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Research Article

CHARACTERISTICS OF HYDRAULIC JUMP ON ROUGH MINOR BED IN A RECTANGULAR COMPOUND CHANNEL

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ABSTRACT

A hydraulic jump is a characteristic phenomenon in open channel flow, downstream of block ramps or rock chutes a hydraulic jump can occur over a rough bed with great energy dissipation. This paper analyses the hydraulic jump that occurs in homogeneous rough minor beds in rectangular compound channels. the parameters that influence the length of the jump were systematically investigated [24]. the analyses of the phenomenon were conducted using the general jump equation. the experimental data were elaborated in order to supply a new formulation of the general jump equation that accounts for the minor bed roughness. New formulas that satisfactorily agree with the experimental data are proposed. The results showed that rough beds can be used to dissipate the excess hydraulic jump energy instilling basins.

Keywords: hydraulic jump, Open channel, compound channel, stilling basins, rough minor bed.

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1. INTRODUCTION

Hydraulic jumps are common phenomena in free surface flows in natural rivers, artificial canals and industrial applications [6;20]. Hydraulic jump is an extremely turbulent flow which implies the development of large-scale turbulence, surface waves, spray and energy dissipation [4;2]. Hydraulic jump is a phenomenon caused by change in stream regime from supercritical to sub – critical flow with considerable energy dissipation and rise in depth of flow. Hydraulic jump primarily serves as an energy dissipater to dissipate excess energy of flowing water downstream of hydraulic structures, such as spillway, sluice gates etc. This excess energy, if left unchecked, will have adverse effect on the banks and the bed.

The length of the hydraulic jump is mostly taken as a design parameter or indicator of the stilling basin length. From the engineering point of view, the length of the stilling basin should be efficient and economical. To be economical, the length of stilling basin should be as short as possible [22;5]. The main concern related to the jumps with baffles is cavitation risk in elements located in the upstream part of the jumps. In cases, the jumps would move toward downstream (unprotected streambed) and cause erosion and possible damages to the structure. On the other hand, if jumps occur on corrugated beds, significant reductions would be result in the required sequent depth and length of the jumps [9,29,13-15].

Investigated a turbulent hydraulic jump over a rough bed in a rectangular channel. They showed that the roughness of the bed in the inner layer had a passive role in imposing wall shear stress in a hydraulic jump that occurred in the outer layer [18]. They proposed analytical solutions for sequent depth ratio, roller length [18;27], and profiles of jump depth and velocity that depend on the upstream Froude number, drag owing to bed roughness and kinetic energy factor. They notified that, by replacing the upstream Froude number with the effective upstream Froude number, results for the hydraulic jump over a rough bed could be directly deduced from classic jump theory. Hydraulic jumps over corrugated beds have been investigated thoroughly, according to the results the length of the jumps and the sequent depth required to form a jump was appreciably smaller than that for the corresponding jumps on smooth beds. Also, the shear stress over the corrugated beds increases in comparison to the classic jump [9; 30; 25; 23], [18; 1; 10; 23; 28] approached the hydraulic jumps on rough beds for the first time. Further studies were conducted by [20;5;11] they investigated the characteristics of mean turbulent motion in an artificially roughened channel; in their study, the rough at the bottom of the channel was made by spheres (acrylic plastic balls on acrylic plastic base plates) and gravel. Other Authors [17;21;9;3] studied the effects of uniform artificial roughness on hydraulic jumps. There are few studies of the jump that occurs in a smooth-bed horizontal compound rectangular channel and it has been studied by [19;2; 26].

The main objective of our study is to provide theoretical approaches and experimental investigations for hydraulic jump, which occurs in a rectangular composite channel with a rough minor bed, in this study we relied in the formation of roughness on uniformly and homogeneously compound plastic pellets.

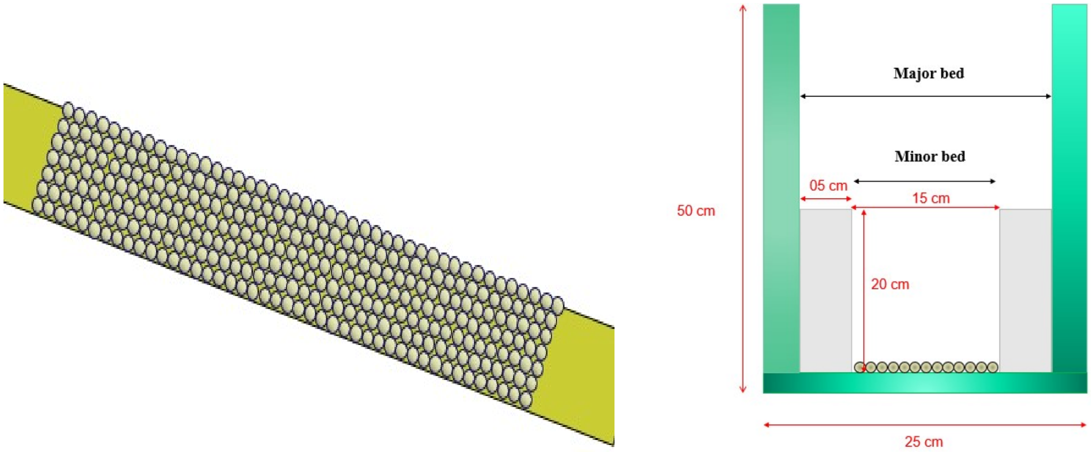

Fig.1. definition sketch for the rough bed inside the channel and the cross section

The differ from the work of [12;21;24] where they adopt a heterogeneous roughness such as gravel. The present study aims to find Theoretical developments regarding the establishment of dimensionless relationships for the length of the jump in the compound rectangular channel with a rough minor bed, the experiments were conducted with five different values; (ε = 06 mm; ε = 08 mm; ε = 10 mm and ε = 12 mm) for the roughness, and through the results, the study proved that the roughness has a significant effect on energy loss, the study also gave simple relationships useful for practical design.

2. MATERIALS AND METHODS

The experimental of hydraulic jump controlled by a thin-walled sill in a rectangular channel with a rough minor bed were made at the Laboratory for the exploitation and development of natural resources in arid zones (EVRNZA) of the Department of Civil and Hydraulic Engineering of the University of Ouargla. The bottom of the canal is perfectly horizontal (with no slope) [7; 8]. A supply basin is connected to the channel by means of a circular pipe 150 mm in diameter. This is connected to a closed metal box, on which is inserted an opening with a flat sheet metal wall of determined width opening into the channel. The role of this wall is to generate an incident flow at high speed. The outlet section is variable and its height will correspond to the initial height h_1 of the hydraulic jump. The volume flows are adjusted by manipulating the valve. The channel is supplied by a pump delivering up to 55.55 l / s. The experiments were conducted in a metal and plexiglass channel with a rectangular cross-section. The channel was 0.25 m wide, 0.5 m deep, and 10 m long. To obtain a compound rectangular cross-section, we gluing boxes of transparent plexiglass on the walls of the canal, allowing the visualization of the flow with a length of 4 m (Figure 2) and the channel was equipped with a sluice gate at the entrance, and the discharge was measured with a rectangular weir placed at the end [7; 8]. The discharge-head relationship (Q-h) for the rectangular weir in experiments was $Q = 0,3794\sqrt{2g}\beta\left(1+0,16496\beta^{2,0716}\right)^{3/2} h_{dev}^{3/2}$ [16;11;12]. The rough bed was simulated by gluing homogeneous plastic pellets onto a plastic plate that was placed on the channel throughout its length 4 m (Figure 2), Where we experimented with five different types of rough bed (ε = 0 mm; ε = 06 mm; ε = 08 mm; ε = 10 mm and ε = 12 mm).

Fig.2. Experimental set-up used in this study [7,8]

Fig.3. Hydraulic jump in a rectangular channel of a composite section with a rough minor bed

The experiment was conducted under five initial heights of flow: h_1 (cm) = 2; 2.5; 3; 3.5 and 4. The formation of the controlled hydraulique jump is conditioned by the establishment of a threshold downstream of the flow. We used thresholds of different heights (2.5 cm to 21 cm) for the formation and control of the hydraulic jump.

3. RESULTS AND DISCUSSION

3.1. Variation of the relative length Lj / h_1 as a function of the Froude number F_1 in the minor bed.

The values of the related length Lj/h_1 of hydraulic jump, was plotted vs. Froude numbers F_1 in (Figure 4). The results obtained from this study showed that the related length of jump on rough minor bed 0 cm ≤ h_2 ≤ 20 cm was smaller than related length of the jump with smooth bed.

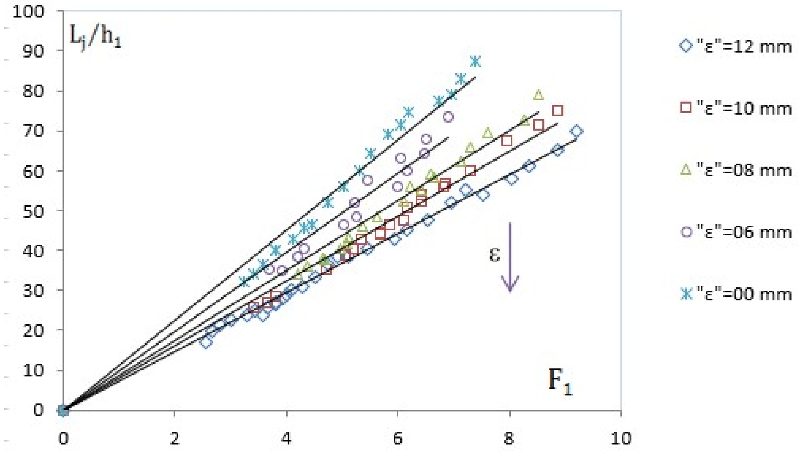

Fig.4. Variation of the related length Lj/h_1 of hydraulic jump with initial froude number F_1 in the minor bed 00 cm ≤ h_2 ≤ 20cm, for five different roughnesses.

(—) Adjustment curves

In addition, the analysis of the experimental measurement points of the rough minor bed of the hydraulic jump shows that for each roughness value "ε" corresponds a linear type curve of the form: $Lj/h_1 = a_1 (F_1)$.

The effect of rough minor bed on the related length Lj/h_1 of hydraulic jump is shown in (Figure 4). From the figure, it can be seen that the sequent depth ratio reduced as the roughness was augment. The reduction magnitude is more obvious for higher Fr_1 values.

In addition, the analysis of the experimental measurement points of the rough minor bed of the hydraulic jump shows that for each roughness value "ε" corresponds a linear type curve of the form, $Lj/h_1 = a_1 (F_1)$. Table 1 groups the values of the coefficient a_1.

Table 1. coefficients a_1 of the adjustment curves.

ε/b	a_1	R^2
0,08	7,349	0,995
0,066	8,117	0,986
0,053	8,727	0,988
0,04	9,887	0,971
0	11,32	0,979

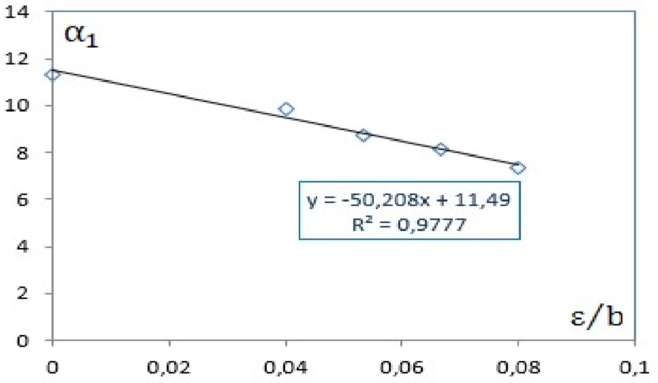

Fig..5. Variation of the coefficient " a_1" with the relative roughness ε/b in the minor bed

Following rough-based equation was derived for Lj/h_1 relations with its dominant parameters:

$$Lj/h_1 = (-50.208(\varepsilon/b) + 11.49)\,F_1 \quad , R^2 = 0.98 \qquad \text{[Eq. 1].}$$

With $0 \leq \varepsilon/b \leq 0.08$

Relative length was computed using equation (1) and compared with the corresponding measured values (Figure 6). It was observed from the figure that the result produced by the proposed relationship showed a ± 6% difference with the corresponding measured values.

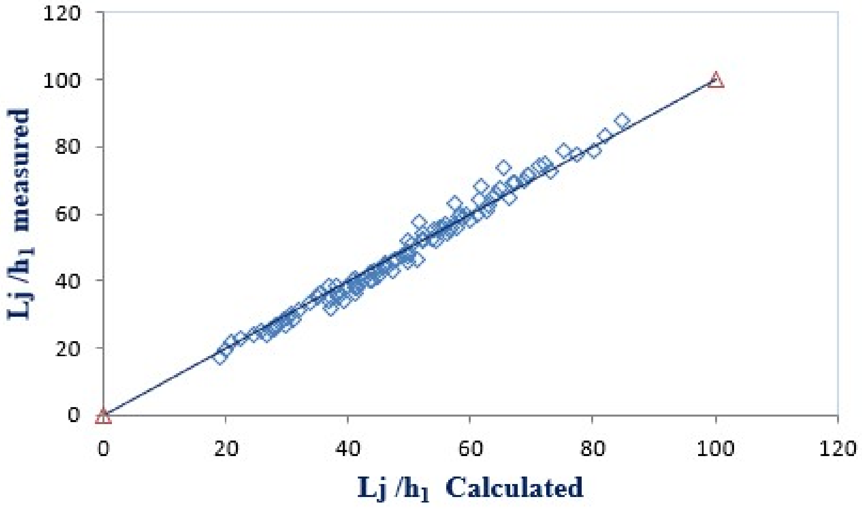

Fig.6. Measured vs. calculated values (using Equation (1)) of (Lj/h_1).

(—) First bisector.

3.2. Variation of relative length Lj/h$_1$ with initial froude number F$_1$ in the major bed.

As we did with the minor bed, we have the values of the related length Lj/h$_1$ of the hydraulic jump in the major bed 0 cm $\le h_2 \le$ 20 cm was plotted vs. Froude numbers F$_1$ in Figure 7.

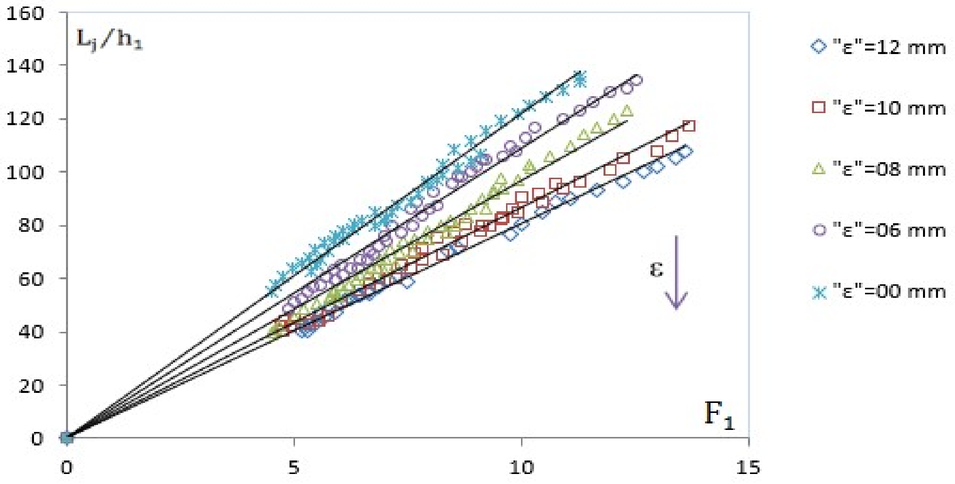

Fig.7 Variation of the relative length Lj / h$_1$ as a function of the Froude number F$_1$, for five different roughness in major bed.

(—) Adjustment curves.

The results obtained from this study showed that the related length of jump on rough minor bed was smaller than the related length of the jump with a smooth bed.

The analysis of the experimental measurement points of the rough minor bed of the jump shows that for each roughness value "ε" corresponds to a linear type curve of the form: $Lj/h_1 = a_2 (F_1)$.

The effect of rough major bed on the related length Lj/h_1 of hydraulic jump is shown in Figure 7. From the figure, it can be seen that the related length reduced as the roughness was augment. The reduction magnitude is more obvious for higher Fr_1 values.

In addition, the analysis of the experimental measurement points of the rough major bed of the hydraulic jump shows that for each roughness value "ε" corresponds a linear type curve of the form, $Lj/h_1 = a_2 (F_1)$. Table 2 groups the values of the coefficient a_2.

Table 2. coefficients a_2 of the adjustment curves.

ε/b	a_2	R^2
0,08	8,06	0,993
0,066	8,648	0,99
0,053	9,66	0,986
0,04	10,88	0,984
0	12,17	0,988

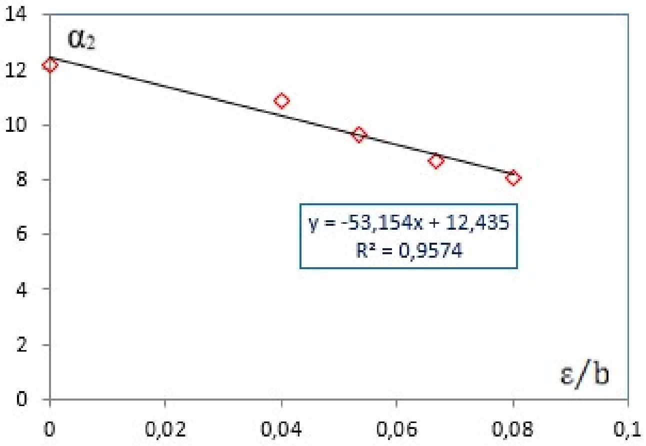

Fig.8. Variation of the coefficient " a_2" with the relative roughness ε/b in the major bed

Following rough-based equation was derived for Lj/h_1 relations with its dominant parameters:

$$Lj/h_1 = (-53.154(\varepsilon/b) + 12.435)\,F_1 \quad , R^2=0.96 \qquad \text{[Eq. 2].}$$

With $0 \le \varepsilon/b \le 0.08$

Relative length was computed using equation (2) and compared with the corresponding measured values (Figure 9). It was observed from the figure that the result produced by the proposed relationship showed a ± 7% difference with the corresponding measured values.

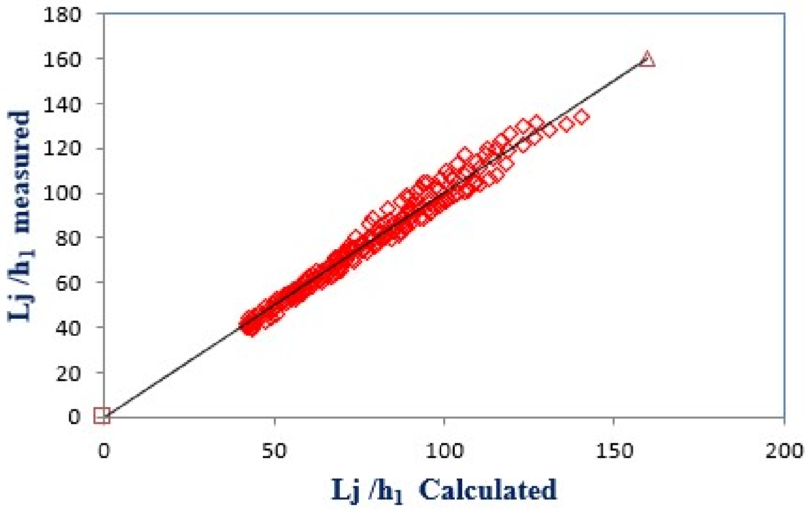

Fig.9. Measured vs. calculated values (using Equation (2)) of (*Lj*/*h*₁).

(—) First bisector

The values of relative length (Lj/h₁) Measured vs. calculated obtained in the present research for two cases (minor bed and major bed) were also compared in the same figure (Figure 10). From the figure, it is seen the effect of the composite section on the jump and we can to note that the effect of roughness elements on the jump was considerable, Thus, we have achieved the desired goal.

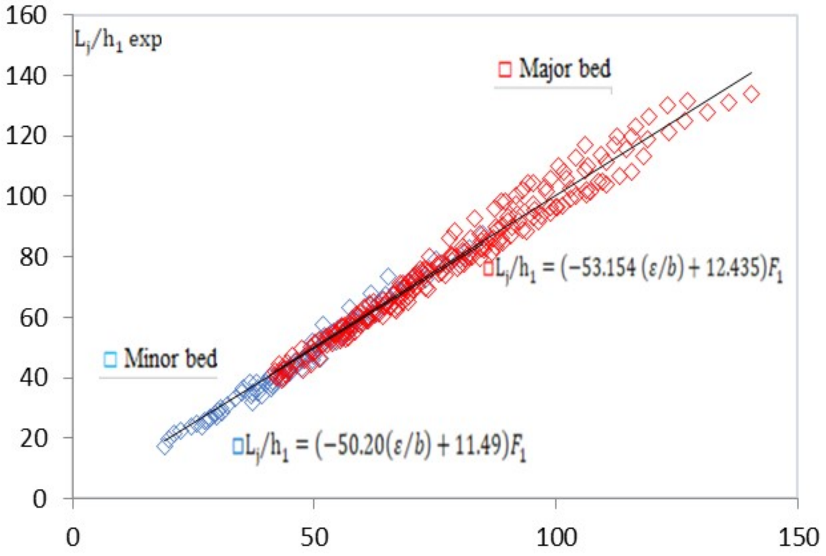

Fig.10. variation of the relative length (Lj/h₁) Measured vs. calculated obtained in the present research for two cases (minor bed and major bed)

4. CONCLUSION

The study was an attempt to find out the impact of bed roughness height on characteristics of a hydraulic jump. The analysis of the collected data revealed that there was a significant effect of the channel roughness height on the jump characteristics. In this study, the characteristics of the hydraulic jump on the rough bed have been investigated. The roughness elements act as depressions in the bed by creating eddies and subsequently bed shear stress increases, resulting in energy dissipation in the supercritical flow.

Hydraulic jump on the smooth bed is an unstable phenomenon that causes some difficulties in controlling the jump. It should be noted that according to the experimental observations, installing roughness elements stabilized the jump. we observed on roughness decreased the length of the jump significantly compared with results presented by previous studies. The results showed that relative energy loss was more than those of the classic hydraulic jump on the horizontal bed. Hence, such a structure could be more economical in dissipating the energy of the flow in comparison to the classical stilling basin.

MAIN RATINGS

b	width of the minor channel bed [m]
B	Width of the major bed [m]
F_1	supercritical Froude number of the hydraulic jump [ ]
g	gravitational acceleration [m / s^2]
h_1	supercritical initial depth of free jump [m]
h_2	Sequent depth of a jump on the rough bed [m]
h	height of minor bed [m]
Lj	length of hydraulic jump [m]
(Lj/h_1)	relative length of roller [ ]
Q	Volume flow [m^3/s]
R^2	Coefficient of determination
ε	height of the roughness elements [m]
(ε / b)	Relative roughness [ ]

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

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

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

[5] 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.

[6] 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.

[7] 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.

[8] Djamaa W, Ghomri A, Khechana S. (2021). *Study of the experimental approach of the relative threshold of the hydraulic jump evolving in a rectangular channel of composed section with rough minor bed.* Journal of Fundamental and Applied Sciences ISSN 1112-9867.

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

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

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

[12] Ghomri A, Riguet F, & Debabeche M. (2013). *Effect for a single roughness e= 5,63mm*

of experimental to study hydraulic jump profile in a channel in ua rough bottom. Journal of Fundamental and Applied Sciences, *5*(1), 25-39.

[13] Ghomri A, & Riguet F. (2010). *Contribution to the experimental study of the hydraulic jump evolving in an U-Shaped channel, with rough bed*. Journal of Fundamental and Applied Sciences, *2*(2), 254-271.

[14] Ghomri A, Riguet F, & Debabeche M. (2012). *Effect for a single roughness E=9,11 mm of ecperimental to study hydraulic jump profile in a channel in U rough bottom*. Journal of Fundamental and Applied Sciences, 4(2), 1-15.

[15] Gupta S K, Mehta R C, & Dwivedi V K. (2013). *Modeling of relative length and relative energy loss of free hydraulic jump in horizontal prismatic channel*. Procedia engineering, 51, 529-537.

[16] Hachemi Rachedi L, (2005), *Analyse d'un écoulement au travers d'une contraction latérale.* Mémoire de magister en hydraulique, Département d'hydraulique, Université de Biskra.

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

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

[19] 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.

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

[21] 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.

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

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

[24] Pagliara S, Lotti I, & Palermo M. (2008). *Hydraulic jump on rough bed of stream rehabilitation structures*. Journal of Hydro-Environment Research. *2*(1), 29-38.

[25] 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.

[26] 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.

[27] Retsinis E, & Papanicolaou P. (2020). *Numerical and Experimental Study of Classical Hydraulic Jump*. Water. 12(6), 1766.

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

[29] Türker U, & Valyrakis M. (2021). *Hydraulic jump on rough beds: conceptual modeling and experimental validation*. Water Supply. 21(4), 1423-1437.

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

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