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EXPERIMENTAL STUDY OF THE SEQUENT DEPTHS RATIO OF THE HYDRAULIC JUMP IN A RECTANGULAR COMPOUND CHANNEL WITH A ROUGH MINOR BED.

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ABSTRACT

The present knowledge on the behavior of hydraulic jumps is only for smooth, horizontal channel beds. Very limited studies have been reported in the literature on the performance of hydraulic jumps on rough beds.

The objective of our study is to investigate the sequent depth ratio of hydraulic jumps in a rectangular compound channel with a rough minor bed under different flow conditions using laboratory investigations. A series of experiments were carried out in a rectangular compound channel flume, which consists of artificially roughened beds formed by homogeneous plastic pellets.

The hydraulic parameters, such as first sequence depth h_1, second sequence depth h_2, and flow rate, were measured for different bed roughnesses. The analysis of experimental data showed that the rough bed reduces the sequent depth ratio more than those on smooth beds while creating a high energy loss. With the availability of a large number of experimental data on hydraulic jumps over rough channel beds, mathematical formulations were obtained to express the sequent depth ratio of hydraulic jumps to roughness parameters such as roughness height.

Keywords: hydraulic jump, sequent depth ratio, flow, rectangular compound channel, roughness bed.

INTRODUCTION

Hydraulic jump is a phenomenon that occurs by converting the supercritical to subcritical flow regimes downstream of hydraulic structures (Nasrabadi, 2021). Hydraulic jumps are a common phenomenon in free-surface flows in natural rivers, artificial canals, and industrial applications (De Leo, 2020). The formation and stabilization of a hydraulic jump in a stilling basin depend on the downstream depth of water in the channel. In cases where the downstream depth is low, the cross-section of the channel can be used to stabilize a hydraulic jump in a stilling basin. Increased energy dissipation is a more significant feature of a hydraulic jump in a non-prismatic channel compared to a prismatic channel (Daneshfaraz, 2021). This excess energy will hurt the banks of the bed if left unchecked. The biggest worry with baffled jumps is the potential for cavitation in upstream parts. In certain situations, the jumps would continue downstream (to an exposed streambed), causing erosion and possibly structural damage. Jumps on rough beds, on the other hand, would result in significant decreases in the required depth and length of the jumps. In a rectangular channel, he studied a turbulent hydraulic jump over a rough bed (Afzal, 2011). They discovered that the roughness of the inner layer bed had a passive role in imposing wall shear stress on the outer layer during a hydraulic jump (Türker, 2021). They offered analytical solutions for the sequential depth ratio, roller length, and jump depth and velocity profiles that are affected by the upstream. The kinetic energy factor, Froude number, and drag due to bed roughness are calculated. They stated that results for the hydraulic jump over a rough bed can be inferred simply from traditional jump theory by replacing the upstream Froude number with the effective upstream Froude number. The jumps that occur in a smooth-bed horizontal compound rectangular channel have been examined by a few authors (Khattaoui, 2012; Benabdesselam, 2020; and Riguet, 2020).

The major purpose of this study is to investigate the hydraulic jump characteristics in a rectangular compound channel with a rough minor bed and to find a relationship between bed roughness and hydraulic jump parameters. The creation of roughness on continuously and homogeneously constructed plastic pellets was used in this experiment.

MATERIAL AND METHODS

The experiments were conducted in a metal and plexiglass channel with a compound rectangular cross-section. The channel was 0.25 m wide, 0.5 m deep, and 10 m long. To obtain a rectangular compound channel, we glued boxes of transparent plexiglass on the walls of the canal, allowing the visualization of the flow at a length of 4 m (Figure.1).

The experimental discharge value was derived from Hachemi-Rachedi's accurate experimental relationship (2006).

The rough bed was created by gluing homogeneous plastic pellets onto a plastic plate that was placed on a 4 m long channel (Figure. 1), where we tested five different types of rough bed (= 06 mm; = 08 mm; = 10 mm, and = 12 mm).

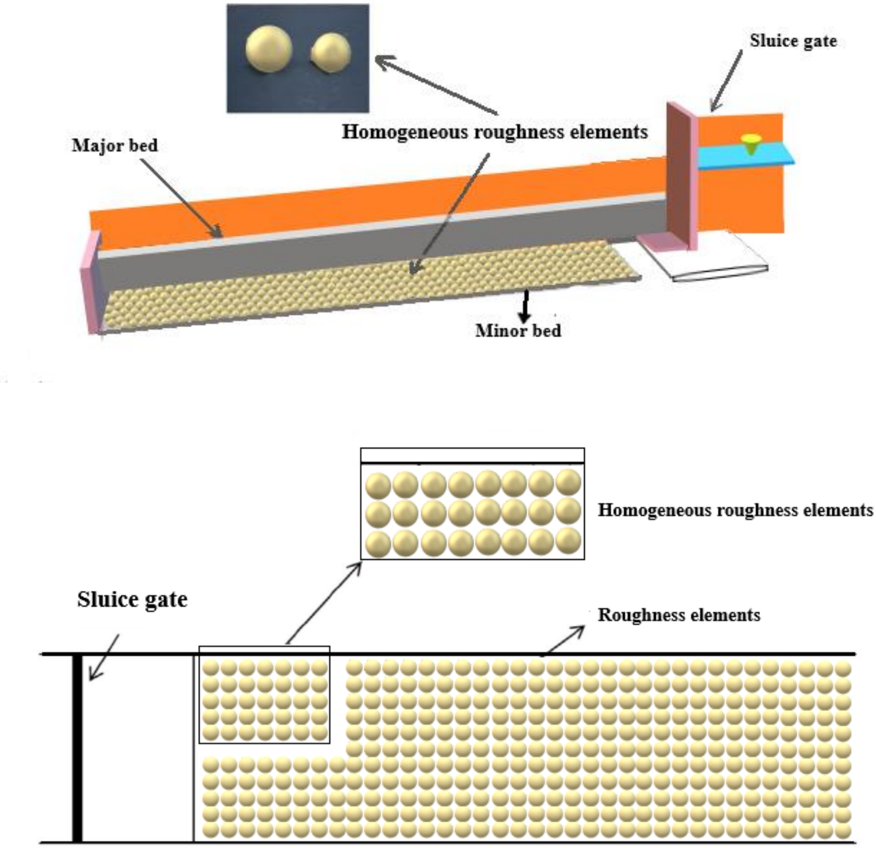

Figure 1: Rectangular compound channel with a rough minor bed

The experimental hydraulic jump controlled by a thin-walled sill in a rectangular channel with a rough minor bed was 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 (Djamaa, 2020; 2021). The bottom of the canal is perfectly horizontal (with no slope). A supply basin is connected to the channel using a circular pipe 150 mm in diameter. This is connected to a closed metal box into which is inserted an opening with a flat sheet metal wall of a 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 flow is adjusted by manipulating the valve. The channel is supplied by a pump delivering up to 55.55 l/s.

Figure 2: Experimental set-up used in this study.

The experiment was conducted under five initial sequent depth of flow: h_1 (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 thresholds of different heights (2.5 cm to 21 cm).

RESULTS AND DISCUSSION

Variation of sequent depth h_2/h_1 ratio with initial Froude number F_1 in the minor bed.

In Figure 3, the values of the sequent depth ratio h_2/h_1 of the jump were plotted vs. Froude numbers.

The findings of this investigation revealed that the sequent depth ratio h_2/h_1 of jump on rough minor bed 0 cm $\leq h_2 \leq$ 20 cm was smaller than sequent depth ratio Y of the jump with a smooth bed.

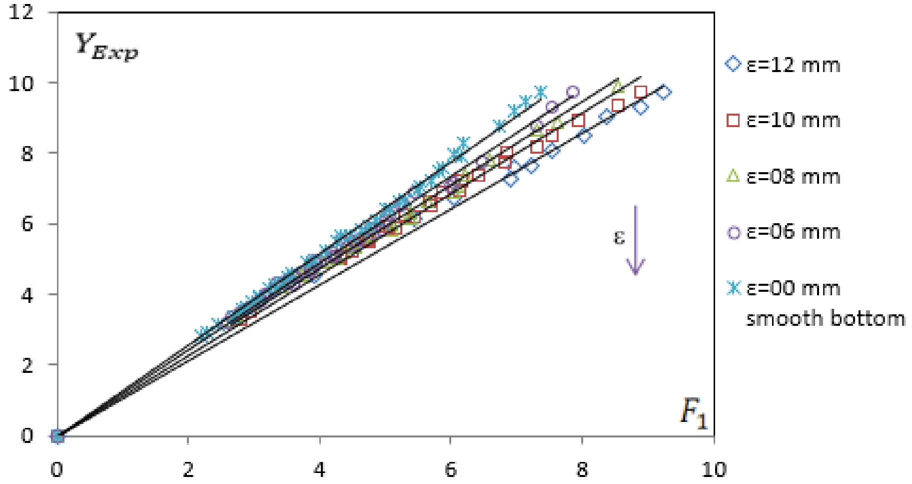

Figure 3: Shows the variation of the sequent depth ratio in the minor bed as a function of the initial Froude number, F_1. 00 cm ≤ h_2 ≤ 20cm, for five different roughnesses. (—) Adjustment curves.

Figure 3 shows the influence of a rough minor bed on sequent depth ratio. As the roughness increased, the sequent depth ratio decreased, as shown in the graph. For larger Fr_1 values, the magnitude of the decline is more apparent.

Furthermore, the study of the experimental measurement points of the rough minor bed of the hydraulic jump suggests that "ε" corresponds to a linear type curve of the form $h_2/h_1 = a_1$ for each roughness value (F_1). The values of coefficient a_1 are organized in Table 1 by the group.

Table 1: Coefficients a_1 of the adjustment curves

ε/b	**a_1**	**R^2**
0.08	1.072	0.982
0.067	1.142	0.989
0.053	1.184	0.99
0.04	1.224	0.994
0	1.288	0.996

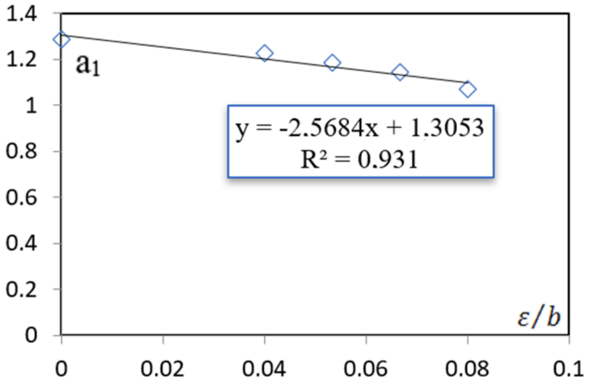

Figure 4: Variation of the coefficient " a_1" with the relative roughness ε/b in the minor bed

The adjustment of the pairs of values (a_1, ε/b) in table 1 resulted in a good correlation according to the following linear relationship: $R^2 = 0.931$ and $a_1 = -2.5684 * (\varepsilon/b) + 1.3053$. Fig. 5 illustrates this equation. As illustrated in the equation, the sequent depth ratio, the Froude number, and the relative roughness ε/b have a relationship (1). Then the values of the subsequent depth ratio for each experiment on the rough minor beds were calculated.

$$\frac{h_2}{h_1} = [-2.5684(\varepsilon/b) + 1.3053]F_1 \qquad \textit{(1).}$$

with $0 \le \varepsilon/b \le 0.08$. Equation (1) was used to calculate the following depth ratio, which was then compared to the measured values (Figure 5). The proposed link produced a result that differed by about ± 6% from the measured values, as seen in the graph.

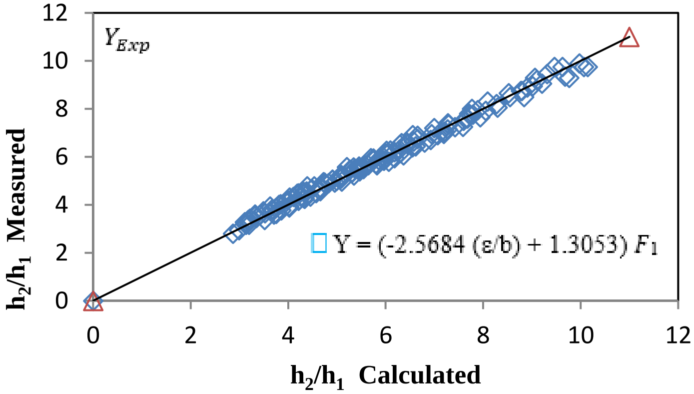

Figure 5: Measured vs. calculated values (using Equation 1) of h_2/h_1. (—) First bisector.

Variation of sequent depths ratio h_2/h_1 ratio with initial Froude number F_1 in the major bed

In figure 6, the values of the jump's sequent depth ratio h_2/h_1 were plotted with Froude numbers F_1. The sequent depth ratio h_2/h_1 of a jump on a rough major bed ($20\ \text{cm} \leq h_2 \leq 50$) was also smaller than the sequent depth ratio of a jump on a smooth bed.

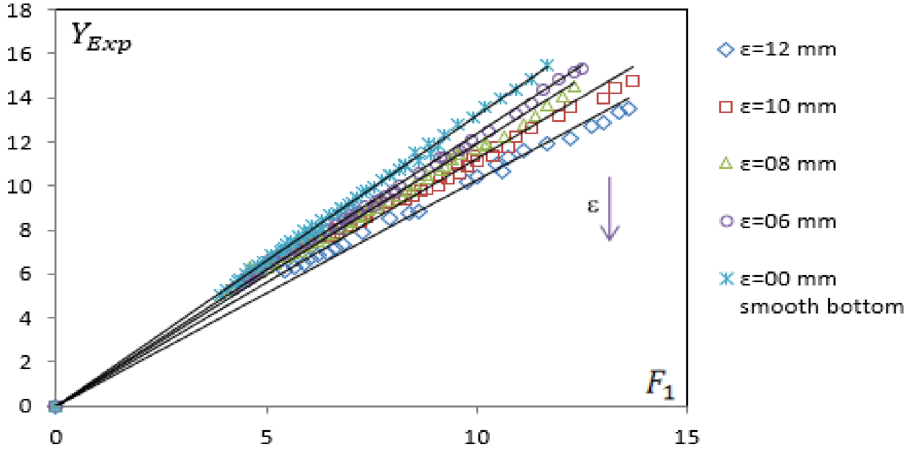

Figure 6: In a major bed, the variation of the sequent depth ratio with the initial Froude number F_1, $20\ \text{cm} \leq h_2 \leq 50$, for five different roughnesses. (—) Adjustment curves

Figure 6 illustrates the influence of a rough minor bed on sequent depths ratio. As the roughness increased, the sequent depth ratio Y decreased, as shown in the graph. For larger Fr_1 values, the magnitude of the decline is more noticeable. Furthermore, an examination of the experimental measurement points of the rough minor bed of the hydraulic jump shows that for each roughness value « ε » a linear type curve of form $h_2/h_1 = a_2$ corresponds (F_1). The values of coefficient a_2 are organized in Table 2.

Table 2: Coefficients a_2 of the adjustment curves

ε/b	a_2	R^2
0.08	1.029	0.987
0.066	1.122	0.986
0.0533	1.192	0.987
0.04	1.235	0.996
0	1.319	0.998

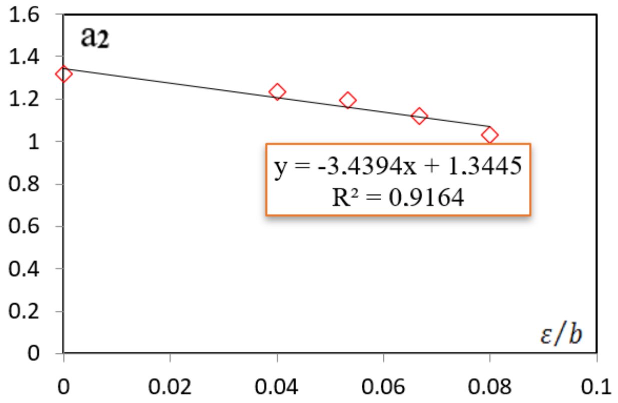

Figure 7: Variation of the coefficient " a2 "with the relative roughness (ε/b) in the major bed.

Adjustment of value pairs (a_2, ε / b) of the table 2, plotted in Fig. 7, made it possible to arrive with a good correlation to the following linear relationship: $a_2 = -3.4394\ (\varepsilon/\ b\ ) + 1.3445$. The equation linking the sequent depth ratio h_2/h_1, the Froude number F_1 and the relative roughness (ε / b) for the major bed is written:

$$\frac{h_2}{h_1} = [-3.4394(\varepsilon/b) + 1.3445]F_1 \qquad (2).$$

with $0 \leq \varepsilon/b \leq 0.08$. Equation (2) was used to calculate the sequent depth ratio, which was then compared to the measured values (Figure 8). The result provided by the proposed relationship indicated a ± 7% difference with the corresponding measured values, as shown in the figure.

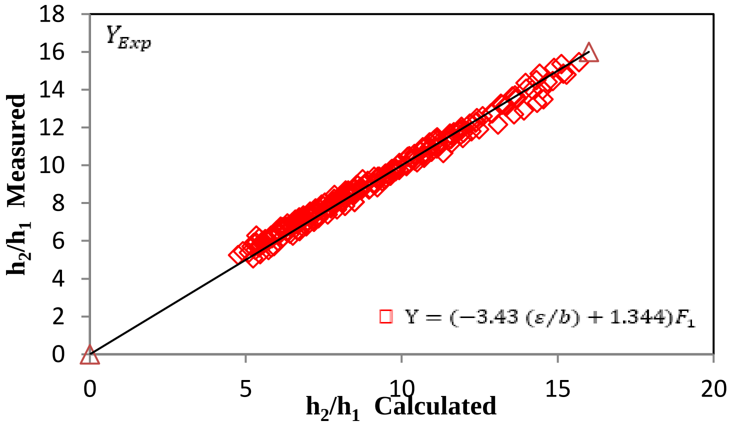

Figure 8: Calculated vs. measured values (using Equation 2) of h_2/h_1 (—) First bisector.

The values of sequent depth ratio (h_2/h_1) Measured vs. calculated obtained in the present research for two cases (minor bed and major bed) were also compared in the same figure (Figure 9). The effect of the composite section on the jump can be observed in the figure, and we can see that the roughness elements had a significant impact on the jump. As a result, we've accomplished our objective.

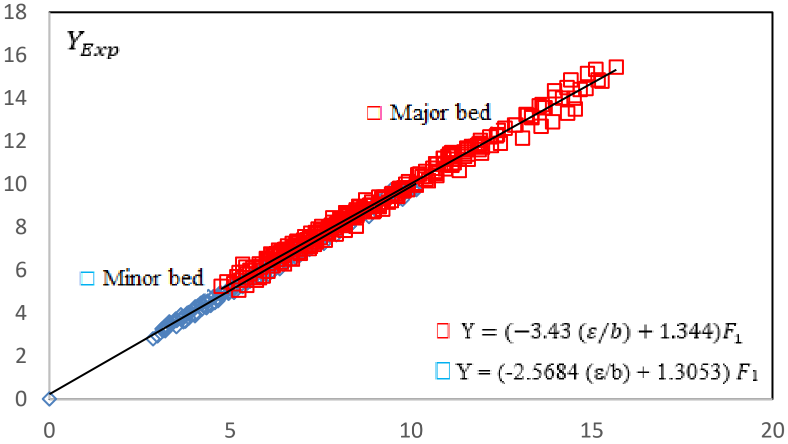

Figure 9: Variation of sequent depth ratio (h_2/h_1) Measured vs. calculated obtained in the present research for two cases (minor bed and major bed).

CONCLUSION

The objective of this research was to determine the effect of bed roughness height on the sequent depth ratio of a hydraulic jump in both the minor and major beds. The obtained data demonstrated that the channel roughness height had a substantial effect on the sequent depths ratio, according to the analysis. Based on global experimental approaches $h_2/h_1 = f\ (F_1, \varepsilon/b)$ where we found we can determine the sequent depth ratio, results that are useful in the design of stilling basins (geometrical properties). Given a stilling basin with a known inflow Froude number and flow depth, the engineer must decide the end sill dimensions and the basin length so that the hydraulic jump is contained in the stilling basin. Finally, from comparison of the measurement results and experiments (Figure 06 and Figure 09), it can be concluded that the approaches $h_2/h_1 = f\ (F_1, \varepsilon/b)$ can be used to calculate measurements in stilling basins with acceptable accuracy.

REFERENCES

ABBASPOUR A., HOSSEINZADEH DALIR D., FARSADIZADEH A., SADRADDINI A.S. (2009). Effect of sinusoidal corrugated bed on hydraulic jump characteristics, Journal of Hydro-environment Research, Vol. 3, No 2, pp. 109-117.

AFZAL N., SEENA A., BUSHRA A. (2011). Analysis of turbulent hydraulic jump over a transitional rough bed of a rectangular channel: universal relations, Journal of Engineering Mechanics, Vol. 137, No 12, pp. 835-845.

BENABDESSELAM A. (2020). Theoretical and experimental approach of the hydraulic jump in a compound channel profile, Doctoral thesis from Mohamed Khider Biskra University, Algeria, In French.

DANESHFARAZ R., AMINVASH E., MMIRZAEE R. (2021). Predicting the energy dissipation of a rough sudden expansion rectangular stilling basins using the SVM algorithm. Journal of Applied Research in Water and Wastewater, Vol. 8, No 2, pp. 98-106.

DE LEO A., RUFFINI A., POSTACCHINI M., COLOMBINI M., STOCCHINO A. (2020). The effects of hydraulic jumps instability on a natural river confluence, The case study of the Chiaravagna River (Italy), Water, Vol. 12, No 7, pp. 20-27.

DJAMAA W., GHOMRI A. (2020). Study of the experimental approach of the relative length of the surface role of the hydraulic jump evolving in the rectangular channel of a section composed with the rough bottom, Journal of Fundamental and Applied Sciences, Vol. 12, No 3, pp. 1190-1203.

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 the composed section with a rough minor bed, Journal of Fundamental and Applied Sciences, Vol. 13, No 2, pp. 1079-1092.

HACHEMI RACHEDI L. (2006). Analysis of a flow through a lateral contraction, Magister thesis, Mohamed Khider Biskra University, Algeria, In French.

KHATTAOUI M., ACHOUR B. (2012). Hydraulic jump in a compound channel, Le Journal de l'Eau et de l'Environnement, Vol. 11, No 20, pp. 44-51, In French.

NASRABADI M., MEHRI Y., GHASSEMI A., OMID M. (2021). Predicting submerged hydraulic jump characteristics using machine learning methods, Water Supply, Vol. 21, Issue 8, pp. 4180-4194.

RIGUET F., DEBABECHE M., GHOMRI A. (2020). Experimental study of the sequent depth ratio of the hydraulic jump in a straight compound rectangular channel, Journal of Fundamental and Applied Sciences, Vol. 12, No 1S, pp. 56-65.

TURKER U., VALYRAKIS M. (2021). Hydraulic jump on rough beds: conceptual modeling and experimental validation, Water Supply, Vol. 21, No 4, pp. 123-143.