–1169.

[17] Khattaoui M & Achour B. (2012). RESSAUT HYDRAULIQUE EN LIT COMPOSE HYDRAULIC JUMP IN COMPOUND CHANEL. Le Journal de l'Eau et de l'Environnement. 11(20), 44-51.

[18] Leutheusser H J, Schiller E J. 1975. Hydraulic jump in a rough channel. Water Power and Dam Construction. 27 (5), 186-191.

[19] Mohamed Ali H S. 1991. Effect of roughened-bed stilling basin on length of rectangular hydraulic jump. Journal of Hydraulic Engineering. 117 (1), 83-93.

[20] Nasr Esfahani M J, and Shafai Bejestan M. (2012). Design of stilling basins using artificial roughness. J. Civ. Eng. 2(4), 159–163.

[21] Negm A M. (2002). Optimal roughened length of prismatic stilling basins. Proc, Int. Conference on Hydro-Science and Engineering Conference, Warsaw, September, 18-21.

[22] Nouacer.B., Kateb.S., Abd Elouahed.B., (2021). Experimental Approach To The Length Of The Threshold-Controlled Hydraulic Flow In A Rectangular Channel With A Rough Bottom; Journal of Fundamental and Applied Sciences ISSN 1112-9867.

[23] Pourabdollah N, Heidarpour M, & Koupai J A. (2019). An experimental and analytical study of a hydraulic jump over a rough Bed with an adverse slope and a positive step. Iranian Journal of Science and Technology, Transactions of Civil Engineering. 43(3), 551-561.

[24] Rajaratnam N. (1968). Hydraulic jump on rough bed. Trans. Eng. Ins, Canada. 11, 1-8.

[25] Riguet F M. Debabeche, and A Ghomri. (2020). Experimental study of the sequent depth ration of the hydraulic jump in a straight compound rectangular channel. Journal of Fundamental and Applied Sciences. 12.1s: 56-65.

[26] Tokyay N D. (2005). Effect of channel bed corrugations on hydraulic jumps. Impacts of Global Climate Change Conference, EWRI, May, Anchorage, Alaska, 408-416.