Experimental investigation of the effect of contracted section at downstream of the rectangular channel on energy dissipation

Rasoul Daneshfaraz[1*], Behrouz Zirei[2], Parisa Ebadzadeh[3], Hamidreza Abbaszadeh[4], Bahman Mosavi[5]

[1],[2], [3], [5] *Department of Civil Engineering, Faculty of Engineering, University of Maragheh, Maragheh, Iran*

[4] *Department of Civil Engineering, Faculty of Engineering, University of Tabriz, Iran*

Received date: **15.05.2024**; Accepted date: **24.06.2024**; Published date : **03.07.2024**

Turkish Journal of Hydraulic (Türk Hid. Der.), Vol (Cilt): **8** , Number (Sayı): **1**, Page (Sayfa), **01-06**, **(2024)**

e-ISSN: **2636-8382**

SLOI: http://www.dergipark.org.tr

*Correspondence e-mail: *daneshfaraz@yahoo.com*

Abstract

This study investigated the hydraulic parameters of rectangular flume with contraction. Experimental studies were done. The contraction section was installed at downstream. Different flow rates: 300 to 900 liters per minute were performed on models. Classic hydraulic jump was compared with contacted section jump. Results showed that installing the contraction section effected the flow depth at downstream. Increase in flow depth at downstream, caused to increase the energy dissipation. Increase in flow rate to 900 liters per minute, caused to energy dissipation be higher than 300 liters per minute. Different sections were studied, and the highest energy dissipation occurred in the distance between section A and C. (A in the upstream and C in contraction section). Therefore, with increase in Froude number, the energy dissipation increases in contraction section.

Keywords: Rectangular channel, Hydraulic jump, Energy dissipation, Flow depth, Discharge

1. INTRODUCTION

The design of hydraulic structures is important for better and optimal control of water resources. This issue has been stated in various researches [1-20]. Hydraulic analysis of structures is one of the important topics in engineering. Design engineers should be careful about the selection of features to satisfy the stability of the jump. The use of channels in different geometrical shapes affects the characteristics of the flow. The necessity of storing water in periods of high water and transferring it to low water areas with the increasing human need for water requires extensive study. Control of Hydraulic jump at downstream is important to protect structures from destruction. corrugated beds are one of the ways to decrease the water's velocity. Ead and Ragaratnam studied the three values of the relative roughness [21].

It was found that the tailwater depth required to form a jump was appreciably smaller than that for the corresponding jumps on smooth beds. Hydraulic jump on horizontal rough beds were investigated in an experimental study Carollo et al., [22]. That study allowed the writers to positively test the reliability of a new solution of the momentum equation for the sequent depth ratio as a function of the Froude number and the ratio between the roughness height and the upstream supercritical flow depth. reports the results of an experimental investigation of hydraulic jump properties in flows over adverse-sloped rough beds, including the effect of air entrainment. Furthermore, a semi-theoretical predictive relationship were proposed to estimate jump characteristics for a wide range of hydraulic and geometric conditions covering both rough and smooth beds. Samani et al., [23] investigated the discharge coefficient of contraction flume in an experimental study. Critical flow is created through contraction of flow cross section by installing a vertical cylindrical column at the center of a rectangular open channel. The stage–discharge relationship was calibrated using a laboratory prototype with various configurations. The stage–discharge function developed in their paper can be used for design and calibration of the flume regardless of the flume size or contraction ratio. Core annular flow of lube oil and water through sudden contraction and expansion has been simulated by Kaushik et al., [24]. Results indicated that the interfacial waves are three dimensional in nature for both an expanded and a contracted flume. algorithm of hydraulic jump over rough beds based on the approach Froude number, Fr1 were studied by Mahtabi et al., [25]. results showed that the first class (A) of hydraulic jump over the rough beds is approximately similar to that for the smooth bed. Moreover, in the next three classes (B, C, and D), upper values of F_{r1} decreased with respect to the smooth bed classes. Lastly, in class D, the upper value of F_{r1} reduced to 7.45, which indicates that the shear stress (i.e., the energy loss) grows sharply with increasing F_{r1}. Misra et al., [26] investigated the turbulent flow structure of a weak hydraulic jump using particle image velocimetry measurements. They reported that a thin, curved shear layer oriented parallel to the surface is responsible for most of the turbulence production with the turbulence intensity decaying rapidly away from the toe of the breaker. Dhar et al., [27] investigated the natural hydraulic jumps in thin film flow through channels slightly deviated from the horizontal. They revealed the existence of submerged jump, wavy jump, smooth jump, and no jump conditions as a function of liquid Reynolds number, scaled channel length, and channel inclination.

Previous research showed the importance of studying and controlling hydraulic jump [28, 29]. In this study, by studying the contraction section in different flow rates, the energy dissipation due to hydraulic jump was investigated.

2. MATERİALS and METHODS

This research was conducted in the hydraulic laboratory in a flume with a length of 5 meters, width of 0.30 meters and height of 0.45 meters. The flume includes an inlet tank, two pumps and a sluice gate. The distance of the sluice gate from the inlet is 1.5 meters and its opening from the channel floor is 0.026 meters. In order to create a sudden contraction in the channel, two wooden contracting switches with a length of 50 cm, a thickness of 7.5 cm and a height of 45 cm were used. Figure (1) and (2) show the control mode and with contraction section.

Figure 1. Rectangular flume, used in this study (Control mode)

Figure 2. Rectangular flume with contraction

Figure (3) shows the Schematic view of the flume and contraction section in this study. Five different sections were studied. Section A is in upstream, B in downstream, C, D, E in contraction section. Super critical flow passed under the gate and entired in contraction section. First classic hydraulic jump was formed then the effect of contraction on hydraulic jump were investigated. Table (1) shows the important data of this study.

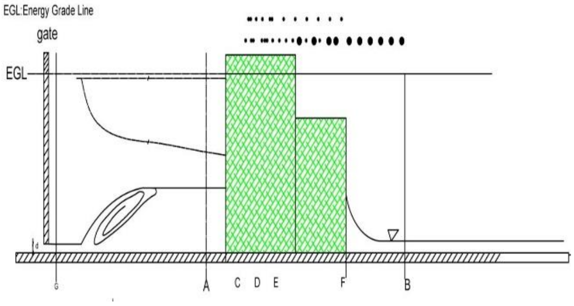


Figure 3. Schematic view of flume in this study

Table 1. Hydraulic characteristics of this research

Parameters	Q (l/min)	Fr Number	Sections
Row	300-900	1-10	A, B, C, D, E, F

After measuring the water depth at different points, the energy dissipation was measured relative to the upstream and downstream froud number by eq (1).

$$E = Y + \frac{V^2}{2g} \qquad (1)$$

Where E is the energy values in the sections (A, B, C, D, E, F), Y the flow depth, V the flow velocity and g the acceleration of earth gravity**.**

3. DIMENSIONAL ANALYSIS

$$f_1(Q, \rho, g, \mu, B, d, W, Y_A, Y_B, Y_C, Y_D, Y_E, Y_F) = 0 \qquad (2)$$

Where Q is the flow rate, ρ is the a specific mass of water, g acceleration of earth gravity, µ dynamic viscosity of water, B the flume width, d the gate opening, W the width of contraction section, Y_A, Y_B, Y_C, Y_D, Y_E, Y_F the flow depth in sections A to F, V velocity of the flow. According to the π—Buckingham method and considering (ρ, g, Y) as iterative variables, the dimensionless parameters can be presented as in Eq (3):

$$f_2(Re, Fr, B/Y_A, d/Y_A, W/Y_A, Y_B/Y_A, Y_C/Y_A, Y_D/Y_A, Y_E/Y_A, Y_F/Y_A) = 0 \qquad (3)$$

After dividing the parameters, the important parameters of the current research were presented as Eq (4).

$$\frac{\Delta E_{AB}}{E_A} = \frac{E_A - E_B}{E_A} = (Fr, W/YA, YA/YB) \qquad (4)$$

4. RESULTS

In this research, the energy dissipation was investigated in rectangular channels with sudden contractions at different flow rates. Flow rates was between 300 - 900 liters per minute. A sudden contraction in downstream installed to dissipatation the energy. Figure 4 shows the energy loss due to the placement of contraction. This figure shows the energy dissipation relative to the upstream and downstream. The horizontal axis shows the values of Froud number at upstream and downstream (section A and B) and the vertical axis shows the values of energy dissipation.

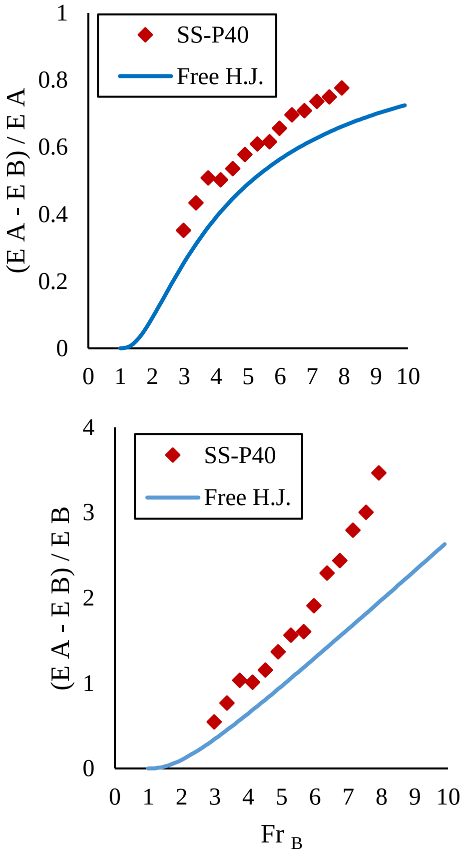


Figure 4. Energy dissipation relative to upstream and downstream

The energy dissipation of the contraction section was investigated in the control mode and with increasing discharge. Results showed that the use of contraction section influence the hydraulic jump. Installing the contraction section at downstream that caused the hydraulic jump, increase in energy dissipation.

Results indicated that for maximum discharge, energy dissipation increase 30% realative to non contracted mode. Figure 5 shows the energy dissipation in different flow rates in this research. The presence of turbulent flows in the area before the narrowing has caused an increase in energy loss.Energy dissipation was investigated at flow rates of 300, 350, 400, 450, 500, 600, 700, 800 and 900 liters per minute. The Energy of the flow along the channel at different flow rates are given in Figure 5. The horizontal axis shows the different points along the channel, where point A is before the contraction, E, D, C are the points inside the contraction and point B is after the local contraction. In this figure the vertical axis shows the value of energy at each section.

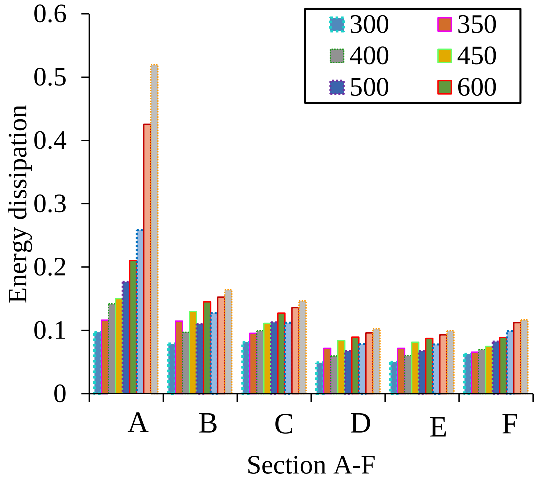
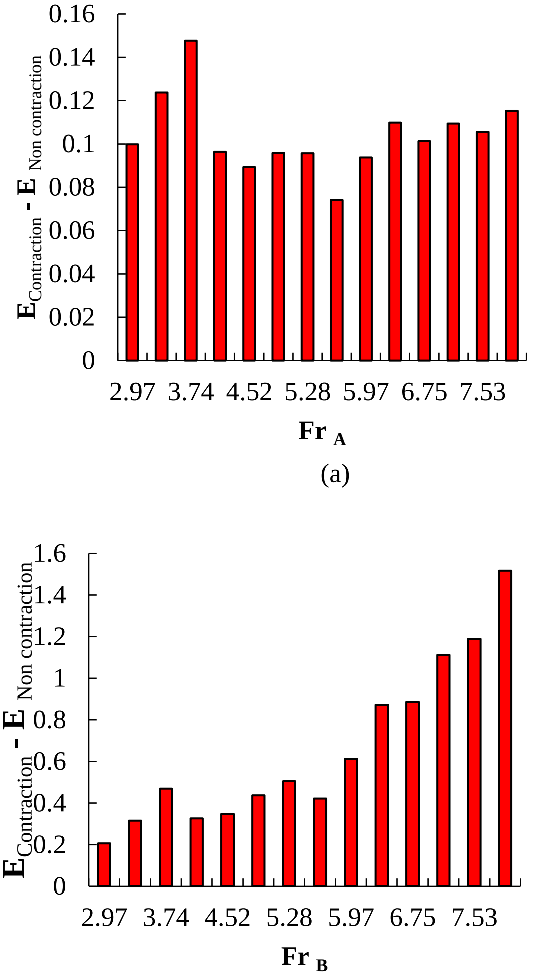


Figure 5. The energy dissipation in section A, B, C, D, E and F along the length of the channel

The results showed that increasing the discharge from 300 to 900 Liters per minute increases energy dissipation in contraction section. Results indicated that increase of Froud number, increases the energy dissipation.

The low depth of the flow after the gate and the high velocity of the flow caused the hydraulic jump to increase with turbulence and interference with the air and increase the downstream flow depth.

The difference from the results of energy dissipation caused by contraction sections with free hydraulic jump (non contraction) was calculated as follows in figure (6 a and b. Results indicated that the energy dissipation compared to upstream and downstream in different Froude numbers is higher in the use of constriction than in the simple case.



(b)

Figure 6. Changes in energy values in contraction section compared to non contraction section: a)Relative to upstream Froud number, b) relative to downstream Froud number

5. CONCLUSION

The main results of this study is as follows:

1- The energy dissipation caused by contraction is more than the energy dissipation of free hydraulic jump.

2- contraction is effective in stabilizing the hydraulic jump section.

3- Results showed that the highest energy dissipation occurred in the distance between section A and C. (Therefore, with the increase in Froude number, the energy dissipation also increases.)

4- The energy dissipation increases with the increase of Froude number.

References

[1] Daneshfaraz, R., Norouzi, R., & Ebadzadeh, P. (2022). Experimental and numerical study of sluice gate flow pattern with non-suppressed sill and its effect on discharge coefficient in free-flow conditions. Journal of Hydraulic Structures, 8(1): 1-20

[2] Daneshfaraz, R., Noruzi, R., & Ebadzadeh, P. (2022). Experimental Investigation of non-suppressed sill effect with different geometry on flow pattern and discharge coefficient of sluice. Journal of Hydraulics, 17(3): 47-63.

[3] Hassanzadeh, Y., & Abbaszadeh, H., (2023). Investigating Discharge Coefficient of Slide Gate-Sill Combination Using Expert Soft Computing Models. Journal of Hydraulic Structures, 9(1): 63-80.

[4] Daneshfaraz, R., Abbaszadeh, H., Gorbanvatan, P., & Abdi, M. (2021). Application of sluice gate in different positions and its effect on hydraulic parameters in free-flow conditions. Journal of Hydraulic Structures, 7(3): 72-87.

[5] Daneshfaraz, R., Norouzi, R., Ebadzadeh, P., Di Francesco, S., & Abraham, JP., (2023). Experimental study of geometric shape and size of sill effects on the hydraulic performance of sluice gates. Water, 15(2): 314.

[6] Norouzi, R., Ebadzadeh, P., Sume, V., & Daneshfaraz, R. (2023). Upstream vortices of a sluice gate: An experimental and numerical study. AQUA—Water Infrastructure, Ecosystems and Society, *72*(10), 1906-1919.

[7] Daneshfaraz, R., Norouzi, R., Ebadzadeh, P., & Kuriqi, A. (2023). Influence of sill integration in labyrinth sluice gate hydraulic performance. Innovative Infrastructure Solutions, 8(4), 118.

[8] Abbaszadeh, H., Daneshfaraz, R., & Norouzi, R. (2023). Experimental Investigation of Hydraulic Jump Parameters in Sill Application Mode with Various Synthesis. Journal of Hydraulic Structures, 9(1): 18-42.

[9] Daneshfaraz, R., Norouzi, R., Patrick Abraham, J., Ebadzadeh, P., Akhondi, B., & Abar, M. (2023). Determination of flow characteristics over sharp-crested triangular plan form weirs using numerical simulation. Water Science, 37(1), 211-224.

[10] Abbaszadeh, H., Norouzi, R., Sume, V., Kuriqi, A., Daneshfaraz, R., & Abraham, J. (2023). Sill role effect on the flow characteristics (Experimental and Regression Model Analytical). Fluids, 8 (8), 235. https://doi.org/10.3390/fluids8080235

[11] Daneshfaraz, R., Norouzi, R., Abbaszadeh, H., & Azamathulla, HM. (2022). Theoretical and experimental analysis of applicability of sill with different widths on the gate discharge coefficients. Water Supply, 22(10): 7767-7781.

[12] Daneshfaraz, R., Norouzi, R., Abbaszadeh, H., Kuriqi, A., & Di Francesco, S., (2022). Influence of sill on the hydraulic regime in sluice gates: an experimental and numerical analysis. Fluids, 7(7): 244.

[13] Daneshfaraz, R., Norouzi, R., Ebadzadeh, P., & Abbaszadeh, H. (2021). Numerical investigation on effective parameters on hydraulic flows in a sluice gate with sill on free-flow condition. J. Environment and Water Engineering. Doi: https://doi.org/10.22034/jewe.2021.295538.1596

[14] Daneshfaraz, R., Norouzi, R., & Ebadzadeh, P. (2023). Evaluation Effect of changing the sill geometries and positions on discharge coefficient of vertical sluice gate. *Journal of Civil and Environmental Engineering*, *53*(112), 117-127.

[15] Pagliara, S., & Palermo, M. (2015). Hydraulic jumps on rough and smooth beds: aggregate approach for horizontal and adverse-sloped beds. Journal of Hydraulic Research, 53(2), 243-252.

[16] Daneshfaraz, R., Norouzi, R., & Abbaszadeh, H. (2022). Experimental investigation of hydraulic parameters of flow in sluice gates with different openings. *Environment and Water Engineering*, *8*(4), 923-939.

[17] Daneshfaraz, R., Norouzi, R., & Abbaszadeh, H. (2021). Numerical Investigation on Effective Parameters on Hydraulic Flows in Chimney Proportional Weirs. *Iranian Journal of Soil and Water Research*, *52*(6), 1599-1616. doi: 10.22059/ijswr.2021.322751.668944

[18] Daneshfaraz, R., Norouzi, R., & Abbaszadeh, H. (2024). Effect of geometric shapes of chimney weir on discharge coefficient. *Journal of Applied Water Engineering and Research*, *12*(1), 27-38.

[19] Karbasi, M., Azamathulla, H.M. (2016). GEP to predict characteristics of a hydraulic jump over a rough bed. KSCE J. Civ. Eng, 20, 3006–3011.

[20] Abbaszadeh, H., Daneshfaraz, R., Sume, V., & Abraham, J. (2024). Experimental investigation and application of soft computing models for predicting flow energy loss in arc-shaped constrictions. AQUA—Water Infrastructure, Ecosystems and Society, jws2024010.

[21] Ead, S.A., & Rajaratnam, N. (2002). Hydraulic jump on corrugated beds. J., Hydraul. Eng. 128(7), 656–663. doi:10.1061/(ASCE)0733-9429(2002)128:7(656) 2

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

[23] Samani, Z. A., Baharvand, S., & Davis, S. (2021). Calibration of stage–discharge relationship for rectangular flume with central cylindrical contraction. Journal of Irrigation and Drainage Engineering, 147(8), 06021006. https://doi.org/10.1061/(ASCE)IR.1943-4774.0001595

[24] Kaushik, V. V. R., Ghosh, S., Das, G., & Das, P. K. (2012). CFD simulation of core annular flow through sudden contraction and expansion. Journal

of Petroleum Science and Engineering, 86, 153-164. https://doi.org/10.1016/j.petrol.2012.03.003

[25] Mahtabi, G., Chaplot, B., Azamathulla, H. M., & Pal, M. (2020). Classification of hydraulic jump in rough beds. Water, 12(8), 2249.

[26] Misra, S.K., Kirby, J.T., Brocchini, M., Veron, F., Thomas, & M., Kambhamettu, C. (2008). The mean and turbulent flow structure of a weak hydraulic jump. Phys. Fluids, 20, 35106.

[27] Dhar, M., Das, G., & Das, P.K. (2019). Planar hydraulic jumps in thin film flow. J. Fluid Mech , 884, 1–26.

[28] Süme, V., Daneshfaraz, R., Kerim, A., Abbaszadeh, H., & Abraham, J. (2024). Investigation of clean energy production in drinking water networks. *Water Resources Management*, 1-20.

[29] Ebadzadeh, P., daneshfaraz, R., & Norouzi, R. (2024). Energy Dissipation of Supercritical Flow with Use of Different Geometric Shapes of Sills. *Water and Soil Science*,doi:10.22034/ws.2023.55791.258.