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Experimental Investigations on Hydraulic Jump Characteristics for Different Hydraulic and Geometric Conditions

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Abstract

Changing the flow condition from supercritical to subcritical flow causes hydraulic jump phenomenon with considerable energy dissipation and rise in depth of flow. This phenomenon primarily serves as an energy dissipater to dissipate excess energy of flowing water downstream of hydraulic structures. This study has been carried out in the Hydraulic Laboratory, Department of Irrigation and Hydraulics, Cairo University. The main objective of this study is to investigate the hydraulic jump characteristics for different hydraulic and geometric conditions. Changing flow discharge and the flow through one or two vents are considered as hydraulic conditions, and pier length and the fence location and porosity are considered as geometric conditions. Results show that sequent depth and hydraulic jump height ratios increase with Froude number for the two vents inflow, also energy loss ratio increases with Froude number but for one vent inflow. It was, also found that the formed whirl length and the hydraulic jump length ratios increase with the increase of pier length and fence porosity. All results were interpreted in forms of dimensionless curves and equations, which are used to estimate the hydraulic jump characteristics for given hydraulic and geometric conditions.

Keywords: *Hydraulic jump; sequent depth; porous fence; energy losses; whirl length.*

SYMBOLS

F_1 = Initial Froude number (-); g = Gravity acceleration (ms^{-2}); Y_1 = Initial depth (m); Y_2 = Sequent depth (m); E_1 = Energy upstream the jump (m); E_2 = Energy downstream the jump (m); ΔE = Energy loss $=E_1- E_2$ (m); n = Fence porosity (-); L_F = Fence distance downstream the gate (m); L = The formed whirl length with fence (m); L_W = The formed whirl length without fence. (m); L_j = Jump length (m);H_j = Jump height (m); B = Flume width (m); Y_2/Y_1 = Sequent depth ratio (-); $\Delta E/E_1$ = Energy loss ratio (-); H_j/Y_1 = The jump height ratio (-); L_j/Y_1 = The jump length ratio (-); L/B = Whirl length ratio (-); L/L_W = Whirl length with fence to whirl length without fence (-)

INTRODUCTION

The transition from supercritical to subcritical open channel flow is characterized by a strong dissipative mechanism called hydraulic jump (Hubert C., 2011). Hydraulic jump is a phenomenon well known to hydraulic engineers as a useful for dissipating excess energy and hence prevent erosion of the channel cross section. (Ebrahimi et al. 2013) studied the numerical study of hydraulic jump on rough beds stilling basins. The results showed that the sequent depth and length of hydraulic jump are reduced while the energy loss is increased, comparing with classic jump. In addition, there was a good agreement between modeled results and experimental data. Roughness shapes in stilling basins bottom can control hydraulic jump. Recently, some investigations have been carried out on hydraulic jump on rough beds. Many different roughness shapes in basin bottom have been studied experimentally by (Izadjoo and Shafai - Bajestan 2005). (Neveen B. 2015), investigated the effect of channel slope on the characteristics of free hydraulic jump and the energy dissipation downstream the gate. It was found that the bottom slope and the inlet Froude number have major effect on the variations of the jump outlet characteristics.

(Mahmoud R. 2016), investigated the hydraulic jump characteristics variations for different rectangular open channel layouts. A new equation was developed to design stilling basin. (Saideh 2013), studied numerical study of hydraulic jump on rough beds Stilling Basins. The computed values were then compared to the experimental values obtained by Elsebaie and (Shabayek 2010). (Rahman et al. 2014), showed that the hydraulic problem of energy dissipation over stepped-gabion weirs by carrying out a series of laboratory experiments. (Hamidreza et al. 2014), Computated Modeling of the Hydraulic Jump in the Stilling Basin with Convergence Walls Using CFD Codes. Theoretical models were developed for computing the relative depth and relative energy loss of submerged hydraulic jump formed in non-prismatic channel reach in the form of radial stilling basin with a vertical drop, (Negm, et al. 2003). Stefano et al. 2008 showed the evaluation of the energy dissipation on block ramps in different submerged conditions. The dissipative process mainly depends on the parameter k/H, on the ramp scale roughness, and on the ramp submergence conditions.

(Meshkati et al. 2014), investigated the influence of different geometry of in-ground stilling basin (ISB), e.g. ISB length, ISB depth, on the flow pattern and its performance in energy dissipation. (Gamal et al. 2017), studied Improving energy dissipation on stepped spillways using breakers.

In the present paper hydraulic jump characteristics have been studied experimentally for different hydraulic and geometric conditions. It was studied the effect of water inflow through one or two vents, pier length and the location and porosity of porous fences on the characteristics of hydraulic jump and the length of the formed whirl.

EXPERIMENTAL FLUME

Laboratory experimental runs were carried out in the Hydraulics Laboratory of the Faculty of Engineering, Cairo University. The experiments were carried out on a horizontal rectangular laboratory flume as shown in Fig 1. The flume has dimensions of 7 m length, 1 m width and 36 cm depth. The sidewalls along the entire length of the flume are made of steel and covered inside with acrylic glass. The water entered the flume from an external water source, the flow passed an intake gravel tank and a screen to reduce turbulence at the flume entrance, Fig 2. The flume is provided with a calibrated digital flow meter, fitted at the flume inlet for discharge measurement. A point gauge of ±0.1 mm reading accuracy is implemented for measuring water depth. An over-shot weir is installed at the end of the channel to control water depth. Moreover, the location of hydraulic jump can be determined by varying the gate openings. The gate opening was changed through the experiments. Four wooden piers with different lengths of 15, 20, 25, and 30 cm, width of 10 cm and height of 20 cm were used as geometric parameters to show the effect of pier length on the hydraulic jump characteristics, Fig 3. Four metal porous fences with different porosities of 56, 72, 80, and 90% were used to determine the effect of fence location and porosity on energy dissipation and the length of whirl.

Fig 1: Flume Layout

Fig 2: Gravel and Screen Intake

Fig.3: Piers with Different Lengths

EXPERIMENTAL METHODOLOGY

Three sets of the experimental runs were conducted. The first set deals with the effect of number of inflow vents, which are opened, (one vent or two vents) on the hydraulic jump characteristics. The second set of experimental runs concerned on the variation of hydraulic jump length and the formed whirl length with the pier length. Finally, the third set studied the effect of fence location and porosity on the formed whirl length and the energy loss.

Each set of runs at different values of discharge were experimented and hydraulic jump was formed by operating the tail gate and sluice gate. A control valve was used to regulate the discharge. For each run initial depth, sequent depth, length of hydraulic jump, and whirl length were measured. The above steps were performed sequentially at different valve opening for free hydraulic jumps, different piers, and different fence location and porosity. Table 1 provides typical conditions used in experimental work for different shapes tests.

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Table 1: experimental setup condition

Run	Pier type	Vent cod.	F_1	Fence porosity %	distance to the fence, cm
G1	----	One, two vents	1.1, 1.18, 1.5, 1.7, 2.8	100	----
G3	I (L=15cm)	One, two vents	1.9, 2.6, 3.3. 4, 4.3	100	----
G5	II (L=20cm)	One, two vents	2.1, 2.7, 3.4, 4.84	100	----
G7	III (L=25cm)	One, Two vents	2.2 2.7, 2.8, 4.15, 4.8	100	----
G9	IV (L=30cm)	One, Two vents	2.2, 3.6, 5.95, 6.4, 8, 8.5	100	----
G11	I, II, III, IV	Two vents	4.5	100	----
G15	II	Two vents	2.92, 3.36, 5, 5.1	56, 72, 80, and 90	22, 50, 100, 150
G25	II	One vent	2.3, 5.6	56, 72, 80, and 90	22, 50, 100, 150, 185
G35	II	Two vents	4.3, 5.8, 7.5, 8.9, 16.5	Without, 56, 72, 80, and 90	Without , 50

RESULTS AND ANALYSIS

First of all, the flume was calibrated by carrying out six runs and the obtained results were compared with that obtained by Belanger, J. B. Equation $\frac{Y_2}{Y_1} = \frac{1}{2}\left[-1+\sqrt{1+8F_1^{\,2}}\right]$, which represent the relation between the initial Froude number F_1 the sequent depth ratio (Y_2/Y_1) see Fig 4. The figure shows that the measured dates are closed to the calculated.

Effect of the Number of Opened Vents on the Hydraulic Jump Characteristics:

The first set of experimental runs was performed to study the effect of using one or two sluice gate vents on the hydraulic jump characteristics. Fig 5 shows that the sequent depth ratio, Y_2/Y_1 increases with initial Froude number, F_1. Also, Fig 5 illustrates that for given pier length and initial Froude number, F_1 the sequent depth ratio, Y_2/Y_1 of using one vent is less than that of using two vents for water inflow. For example, at Froude's number with value of 3 and pier length of 20 cm, the sequent depth ratio Y_2/Y_1 increases from 2.70 for one vent flow to 3.25 in two vents flow which means that the value of sequent depth ratio increases approximately by a ratio of 21%. The figure shows also that as increase the length of pier the relative depths increase. The following fitted equations may be used for calculating the sequent depth ratio, Y_2/Y_1 for each case;

$Y_2/Y_1 = -0.015\,F_1^2 + 0.564\,F_1 + 1.401$ For using two vents (1)

$Y_2/Y_1 = -0.007\,F_1^2 + 0.526\,F_1 + 0.684$ For using one vent (2)

Similarly, hydraulic jump height ratio, H_j/Y_1 has the same trend of the sequent depth ratio, Y_2/Y_1 variation with the two cases of inflow, where $H_j/Y_1 = Y_2/Y_1 - 1$ as shown in Fig 6 and Equations 3 and 4.

$H_j/Y_1 = -0.015\,F_1^2 + 0.564\,F_1 + 0.401$ For using two vents (3)

$H_j/Y_1 = -0.007\,F_1^2 + 0.526\,F_1 - 0.316$ For using one vent (4)

The energy loss ratio, $\Delta E/E_1$ and initial Froude number, F_1 for different pier lengths were represented in Fig 7. The figure demonstrates that the energy loss ratio increases with non-linear relation with the Froude number. Also, It was observed that the length of pier approximately has no impact on the energy loss ratio, $\Delta E/E_1$ in the two cases. The flow through two vents gives less energy loss ratio than that through one vent. This may be due to the formed vortices in the dead zone downstream the closed vent. For example; at Froude number of 3, the

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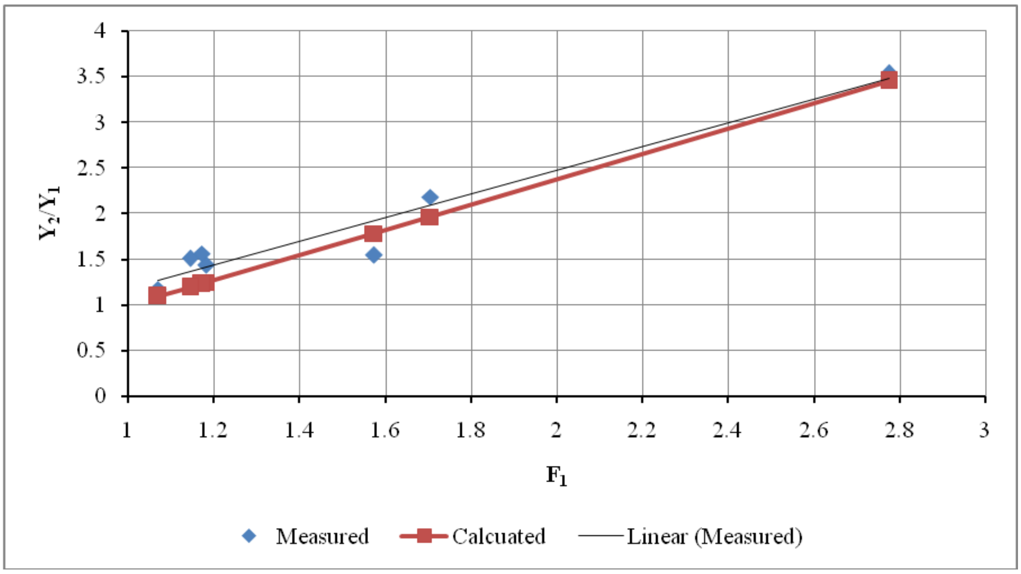

Fig. 4: Comparison between Calculated and Measured sequent depth

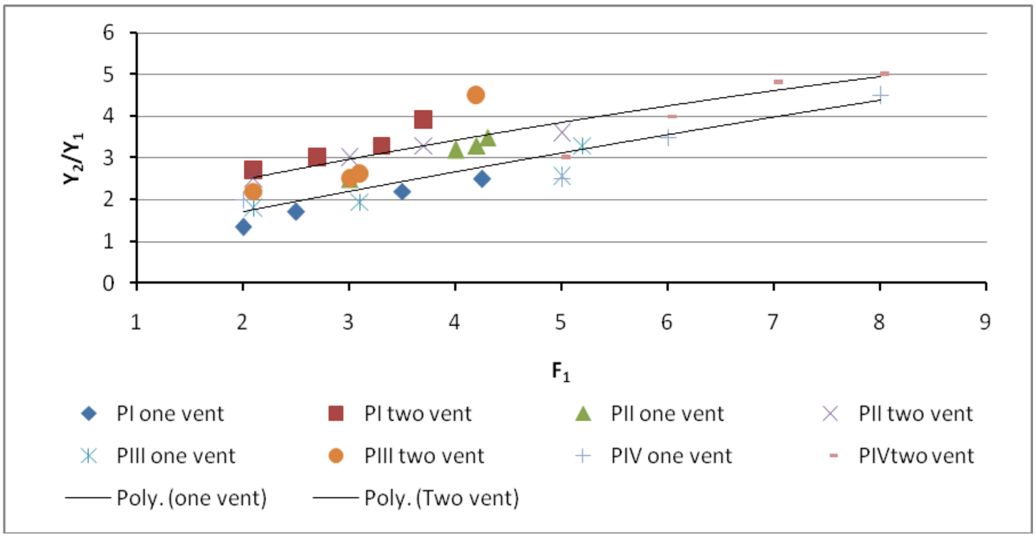

Fig. 5: Froude number versus sequent depth ratio for one and two vents

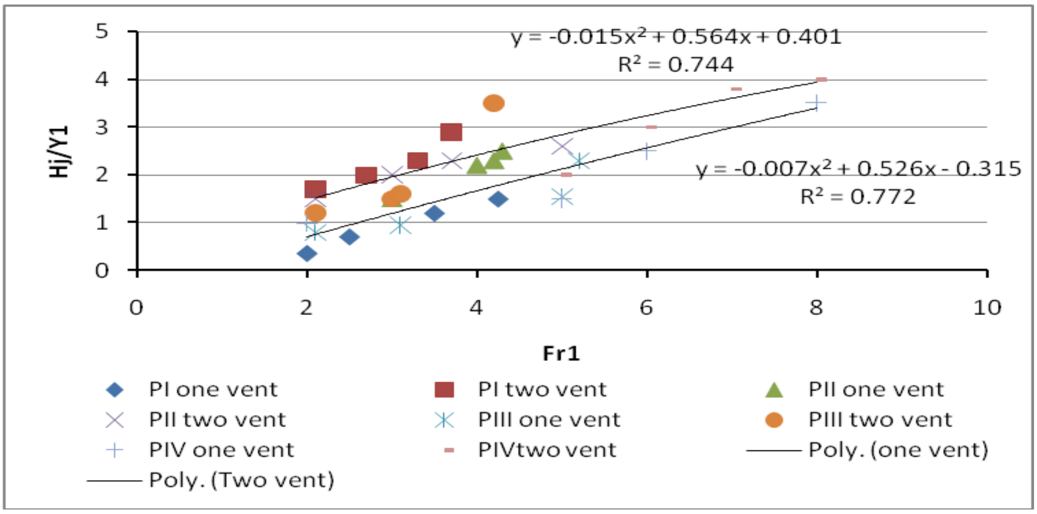

Fig. 6: the effect of Froude number on hydraulic jump height ratio for different piers

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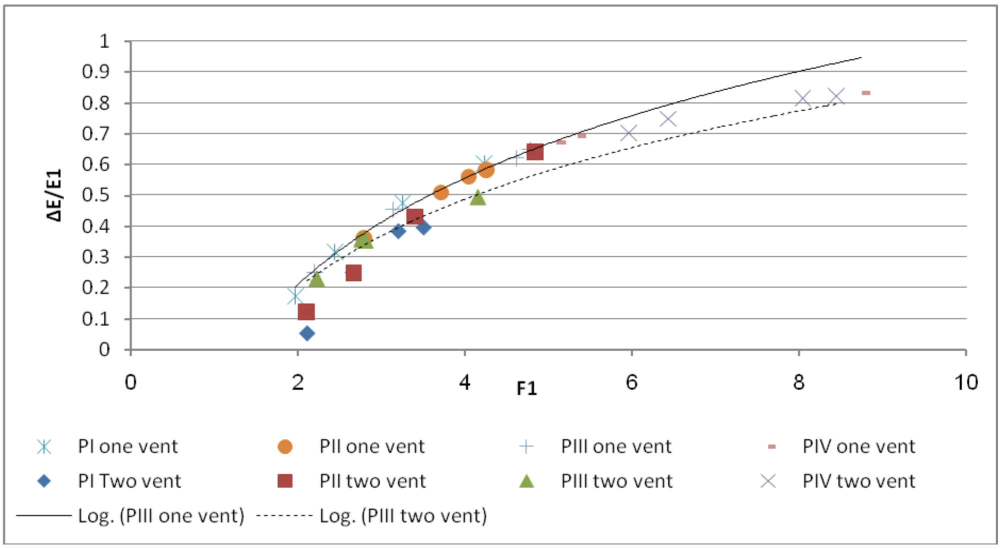

Fig. 7: Effect of Froude number on energy loss ratio for different piers inflow vents

energy loss ratio increases from 0.35 in case of flow through two vents flow to 0.44 in case of one vent which implies that the estimation of the energy loss ratio increments roughly by a proportion of 26%. The estimated equations for calculating energy loss ratio for the two cases of inflow are;

$\Delta E/E_1 = 0.41 \ln (F_1) - 0.079$ For using two vents (5)

$\Delta E/E_1 = 0.499 \ln (F_1) - 0.135$ For using one vent (6)

Variations of the formed whirl length and hydraulic Jump height due to variation of pier length:

The second set of experimental runs was carried out to study the effect of pier length on the formed whirl and the hydraulic jump lengths. Fig 8 shows that the formed whirl length ratio, L_P/B increases as the pier length ratio, L/B increases, at Froude number 2.97. Fig 9 shows the effect of the pier length, L_P/B on the length of hydraulic jump (L_j/B) at Froude number 2.97. It was found that, increasing of pier length ratio by 60% results in hydraulic jump length ratio increase by 60%.

Effect of the fence location and porosity on the formed whirl length and hydraulic Jump energy loss:

Finally, the third set of experimental runs studied the effect of the fence location and porosity on the formed whirl length and energy loss. Four metal porous fences with porosities, n of 56, 75, 80, and 90% were used in this set. Fig 10 shows that, the formed whirl length ratio, L /B increases as the fence distance from the gate, L_F to the flume width, B ratio, L_F/B increases for one vent and two vents inflow. Also, it is observed that the whirl length increases as the fence porosity, n and Froude number increase.

Analysis of this set of experiments show that the fence porosity has an effect on each the formed whirl length and the energy loss ratio. It was found that, increasing the fence porosity results in decreasing in the energy loss ratio and increasing in the formed whirl length, L/L_w, as shown in Figs 11 and 12.

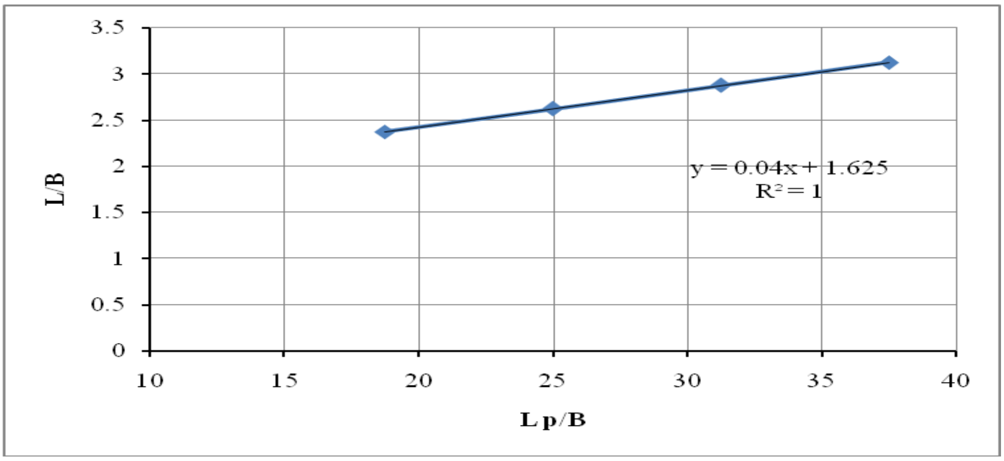

Fig. 8: the effect of pier length on the whirl length

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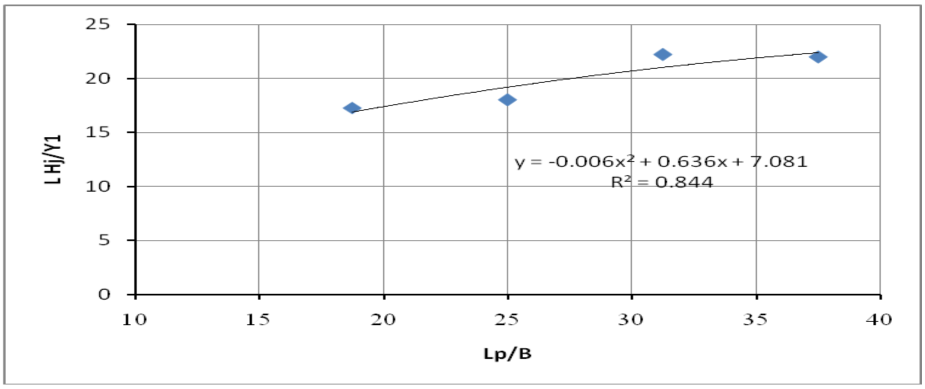

Fig. 9: The effect of length pier on hydraulic jump

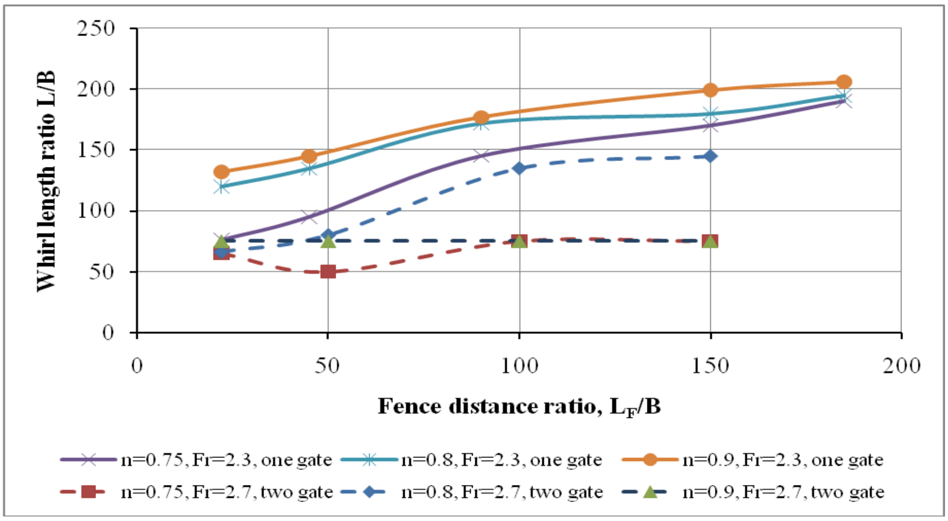

Fig 10 Variation of the formed whirl length ratio with the fence location ratio

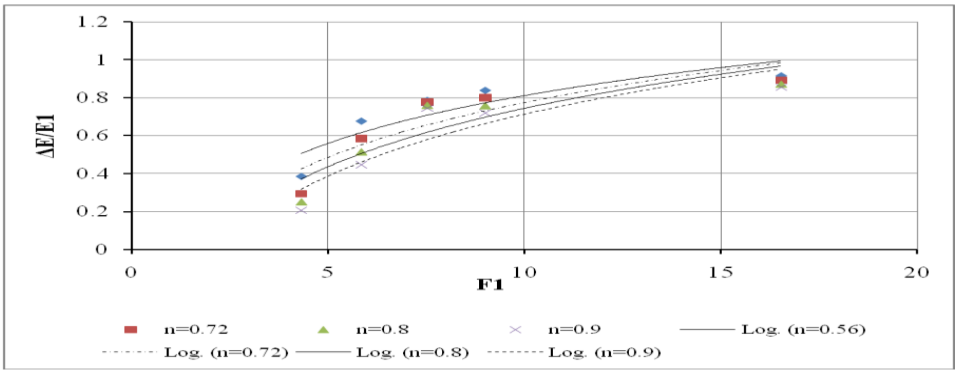

Fig 11: Variations of energy loss ratio with Froude number for different fence porosity

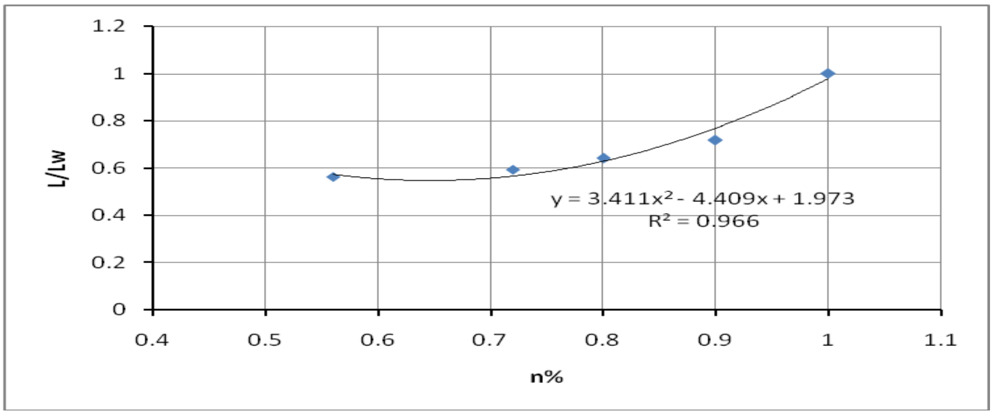

Fig 12 Effect of fence porosity on the formed whirl length to whirl length without fence ratio, L / L_w

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CONCLUSIONS

The purpose of this paper is to study the effect of hydraulic (number of used inflow gate) and geometric (pier length and the fence location and porosity) conditions on the hydraulic jump characteristics. Based on the obtained results, fitted curves and equations, the following conclusions are reached:

1- The sequent depth ratio, Y_2/Y_1 increases with the Froude number.
2- The sequent depth ratio, Y_2/Y_1 has higher values in case of using two vents inflow than that using one vent inflow for the same Froude number.
3- Also, the hydraulic jump height ratio, H_J/Y_1 has the same results trend of Y_2/Y_1.
4- The energy loss ratio, $\Delta E/E1$ has lower values in case of two vents inflow than that in case of one vent inflow.
5- Each of the formed whirl length ratio, L/B and the hydraulic jump length ratio increases as the pier length increases.
6- Also, the formed whirl length ratio increases as the fence distance ratio and porosity increases.

REFERENCE

Agarwal. V. C., 2001, "Graphical Solution to the Problem of Sequent Depth and Energy Loss in Spatial Hydraulic Jump", Water & Maritime Engineering 14 B, Issue 1A, pp. 1 - 3.

Belanger, J. B., 1828 "Test on the numerical solution of some problems relating to the permanent movement of running waters". Carilian-Goeury, Paris.

Bidone G., 1818, "Observations on the Height of Hydraulic Jump", report presented in Royal academy of sciences of Turin, 21 – 80.

Ebrahimi S., Salmasi F., Abbaspour A., 2013, "Numerical Study of Hydraulic Jump on Rough Beds Stilling Basins", Journal of Civil Engineering and Urbanism, Vol. 3, Issue 1: 19-24.

Elsebaie IH, Shabayek Sh. 2010. "Formation of hydraulic jumps on corrugated beds", Civil and Environmental Engineering, IJCEE-IJENS 10(1): 40-50 Google Scholar.

Gandhi S, and Yadav V., 2013 "Characteristics of supercritical flow in rectangular channel". International Journal of Physical Sciences. 8(40):1934-1943.

Hager WH., 1992 "Energy dissipaters and hydraulic jump" Kluwer Academic, Dordrecht.

Hager W., 1994 "Impact hydraulic jump" J. Hydraul. Eng.; 120(5):633–637.

Hasan, M. R and Matin, M.A, 2008, "Experimental study for sequent depth ratio of hydraulic jump in horizontal expanding channel", Journal of Civil Engineering (IEB), Vol.37, No. 1, pp.1-9.

Hubert C., and Yann C. 2011 "Bubbly Flow Measurements in Hydraulic Jumps with Small Inflow Froude numbers", International Journal of Multiphase flow, Vol. 37, pp. 555 – 564.

Izadjoo F, Shafai-Bajestan M. 2005 "Effects of trapezoidal shape corrugated bed on the characteristics of hydraulic jump", In: 17th Canadian hydrotechnical conference, Alberta, Canada, August 17–19.

Leutheusser, H.J.; Kartha, V.C., 1972 "Effects of inflow conditions on hydraulic jump", J. Hydraul. Div., 98, 1367–1385.

Mahmoud Ali R. Eltoukhy , 2016 , "Hydraulic Jump Characteristics For Different Open Channel and Stilling Basin Layouts" , International Journal of Civil Engineering and Technology (IJCIET). Volume 7, Issue 2, March-April 2016, pp. 290–301.

Matin, M.A., Hassan, M.M.R., Islam, M.A. 2008, "Experiment on hydraulic jump in sudden expansion in a rectangular channel", Journal of Civil Engineering (IEB), Vol.36, No. 2, pp.65-77.

Mc Corquodale JA, 1986. "Hydraulic jump and internal flows". Encyclopedia of fluid mechanics, 2: Flow phenomena and measurements. Ed: Cheremisin off, Gulf Publishing Company: Houston; Chapter 6:122-173.

Negm A. M, Abdel-Aal G. M., Elfiky M.M. and Abdalla Mohamed Y., 2003, "Characteristics of submerged hydraulic jumps in radial basins with a vertical drop in the bed", Alexandria Engineering Journal.

Mossa, M., 1999 "On the oscillating characteristics of hydraulic jumps", J. Hydraul. Res.,37,541–558.

Neveen B. Abdel-Mageed, 2015, "Effect of Channel Slope on Hydraulic Jump Characteristics", Physical Science International Journal. Vol. 7, Issue: 4.

Rahman K., Farzin S., Mohammad A. G. and Hakimeh A., 2014, "Modelling Energy Dissipation over Stepped-gabion Weirs by Artificial Intelligence", Springer Science Business Media Dordrecht. Volume 28 Number 7 Water Resour Manage.

Saideh E., Farzin S., and Akram A., 2013, "Numerical Study of Hydraulic Jump on Rough Beds Stilling Basins, Journal of Civil Engineering and Urbanism. Volume 3, Issue 1: 19-24.

Stefano P., Rajib D., and Michele P., 2008, "Energy Dissipation on Submerged Block Ramps", Journal of Irrigation and Drainage Engineering.