

Field Experiments on Hydraulic Jump in a Sloped Triangular Channel

ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

Triangular ditch irrigation may be used to raise the downstream water surface. In this paper hydraulic jump in a sloped triangular channel of 90° central angle has been studied and analyzed using field experiments. The paper aims to determine the effect of the triangular channel's bed slope on the hydraulic jump characteristics such as sequent depth ratio, relative jump height, relative energy loss, and the relative jump length. For this motive, nine positive slopes were tested. The obtained results were represented in dimensionless curves and empirical models using Buckingham's π -Theorem. The developed curves and empirical computational models were used to estimate the different hydraulic jump characteristics for different initial Froude number and triangular channel bed slope. Also, the obtained results were compared with the pervious results of horizontal triangular channel layout.

Keywords: hydraulic jump, triangular channel, positive slope, open channels, irrigation ditches.

List of Symbols

E_1 = Energy upstream the jump (m)
 E_2 = Energy downstream the jump (m)
 E = Relative energy loss = $(E_1 - E_2)/E_1$ (-)
 F_1 = Initial Froude number (-)
 g = Gravity acceleration (ms^{-2})
 H = Relative jump height = $(y_2 - y_1)/y_1$ (-)
 L = Relative jump length = L_j/y_1 (-)
 L_j = Jump length (m)
 S = bed slope (-)
 y_1 = Initial depth (m)
 y_2 = Sequent depth (m)
 Y = Sequent depth ratio = y_2/y_1 (-)

1. INTRODUCTION

Hydraulic jump in a triangular open channel has not studied with a great interest that granted his counterpart of the rectangular channel. However, although rare studies were devoted to suggest that, the hydraulic jump in a triangular channel is much more advantageous vis-a-vis the energy dissipation and requires a lower sequent depth to the same initial value of Froude number Hager and Wanoschek [1]. However, the cross section geometry depends on the stability of the formed jump the earliest known studies are those of Argyropoulos [2], Rajaratnam [3], and Silvester [4]. The first and second leds used a symmetrical channel 47o and 60o opening angles respectively. The results showed, as a general rule, the momentum equation remains sufficient to evaluate the sequent depth ratio, Y of the jump, and the obtained experimental Y values are slightly lower than the theoretical Y values. This difference was about 5% which is also observed by Hager and Wanoschek [1] for 90o triangular channel opening angle. Larry [5] concluded that the main design and analysis principles of open channel flow are valid for ditches. Achour and Debabeche [6] showed that the formed hydraulic jump in triangular ditch may be used to raise the downstream water surface. Das [7] used solutions of quadratic and cubic equations for

determination of alternate depths and sequent depths in trapezoidal, rectangular and triangular channels. Vatankhah and Kouchakzadeh [8] presented solutions of specific energy and specific force equations in trapezoidal, rectangular and triangular open channels using iterative fixed-point method. In 2010, Vatankhah [9] solved analytically the specific energy and specific force equations for the three channel cross sections. Vatankhah and Omid [10] showed steps to reach an acceptable physical analytic solution for sequent depth ratios in horizontal triangular channels. Rashwan [11] developed accuracy equations for calculating hydraulic jump elements for given initial conditions but using equation depend on estimation value for relative head loss. Achour and Debabeche [12] investigated theoretically and experimentally, the hydraulic jump in a sloped triangular channel with a central angle of 90°. Mahmoud [13] studied experimentally the effect of rectangular channel bed slope on the hydraulic jump characteristics.

The present paper carried out field experiments on hydraulic jump in a sloped bed triangular channel with a central angle of 90°. Empirical computational models for different hydraulic jump characteristics were developed and calibrated to estimate any of hydraulic jump characteristic for given initial Froude number and bed slope.

2. EXPERIMENTAL PROCEDURE

The present paper carried out field experiments on a triangular channel with central angle of 90° with dimensions of 2.50 x 0.40 x 0.40 m. Series of runs at different values of discharge were conducted and hydraulic jump was formed by operating the tail gate and sluice gate. For each run initial depth, y_1 sequent depth y_2 and length of hydraulic jump L_j were recorded. The above steps were performed sequentially at different valve openings. The discharge in the channel was supplied from artesian well and it is measured with a calibrated sharp crested rectangular weir. y_1 , y_2 , and height of water flowing over the weir crest were measured with point gauge, Figure 1. Nine bed slopes, S with values of 0 (horizontal bed), 0.01, 0.02, 0.03, 0.035, 0.04, 0.05, 0.07, and 0.11 were used.

3. RESULTS AND DISCUSSIONS

Variations of different hydraulic jump characteristics such as Y , relative jump height $H ((y_2 - y_1)/y_1)$, relative jump length $L (L_j/y_1)$, and relative energy loss $E ((\text{initial energy}, E_1 - \text{sequent energy } E_2)/E_1)$ with initial Froude number, F_1 and channel bed slope, S are given below.

3.1 Variation of Y with F_1 and S

Figure 2 shows that Y increases with increase in F_1 and S . It is evident from the figure that the least square root, R^2 of the fitted lines has values of 0.97 to 0.99.

3.2 Variation of H with F_1 and S

It is observed from the obtained data that H increases as F_1 and S increase. It is evident from the figure that approximately over than 96% of the results are lying within $\pm 10\%$ of the fitted lines, as shown in Figure 3.

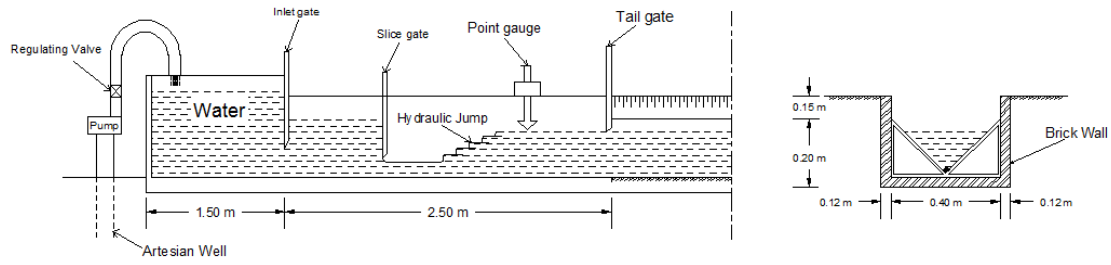


Figure 1 Schematic layout of experimental setup

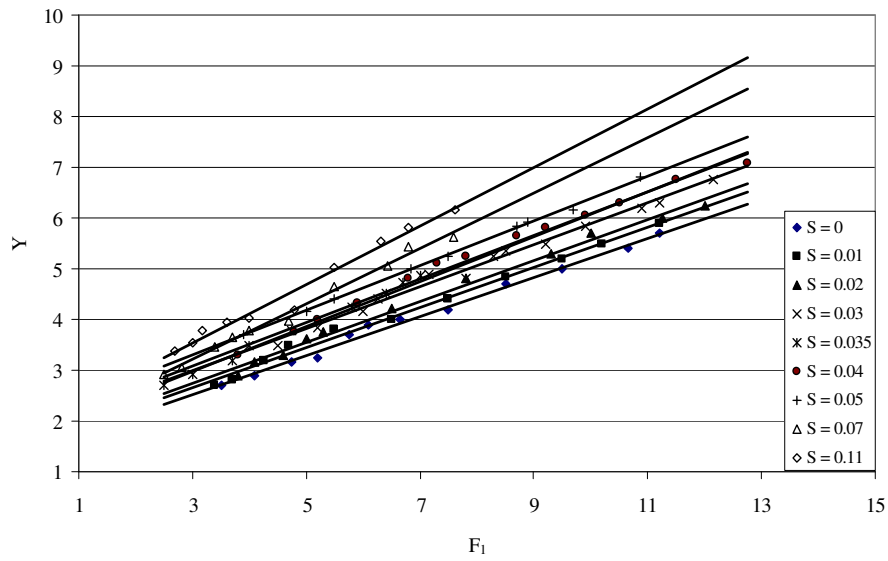


Figure 2 Variation of Y with F_1 at different S

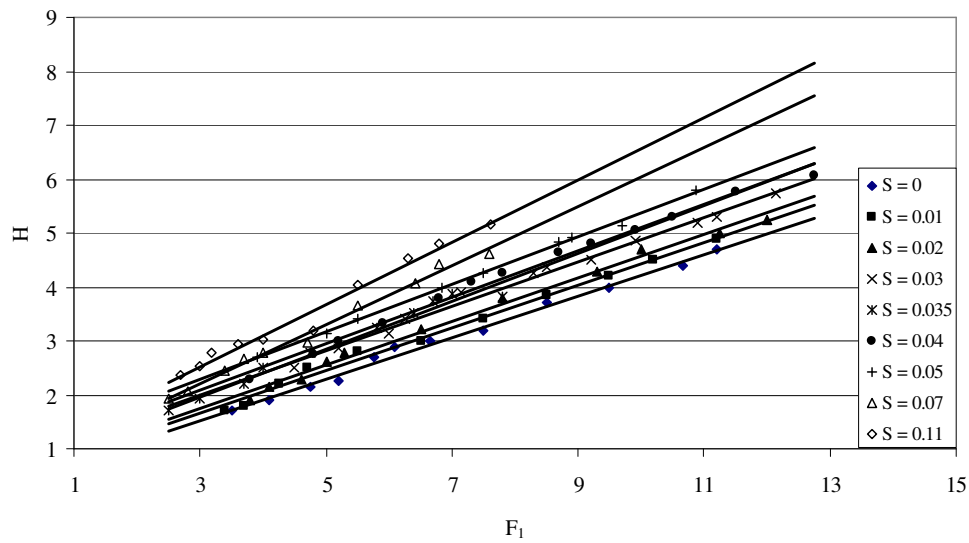


Figure 3 Variation of H with F_1 at different S

3.3 Variation of E with F_1 and S

From the Figure 4, it is observed that E increases with increase in F_1 and decreases with increase S. It shows also, that approximately over 98% of experimental data are lying within $\pm 10\%$ of the fitted lines.

3.4 Variation of L with F_1 and S

Through the analysis of the obtained data in this section, it was found that L increases with increase in F_1 and decreases with increase in S. Approximately over than 97% of experimental data are lying within $\pm 10\%$ of the fitted lines, see Figure 5.

The reason of deviation of few data points from the fitted lines may be due to inaccuracy in measurement of y_1 , discharge and L_j .

3.5. Empirical computational models

Using Buckingham's π -theorem and regression analysis of the obtained experimental data, empirical computational models were developed. On the basis of linear fitting between Y, H, E, and L and dimensionless sequent depth factor I_D , jump height factor I_H , energy loss factor I_E , and jump length factor I_L respectively, the empirical models were developed, Equations (5,6,7, and 8). The values of Y, H, E, and L can be estimated using the fitted lines in Figures (6,7,8, and 9) or directly from Equations (5,6,7, and 8). Also, Figures (6,7,8, and 9) show comparison of Y, H, E, and L of these equations with the model equations developed by Debabeche (2009) and Rashwan (2013). It was observed that approximately all the model data of Debabeche (2009) are close to the present model but the model equation developed by Rashwan (2013) gives values beyond the present model this may be due to his model requires an estimation value of the dimensionless head loss. It proves that the present model and Debabeche model are equally better than the model of Rashwan.

Where

$$I_D = 0.4482 F_1 + 8.7798 S + 1.4194 \quad (1)$$

$$I_H = 0.4482 F_1 + 8.7798 S + 0.4194 \quad (2)$$

$$I_E = 0.1202 F_1 - 2.0668 S - 0.1176 \quad (3)$$

$$I_L = 5.9695 F_1 - 45.854 S + 6.1432 \quad (4)$$

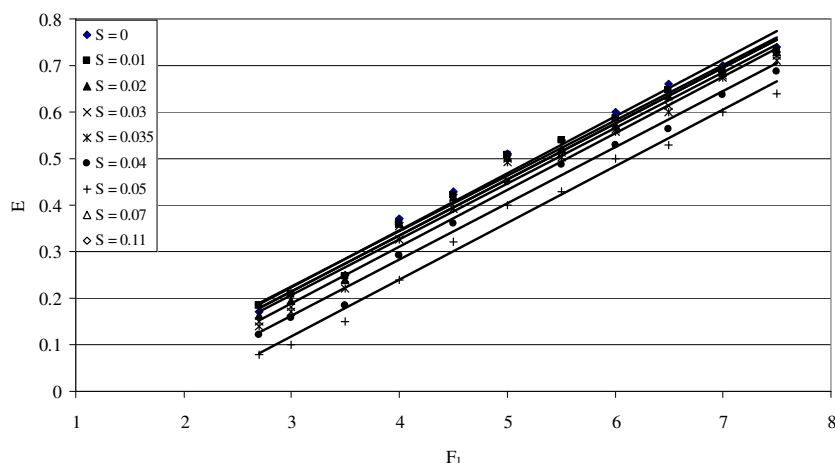


Figure 4 Variation of E with F_1 at different S

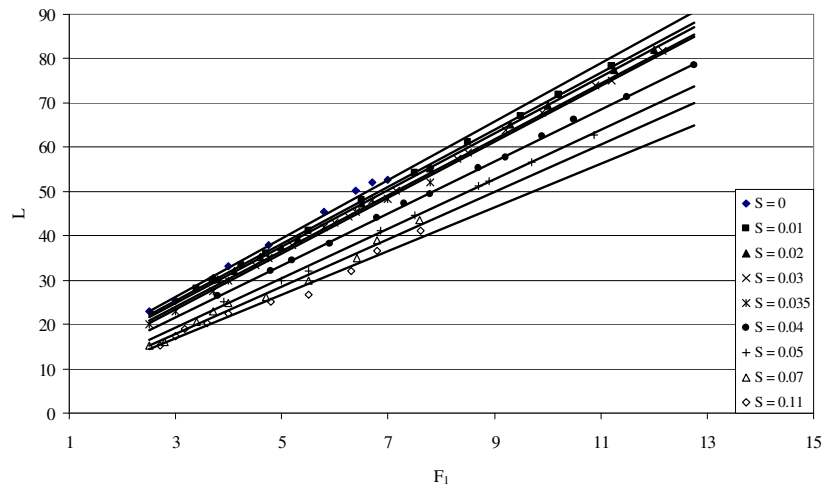


Figure 5 Variation of L with F_1 at different S

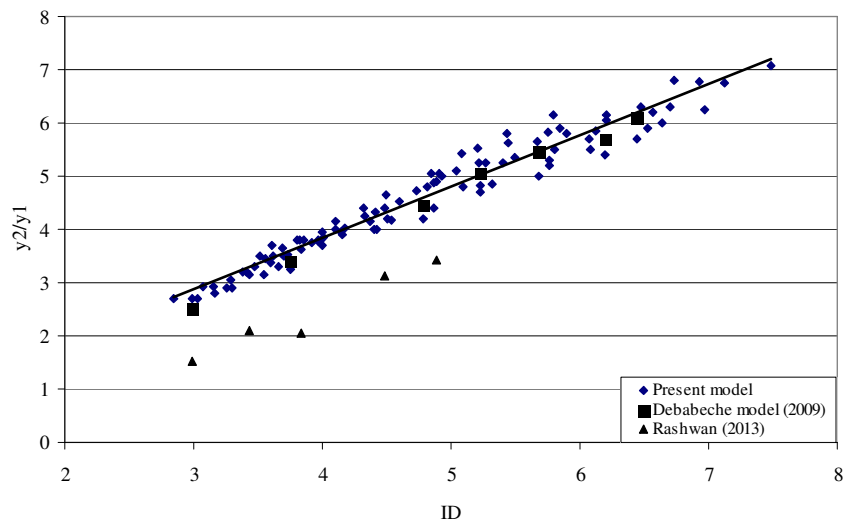


Figure 6 Comparison of model Equation 5 with Debabeche and Rashwan models

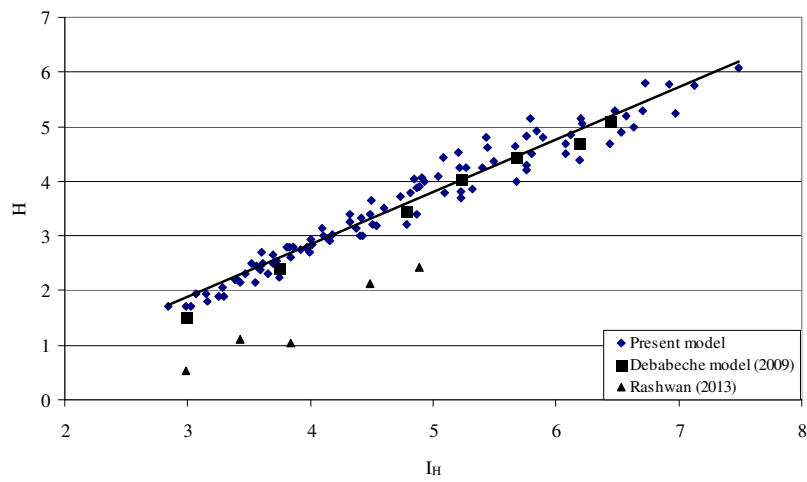


Figure 7 Comparison of model Equation 6 with Debabeche and Rashwan models

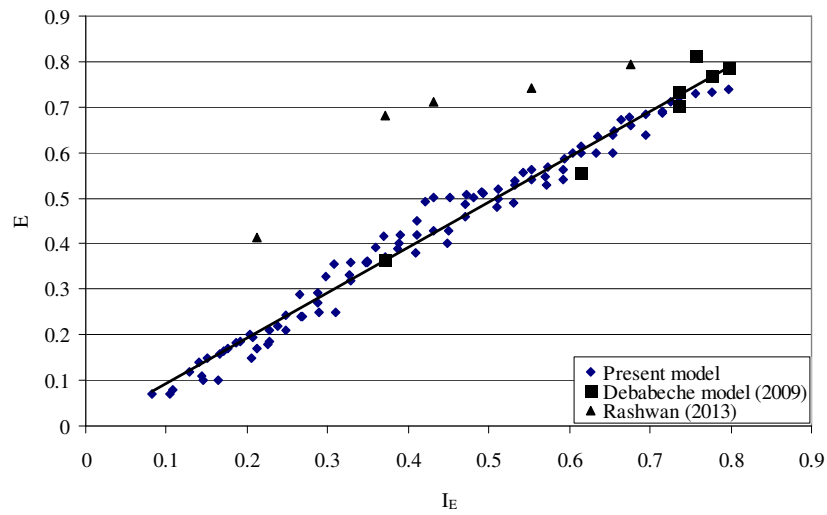


Figure 8 Comparison of model Equation 7 with Debabeche and Rashwan models

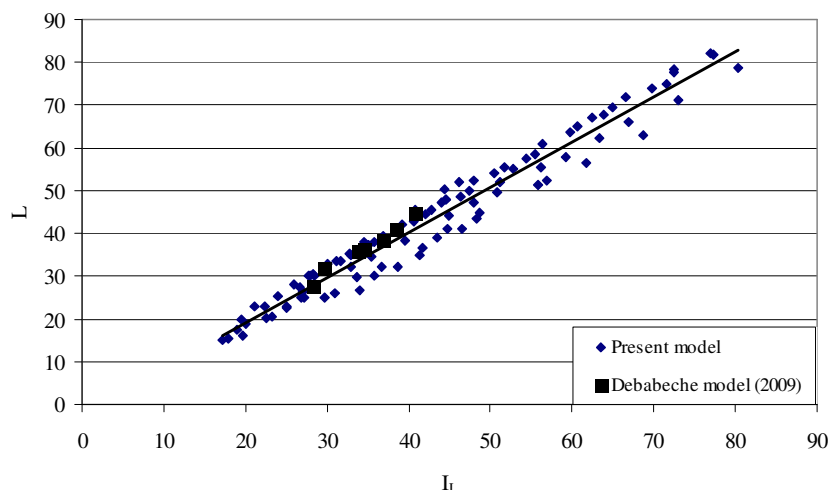


Figure 9 Comparison of model Equation 8 with Debabeche model

$$Y = 0.4315 F_1 + 8.4532 S + 1.3504 \quad (5)$$

$$H = 0.4315 F_1 + 8.4532 S + 0.3504 \quad (6)$$

$$E = 0.1193 F_1 - 2.0511 S - 0.1222 \quad (7)$$

$$L = 6.302 F_1 - 48.408 S + 4.464 \quad (8)$$

4. CONCLUSION

Through the analysis of the obtained field experimental results of hydraulic jump in triangular channel with different bed slopes, the following conclusions were obtained;

- 1- For a given bed slope, S , the hydraulic jump characteristics, Y , H , E , and L increase with the increase of the initial Froude number, F_1 .
- 2- At a known Froude number, F_1 , Y and H increase with the increase of the bed slope, S but E and L decreases with the increase of S .
- 3- The developed empirical computational models are applicable to be used for estimating the values of hydraulic jump characteristics, Y , H , E , and L for given F_1 and S .

REFERENCES

- 1- Hager, W.H. and Wanoschek, R. hydraulic jump in a triangular channel, "J. Hydraulic Research, 25 no 5, 549-564, 1985
- 2- Argyropoulos, P.A. General Solution of the Hydraulic Jump in Sloping Channels, Proc. ASCE, J. Hydr. Div., 88(HY4), 61-75., 1962
- 3- Rajaratnam, N. The Forced Hydraulic Jump, Water Power, January, 14-19, February, 61-

- 137 65.,1964
- 138 4- Silvester, R. Hydraulics Jumps in all Shapes of Horizontal Channels. Proc. ASCE, J. Hydr. Divi.,
139 90, 23–55, 1964
- 140 5- Mays Larry W. Hydraulic design handbook. McGraw Hill, 1999
- 141 6- Achour B, Debabeche M. Control of hydraulic jump by sill in triangular channel. J Hydraulic Res;
142 41(1):319–25, 2003
- 143 7- Das A. Solution of specific energy and specific force equations; trapezoidal and triangular
144 channels. J Irrigat Drain Eng, ASCE;134(4):407–10, 2007
- 145 8- Vatankhah Ali R, Kouchakzadeh S. Discussion of solution of specific energy and specific force
146 equations. In: Das A. Journal of irrigation and drainage engineering ASCE; vol. 134(6). p. 880–
147 82, 2008
- 148 9- Vatankhah Ali R. Analytical solution of specific energy and specific force equations; trapezoidal
149 and triangular channels. Adv Water Res;33:184–9, 2010
- 150 10- Vatankhah Ali R, Omid MH. Direct solution to problems of hydraulic jump in horizontal triangular
151 channels. Appl Math Lett;23:1104–8, 2010
- 152 11- Rashwan I.M.H. Analytical solution to problems of hydraulic jump in horizontal triangular
153 channels. Ain Shams Engineering Journal 4, 365–368, 2013
- 154 12- Achour B. and Debabeche M. Hydraulic jump in a sloped triangular channel. Can. J. Civ. Eng.36:
155 655–658, 2009
- 156 13- Mahmoud R. Eltokhy, Hydraulic jump characteristics for different open channel and stilling basin
157 layouts. International Journal of Civil Engineering and Technology (IJCIET) Volume 7, Issue 2,
158 pp. 290–301, 2016