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EFFECT OF ROUGHNESS ON THE CHARACTERISTICS OF THE HYDRAULIC JUMP EVOLVING INTO A RECTANGULAR CHANNEL OF COMPOUND SECTION

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ABSTRACT

The hydraulic jump is a phenomenon which characterizes the flow in the open channels. It can occur in the channels with rough beds making it possible to dissipate the significant kinetic energy. this work will analyze this kind of hydraulic jump producing in rough major beds for rectangular channels of compound section. the parameters influencing the length of the jump have been systematically studied. the analyzes of the phenomenon were conducted using the general jump equation. the experimental data were carried out with the aim of establishing dimensional empirical approaches which vary according to the roughness imposed on the major bed. these additional approaches obtained are proposed. The results obtained showed that the rough major beds can be used to dissipate the hydraulic energies of the hydraulic jump that occurs in the stilling basins.

Keywords: hydraulic jump, open channel, compound section channel, buffer basin, roughness

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1. INTRODUCTION

Hydraulic jumps are common free-surface phenomena that occur in natural rivers, artificial channels [6,20]. The hydraulic jump is a rough near-turbulent flow that causes significant turbulence development and energy dissipation [4,2]. The hydraulic jump is a phenomenon caused by the change of the supercritical flow regime towards the supercritical regime with a significant dissipation of energy and an increase in the depth of the flow. The hydraulic jump essentially serves as a dissipator of excess energy from the water flowing downstream of the hydraulic structures, such as in the weirs, for example. This excess energy must be controlled, otherwise it will have a negative effect on the banks and the bed.

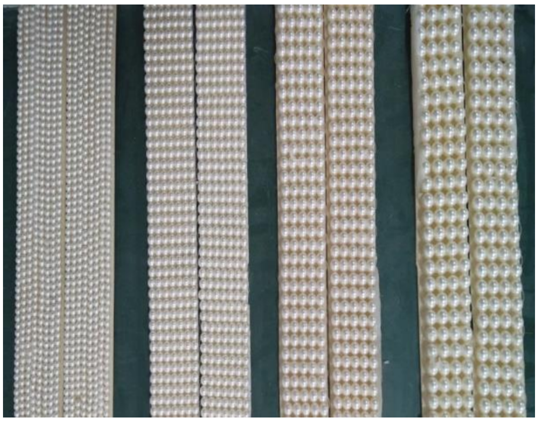
The lengths of the hydraulic jump are considered as design parameters of the stilling basin. From a technical point of view, these lengths of the stilling basin must be efficient and economical. For the economy of stilling basins, these features should be as short as possible [22,5]. (Izadjoo and Shafaei Bejestan 2007). studied a turbulent hydraulic jump above a rough bed in a rectangular channel. They showed that the roughness of the bed had a passive role by imposing a shearing stress on the walls during a hydraulic jump which occurred in the external layer. They proposed analytical solutions for the ratio of conjugate depths, surface roll length [18], and jump depth and velocity profiles that depend on the upstream Froude number and bed roughness.

They noted that replacing the upstream Froude number by the effective Froude number, the results of the hydraulic jump on a broken bed can be directly deduced from the classical theory of the jump. Hydraulic jumps on undulating beds have been studied thoroughly, according to the results, the length of the hydraulic jumps and the combined depths required to form a jump were significantly smaller than those of the corresponding jumps on smooth beds. Moreover, the shear stress on the corrugated beds increases compared to the classic jump [9,10,23,25,28,30,].

Approached hydraulic jumps on rough beds for the first time. Other studies have been conducted by Leutheusser and Schiller, 1975; Mohmoud debabeche et al, 2006 and Ali Ghomri, 2012; they studied the characteristics of turbulent motion in an artificially rough channel; in their study, the roughness at the bottom of the channel consisted of 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 fewer studies on the jump that occurs in a rectangular channel of compound section with zero and smooth slope, which has been studied by (Khattaoui et al, 2012; Benabdesselam, A.2020; Riguet, F et al. 2020).

The primary objective of our research is to develop empirical approaches for the hydraulic jump, which occurs in a rectangular channel composed with a rough major bed, in this study, we were interested in the design of the roughness with plastic granules uniformly and homogeneously composed.

Photograph of a rough carpet carefully glued to the the bed major of the rectangular channel of compound section



Photograph of the four rough mats: ε=06 mm, ε=08 mm, ε=10 mm and ε12 mm

They differ from the works of (Ali Ghomri, 2012; Pagliara et al 2008 and Mahamoud debabeche et al, 2006) where they adopt a heterogeneous roughness like gravel. The present study aims to find theoretical approaches regarding the establishment of dimensionless relationships for the surface roll length in the compound rectangular channel with a rough major bed, the experiments were conducted with five different roughness values; (ε = 06 mm; ε = 08 mm; ε = 10 mm and ε = 12 mm), and through the results, the study proved that roughness has a significant effect on energy loss, the study also gave simple relationships useful for design practice.

2. MATERIALS AND METHODS

Hydraulic jump experiments controlled by a thin-walled sill in a rectangular channel of compound section with a rough major bed were carried out at the Laboratory for the Exploitation and Development of Natural Resources in Arid Zones (EVRNZA) of the Civil Engineering Department. and Hydraulics of the University of Ouargla. The bottom of the channel is perfectly horizontal (without slope) [7, 8].

A supply basin is connected to the canal by means of a pipe of circular section 150 mm in diameter. it is connected to a closed metal box, on which is inserted an opening with a flat sheet metal wall of fixed width opening into the channel. The role of this wall is to generate a torrential flow at high speed.

The outlet section of the box is variable and its height corresponds to the initial height h1 of the hydraulic jump. Specific flow is measured by manipulating the valve. The channel is fed by a pump delivering up to 55.55 l/s. The experiments were done out in a metal and Plexiglas channel of rectangular section.

The channel is 0.25 m wide; 0.5m deep and 10m long. To obtain a compound rectangular section, transparent Plexiglas tols were glued to the walls of the channel, allowing visualization of the flow for a length of 4 m (Figure 2) then the channel was fitted with a valve at the entrance, and the flow was measured with a rectangular weir placed at the end [7,8]. The head-height (Q-h) relationship for the rectangular weir in the experiments was $Q = 0{,}3794B\sqrt{2g}\beta(1 + 0{,}16496\beta^{2{,}0716})^{3/2}H_{dev}^{3/2}$ [16,11,12]. The rough floodplain was prepared by gluing homogeneous plastic pellets onto a plastic plate which was placed over the channel along its entire 4 m length (Figure 2), where we experimented with five different types for the the rough major 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 compound section with a rough major bed

the experiment was made out under five initial heights: h1 (cm)=2; 2.5; 3; 3.5 and 4. The formation of the controlled hydraulic jump is conditioned by the establishment of a threshold downstream of the flow. We used weirs 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 Lr / h_1 as a function of the Froude number F_1 in the major bed.

Figure 4: shows the graphical representation of the variation of the relative length Lr/h1 of the roller as a function of the Froude number Fr of the incident flow, for Five absolute roughnesses: $\boldsymbol{\varepsilon}$ (mm)= 0; 6; 8; 10 and12. Five distinct point clouds are noticeable, each corresponding to an absolute roughness $\boldsymbol{\varepsilon}$. It can be seen that for a fixed absolute roughness, the increase in the Froude number generates that of the relative length of the surface roll. Moreover, for a fixed value of the incident Froude number, the increase of the absolute roughness causes the decrease of the relative length of the roll.

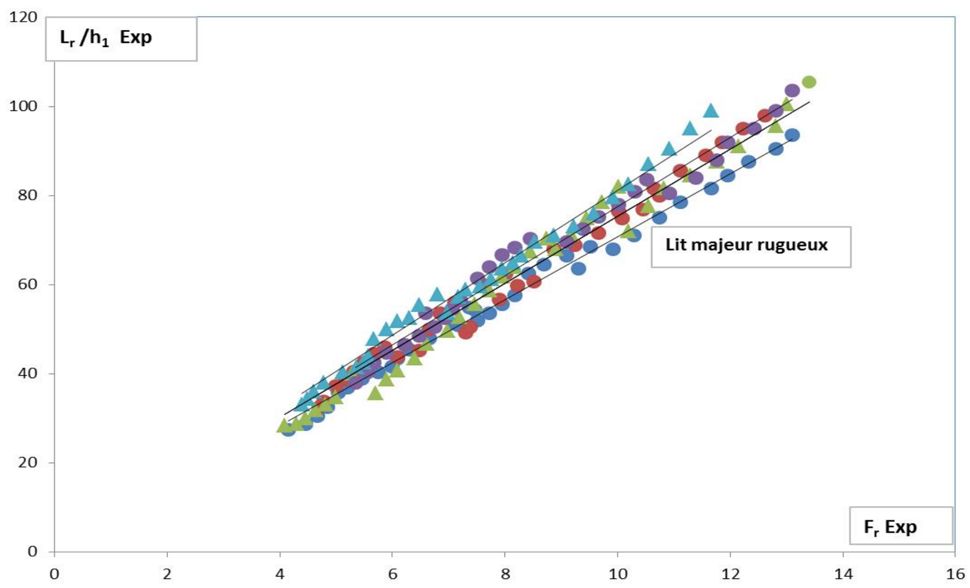


Fig.4. Variation of the related length Lj/h1 of hydraulic jump with initial froude number F_r in the minor bed, 00 cm ≤ h2 ≤ 20 cm, for five different roughnesses. (—) Adjustment curves

Moreover, the statistical analysis of the experimental measurement points by the nonlinear least squares method shows that for each absolute roughness, a linear adjustment of the form Lr/h1 = a Fr is possible. Figure-4 shows it well. The table below groups the values of the coefficient a.

The table shows, that the coefficient ‘a’ gradually decreases with increasing relative roughness **ε**/(B-b). The statistical adjustment of the pairs of values (**ε**/(B-b), a) by the method of least squares gives the following linear type relation.

Table 1. coefficients a_1 of the adjustment curves

ε/B-b	a_1	R^2
0,08	7.0694	0.9934
0,066	7.534	0.9836
0,053	7.5307	0.9767
0,04	7.7516	0.9797
0	8.1166	0.9884

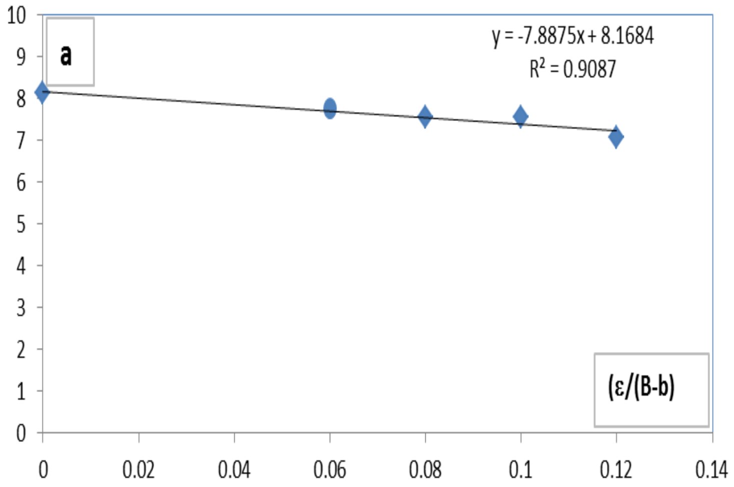


Fig.5. The statistical adjustment of the pairs of values (ε/(B-b),

a = - 7.8875 (ε/(B-b)) +8.1684; This is shown in Figure.5

Following rough-based equation was derived for Lj/h_1 relations with its dominant parameters: L_r/h_1= (-7.8875 (ε/(B-b))+8.1684)*F_r equation (1) ; R^2=0.98 With $0 \leq \varepsilon/B\text{-}b \leq 0.12$ the relative length was calculated using equation (1) and compared to the corresponding measured values (Figure 6). It was observed that from the figure below that the results produced by the proposed relationshipshowed a relative error mostly not exceeding 6% with the corresponding measured values.

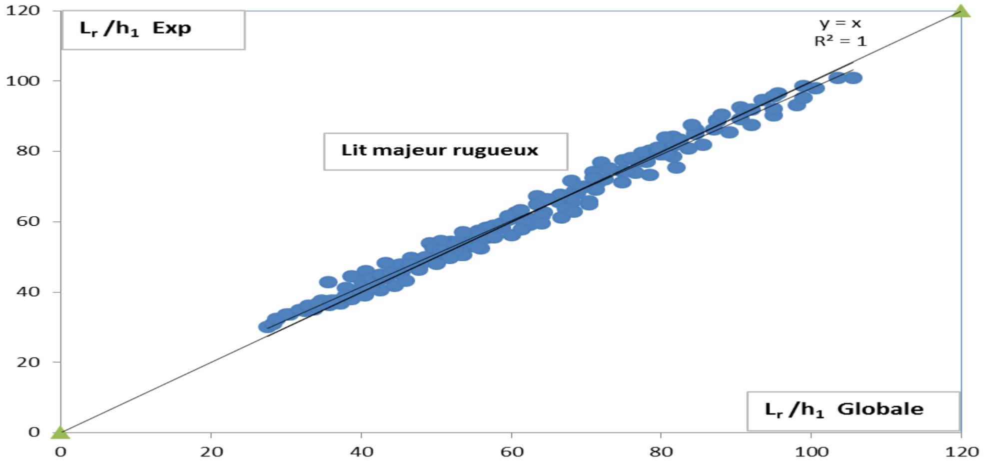


Fig.6. Graphic representation of experimental Lr/h1 as a function of global Lr/h1 of a rough major bed (—) First bisector

4 Hydraulic Jump Yield:

Expression of efficiency η=ΔH/H1 This relation makes it possible to explicitly calculate the yield of the hydraulic jump which occurs in a rectangular channel of rough and smooth compound shape, knowing Fr, Y, β and τ.

Assuming that the values of Y can be calculated by the following relation:

$$2F_1^2\left(\frac{\beta}{Y-(1-\beta)/\tau}-1\right)=1-\frac{(2Y-1/\tau)}{\tau}-\frac{(Y-1/\tau)^2}{\beta}-(Y-\frac{1}{\tau})(\frac{1}{\beta}-1)$$

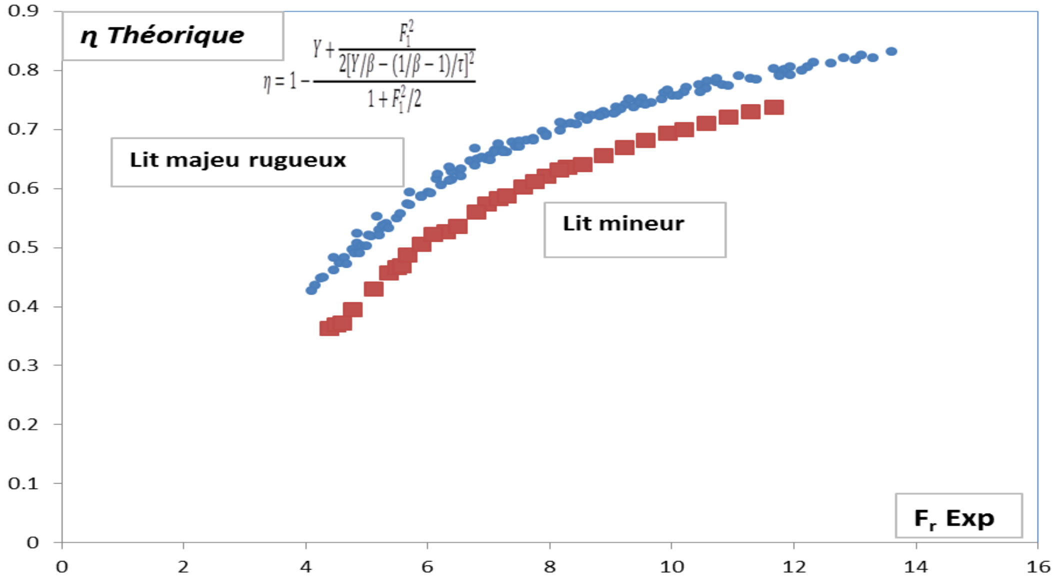


Fig.7. The variation of η as a function of Fr

Figure 7, presents the variation of η varying as a function of Fr. For a given τ and β, it is clearly shown in this figure that the efficiency η of a hydraulic jump evolving in a compound channel, increases proportionally with l increase in Fr. The relationship allows the calculation of the efficiency η*, Sinniger and Hager (1986) present an approximate expression, which applies for Fr >2:

$$\eta^*{}_{the}=\left[1-\frac{\sqrt{2}}{F_1}\right]^2 \qquad \eta_{exp}=1-\frac{Y+\frac{F_1^2}{2[Y/\beta-(1/\beta-1)/\tau]^2}}{1+F_1^2/2}$$

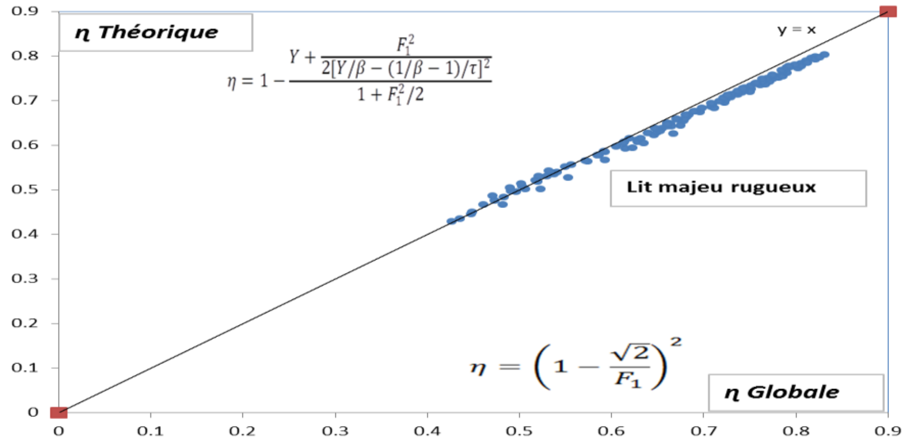


Fig.8. The variation of η_{exp} variant as a function of η theo

It can be seen from this figure that the hydraulic yield for the hydraulic jump is important depending on the importance of the roughness. Thus, the energy dissipation is remarkable depending on the importance of the roughness.

5. CONCLUSION

The analysis of all the experimental measurements obtained for the advanced hydraulic jump in a compound rectangular channel with a rough major bed gave us the following results: Explicit experimental relationships on the variation of the relative surface roll length Lr/h1 of the hydraulic jump with a rough major bed varying with the Froude number F1 for five tested roughness values have been obtained.

It was found that the reducing effect of the roughness imposed on the major bed, on the characteristics of the hydraulic jump is perceptible in the major bed than in smooth beds.

Finally, the experimental study was focused on the dissipation of kinetic energy. This is shown by the hydraulic efficiency. Consequently, the variation of the efficiency η with the Froude number F1 shows that the dissipation of kinetic energy is important by the creation of the hydraulic jump evolving in this type of experimental bench, generated primarily by the importance of the imposed roughness. in the major bed of the canal.

5. 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]
Lr	surface roll length [m]
(Lr/h_1)	surface roll relative length [ ]
Q	Volume flow [m^3/s]
R^2	Coefficient of determination
ε	height of the roughness elements [m]
(ε / B-b)	Relative roughness [ ]

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