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EXPERIMENTAL STUDY IN IMPACT OF CHANNEL SLOPE ON HYDRAULIC JUMP

[1]Dhimmar P. J., [2]Gandhi H. M., [3]Acharya N. D.

[1]M.E. student, [2]Associate Professor, [3]Assistant professor
[1]Civil Engineering Department (Water Resources Engineering),
[1, 2, 3]Shantilal Shah Engineering College, Bhavnagar, Gujarat, India

Abstract: Hydraulic jump mainly is an energy dissipater to dissipate excess energy of flowing water downstream of hydraulic structures like Conduits, spillway, sluice gates etc. This study investigates the result of channel slope on the characteristics of free hydraulic jump and the energy dissipation downstream of the spillway. Study of jump has been carried out upon Varied slopes including horizontal bed and Sloping bed in cases of smooth bed condition. The experimental program was conducted on a 6.08 m long, 0.28 m wide and 0.75 m deep rectangular flume. Five channels slopes were used viz 0.00, 0.0016, 0.0025, 0.0033, 0.0041. The hydraulic parameters like initial water depth, sequent water depth, and flow rate were measured for varied bed slope in cases of varied discharge condition. A laboratory investigation was then made evaluate the impact of channel slope over smooth bed on the properties of hydraulic jump, namely Froude’s number, the Sequent depth ratio, Length of jump and Relative energy loss. It was concluded that, the relative energy loss increases nonlinearly with increases Froude's number and channel slope. Theoretical and observed value of sequent depth ratio for approached Froude’s number shows greater variation in some cases. The sloping bed require more tail water depth than the corresponding flatter bed. The length of the jump on a sloping channel bed more than the corresponding length of jump on a flatter slope. Comparison of observed value of sequent depth ratio with theoretical values calculated using USBR recommendation showed satisfactory agreement.

Key Words: Hydraulic jump, Channel Slope, Bed characteristic, Stilling basin, Froude's number, Sequent depth, Energy dissipation.

1. INTRODUCTION

Hydraulic jump in a prismatic channel is a transitional phenomenon that occurs when the flow varies from supercritical to subcritical flow. The jump can occur in the prismatic as well as non-prismatic channels such as triangular, parabolic, trapezoidal, gradually expanding and abruptly expanding channels. A hydraulic jump takes place when a discharge of water with higher velocity of supercritical flow on the upstream side is met with a subcritical flow on downstream side of decreased velocity and with varied depth of flow. The occurrence of hydraulic jump is dependent upon the initially fluid speed. If the beginning speed of the fluid is below the critical speed, and then their no jump is possible.

1.1 Condition for formation of hydraulic jump

The criteria for formation of hydraulic jump is as follows:

- When the depth of flow varies from supercritical to sub critical.
- The hydraulic Jump in the flowing will not occur when the value of Froude’s number is less than 1 or greater than 1.
- When the Froude’s number value range varies in less than 1 or greater than 1.
- No jump will form when the flow will occur from subcritical to supercritical flow condition – only vice versa condition.

1.1.1 Hydraulic jump forms

The various forms of hydraulic jump occurrence based on channel slope and roughness condition as described. The generation of hydraulic jump is depending on channel bed and roughness condition. In natural stream only submerged jump is possible.

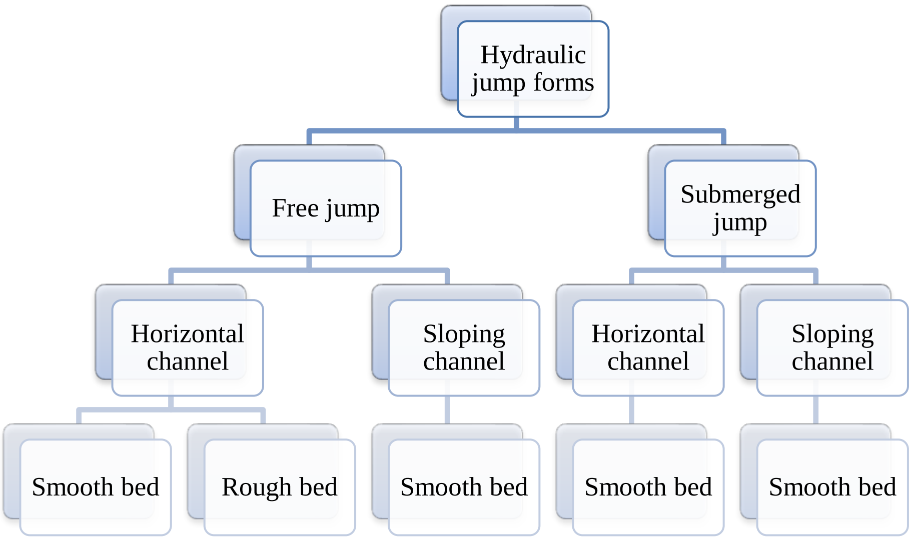

Figure: Hydraulic jump forms

1.2 Objectives Of the work

The objective of the study is as follows:

- To evaluate the impact of channel slope on the hydraulic jump.
- Find out location and length of hydraulic jump with relation to channel slope And Smooth Bed condition.
- To examined the flow characteristics of hydraulic jump.
- To validate the experimental results with the empirical equation.

1.3 Limitations of the work

The present study conducted with the following limitations:

- The study is mainly based on the experimental investigation made by using a rectangular channel.
- Prismatic rectangular channel of fixed dimensions 6.08 m length, 0.75 m depth, 0.28 m wide was used for investigation.
- Five channel bed slopes were used as 0.00, 0.0016, 0.0025, 0.0033, 0.0041 for varied discharge condition.

2. EXPERIMENT SETUP AND PROCEDURE

The whole set of experimental work is carried out at the Hydraulic Engineering Laboratory of Shantilal Shah Engineering College, Bhavnagar, Gujarat. The experimental set-up consists of a Recirculating flume and sharp crested spillway for flow rate measurements. Several hydraulic jumps were produced in the flume with varied channel bed slope. The re-circulating flume used to have dimensions 0.28 m wide, 0.75 m deep and 6.08 m long. The experimental set-up and data collection procedure used are as described.

The set-up of the experiment includes:

- A 6.08-meter flume in length.
- Spillway.
- Velocity measurement by float method.
- Water collecting tank.
- Bucket and measuring cylinder.
- Pump for the supply of water.
- Measuring tape.
- Meter gauge with a scale & pointer.

2.1 Experimental Procedure summery

Experimental procedure is as summarized below:

1. Fill the storage tank (Located at the d/s end of flume) with clear water for circulation of water.
2. Circulate the flow of water for flume bed cleaning.

Figure: Hydraulic flume

3. Fix the spillway location at u/s side i.e., 2.02 m from u/s gate.

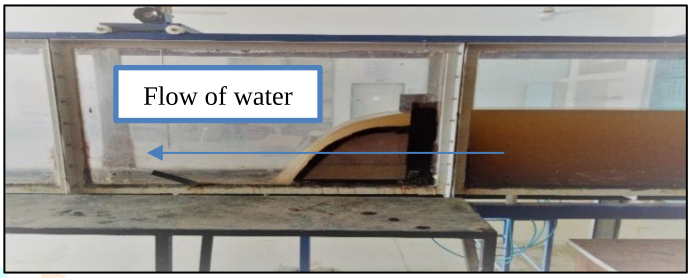

Figure: Spillway Location & Flow of water

4. Mark the depth of flume (u/s side).
5. Set the channel bed slope, For Horizontal channel bed i.e., 0.
6. Set valve opening for flow regulation. i.e.,1,2,3,4,etc...
7. Switch on the Hydraulic flume.
8. Measured the depth of flow and tail water head over spillway.
9. Measured the velocity of by Float method.
10. Calculate the Discharge using continuity equation.
11. Adjust tail gate opening for formation of Hydraulic Jump.

Figure: Tail gate adjustment

12. Measured pre jump depth, post jump depth and velocity of flow at post jump depth.
13. Calculate Froude's number at pre jump depth, length of jump, Height of jump & Relative energy loss using belanger equation.
14. Change the valve opening for same slope and proceed step 7 to further for taking more observation.
15. Change the channel bed slope and proceed step 6 to further for more observation.

Figure: Depth Measurement.

2.2 Experimental data collection and Estimation

Experiment on hydraulic jump have been carried out for varied slopes including horizontal channel bed and several discharge condition. Details of these are presented here.

The experiment work has been carried out in two ways;

1. The collection of data on hydraulic jump in a horizontal channel bed.
2. The collection of data on hydraulic jump in a varied sloping channel bed.

Table 2.1 Experimental measurements and related estimation for, Q = 0.0121 m^3/s (ϴ = 0.00)

Sr. No.	Depth of flow (cm)	Head over spillway (cm)	Velocity of flow at u/s (m/s)	d/s gate opening (cm)	Y_1 (cm)	Y_2 (cm)	V_2 (m/s)	Y_2/Y_1	F_{r1}	L_j/Y_2	E/E_1 (%)
1	39.8	5.8	0.108	3.5	4.1	13.6	0.316	3.32	1.65	4.82	3.909
2				4.0	3.8	12.7	0.338	3.34	1.85	4.84	6.71
3				3.4	3.2	13.1	0.328	4.09	2.40	5.21	15.82
4				3.9	2.9	12.9	0.333	4.45	2.78	5.35	22.18

Table 2.2 Experimental measurements and related estimation for, Q = 0.00578 m^3/s (ϴ = 0.0016 or 1 in 608)

Sr. No.	Depth of flow (cm)	Head over spillway (cm)	Velocity of flow at u/s (m/s)	d/s gate opening (cm)	Y_1 (cm)	Y_2 (cm)	V_2 (m/s)	Y_2/Y_1	F_{r1}	L_j/Y_2	E/E_1 (%)
1	38.5	4.2	0.0536	2.0	2.1	7.8	0.263	3.71	2.15	5.04	11.57
2				2.2	2.0	8.2	0.251	4.1	2.32	5.22	14.46
3				2.1	2.1	7.9	0.261	3.76	2.16	5.07	11.38
4				1.9	22	8.4	0.245	3.82	2.19	5.09	12.24

Table 2.3 Experimental measurements and related estimation for, Q = 0.00585 m^3/s (ϴ = 0.0025 or 1 in 405.3)

Sr. No.	Depth of flow (cm)	Head over spillway (cm)	Velocity of flow at u/s (m/s)	d/s gate opening (cm)	Y_1 (cm)	Y_2 (cm)	V_2 (m/s)	Y_2/Y_1	F_{r1}	L_j/Y_2	E/E_1 (%)
1	38.5	4.2	0.0543	2.0	2.1	10.2	0.204	4.86	2.18	5.48	12.07
2				2.1	1.8	9.6	0.217	5.33	2.75	5.61	21.69
3				1.8	1.6	9.8	0.513	6.13	7.93	5.77	66.1
4				1.7	1.3	10.4	0.200	8.00	4.48	6.04	44.09

Table 2.4 Experimental measurements and related estimation for, Q = 0.00579 m^3/s (ϴ = 0.0033 or 1 in 304)

Sr. No.	Depth of flow (cm)	Head over spillway (cm)	Velocity of flow at u/s (m/s)	d/s gate opening (cm)	Y_1 (cm)	Y_2 (cm)	V_2 (m/s)	Y_2/Y_1	F_{r1}	L_j/Y_2	E/E_1 (%)
1	38.8	4.6	0.0533	2.5	1.3	7.1	0.289	5.46	4.42	5.64	43.69
2				2.4	1.9	6.9	0.298	3.63	2.51	5.00	17.69
3				2.3	2.1	8.4	0.245	3.59	2.16	5.18	11.74
4				2.6	2.4	6.2	0.332	2.58	1.77	4.23	5.53

Table 2.5 Experimental measurements and related estimation for, Q = 0.00611 m^3/s (ϴ = 0.0041 or 1 in 243.2)

Sr. No.	Depth of flow (cm)	Head over spillway (cm)	Velocity of flow at u/s (m/s)	d/s gate opening (cm)	Y_1 (cm)	Y_2 (cm)	V_2 (m/s)	Y_2/Y_1	F_{r1}	L_j/Y_2	E/E_1 (%)
1	38.8	4.5	0.0562	2.5	1.8	8.4	0.259	4.67	2.88	5.42	23.79
2				2.4	1.6	9.2	0.236	5.75	3.43	5.70	31.95
3				2.3	1.7	9.5	0.229	5.59	3.13	5.67	27.64
4				2.2	1.7	10.8	0.201	6.35	3.13	5.81	27.64

3. GRAPHICAL ANALYSIS

The following graph shows the variation of hydraulic jump characteristic with reference to Froude's number, Varied discharge condition and Channel bed slope.

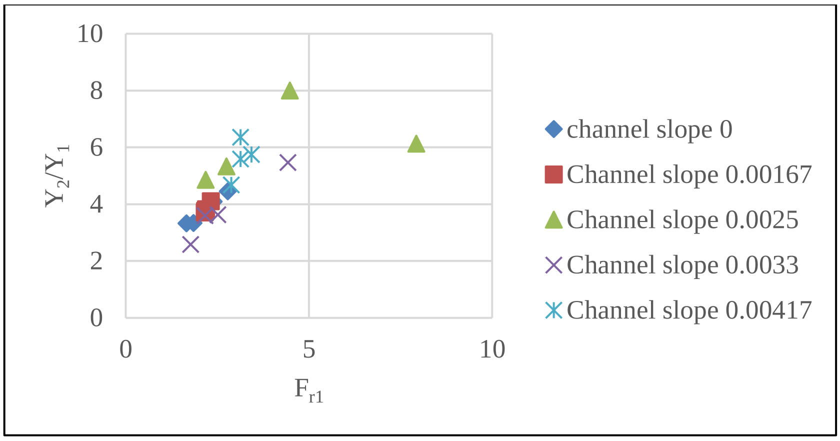

Chart -1: Y_2/Y_1 versus F_{r1}

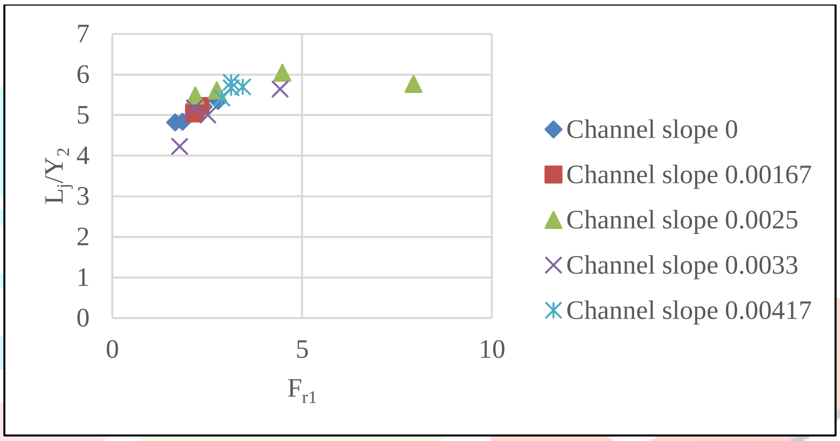

Chart -2: L_j/Y_2 versus F_{r1}

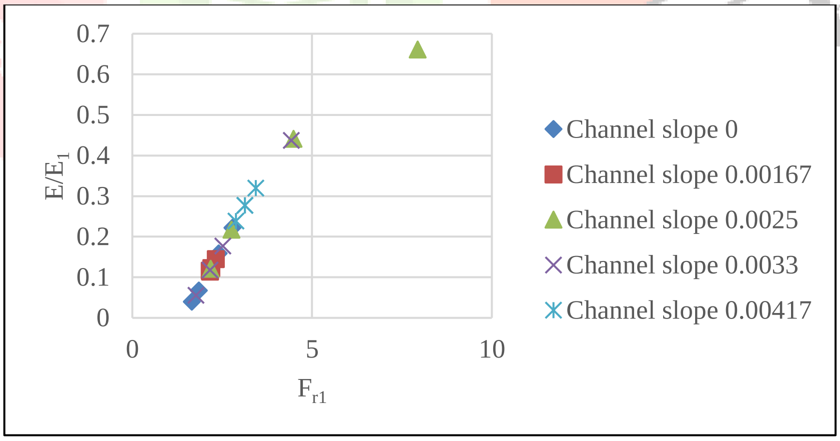

Chart -3: $\Delta E/E_1$ versus F_{r1}

Based on experimental observation, To understand the characteristic of hydraulic jump like Froude's number, Sequent depth ratio, Length of jump, Relative energy loss, Graph plotted between (1) Sequent depth ratio versus Froude's number (2) Length of jump versus Froude's number (3) Relative energy loss versus Froude's number$_1$ for each slope variation and comparison between them are presented. The experiment was performed on smooth bed and the observed data from table was plotted between Froude number and hydraulic jump properties (smooth bed), which is shown in chart.

From the chart it was observed that with increase in Froude's number for varied flow rate was nonlinear in terms of sequent depth ratio, Relative energy loss, L_j/Y_2. It was observed that with increase in Froude number length of jump also increases. For small slope, length of jump is higher which decreases with increase in slope. With increase in Froude number, sequent depth ratio increases in varied discharge conditions. For small slope sequent depth ratio is higher which decreases with increase in slope. With increase in Froude's number energy loss also increases. For small slope energy loss is lesser which increase with increases in slope.

4. RESULTS AND DISSCUSSION

The primary objective was to study the impact of channel slope on hydraulic jump. For this purpose, five slopes 0.0, 0.0016, 0.0025, 0.0033, 0.0041 were introduce in the channel. Observation conducted by varying flow rate, gate opening. A laboratory investigation evaluates the impact of channel slope over smooth bed on the properties of hydraulic jump, namely Froude’s number, The sequent depth ratio, Length of jump and Relative energy loss. Hydraulic jump characteristics were measured in a horizontal and inclined rectangular flume. The following conclusion are drawn, from result:

- The hydraulic jump length, Sequent depth ratio and relative energy loss greatly depend on the Froude’s number.
- With increase in Froude’s number the sequent depth ratio, length of jump increases in varied flow rate at same channel slope.
- The reduction in jump length and sequent depth greatly depends on the Froude’s number. For small Froude’s number the amount of reduction was low while large value Froude’s number showed a higher reduction.
- The bottom slope and inlet Froude’s number have higher impact on the variation of the jump outlet characteristic.
- The relative energy loss increases nonlinear with increases Froude's number and channel slope.
- In horizontal channel bed i. e. channel bed slope 0.00, The water surface is undulating with a very small ripple and rollers which results in Undular and Weak jump.
- In sloping channel bed , As the rectangular flume have prismatic cross-section only Type E hydraulic jump observed.
- Theoretical and observed value of sequent depth ratio for approached Froude's number shows greater variation.
- The sloping bed require more tail water depth than the corresponding flatter bed.
- The length of the jump on a sloping channel bed more than the corresponding length of jump on a flatter slope.

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Appendix: Notation

The following symbols used in this paper:
b = Channel bed width (m);
E_1 = Specific energy at supercritical flow depth;
E/E_1 = Relative energy loss (%);
F_{r1} = Froude’s number at supercritical flow depth;
Y_1 = upstream supercritical flow depth (cm);
Y_2 = downstream subcritical flow depth (cm);
Y_2/Y_1 = Sequent depth ratio;
L_j = Length of hydraulic jump;
L_j/Y_2 =Relative length of jump;
Q = Discharge through the channel (m^3/s);
V = Measured velocity of flow (m/s);
V_2 = Velocity of flow at section 2 (m/s);
ϴ = Slope of the channel bed;
d/s = Downstream;
u/s = Upstream;

REFERENCES

[1] Carollo, F.G., Ferro,V.and Pampalone, V. (2007) “Hydraulic jumps on Rough beds". Journal of Hydraulic Engineering, ASCE.
[2] Chow, V.T., Open Channel Hydraulics, McGraw-Hill, United states, 1965.
[3] D. Husain, A. Shamus, Abdel-azim Negative (2010) "Length and depth of Hydraulic jump in sloping channel". Journal of Research Hydraulics, Taylor and Francis.
[4] Fritz J. and Dolores H. Russ, MSc. Thesis, “Determining the location of hydraulic jump by Model test and HEC-2 Flow routing”, Ohio University, August 1995.
[5] H. M. Imran, Shariah Akib (2013) "Hydraulic jump properties under different channel bed conditions". Life Science Journal.
[6] Irfan Khan, Vikash R. Nadig, Sumukha R. A. & Sanjith J (2015),”Jump characteristics over the downstream of the weir”, International Journal of Engineering Research & Technology.
[7] Iwao ohtsu, Youichi yasuda, Hiroshi gotcha (2003), "Flow conditions of Undular hydraulic jump in horizontal rectangular channel". Journal of Hydraulic Engineering, ASCE.
[8] K. Subramanaya, Flow in Open Channels, McGraw-Hill Education (India) Private Limited, 2014.
[9] Kundan Kumar, MTech. Thesis, “Effect of channel slope on hydraulic jump characteristics over rough bed”, Delhi Technological University, June 2016.

[10] M. K. Beirami, and Mohammad R. Chamani (2006) "Hydraulic jump in sloping channel : Sequent depth ratio". Journal of Hydraulic Engineering, ASCE.

[11] Madhura Deshpande, Vijay Thombare, S. Talegaonkar (2015) "Characteristics of hydraulic jump on corrugated beds", IRJET.

[12] Mohit Kumar, MTech Thesis, "Hydraulic jump on sloping floor", IIT Roorkee, June 2012.

[13] Mustafa gulan, Rangaswami narayanan (1996) "Hydraulic jump in sloping channel". Journal of Hydraulic Engineering, ASCE.

[14] Nandi, S. Das & A. Mazumdar (2020), "Experimental Analysis & Numerical Simulation of Hydraulic jump", International conference on Environment & Renewable Energy.

[15] Neveen B. Abdel Mageed (2015) "Effect of Channel Slope on Hydraulic Jump Characteristics". Physical Science International Journal.

[16] "Hydraulic jump Types and Characteristics", https://theconstructor.org/water-resources/hydraulic-jump-types-characteristics/12091/

[17] "Hydraulic jump", https://en.wikipedia.org/wiki/Hydraulic_jump#:~:text=A%20hydraulic%20jump%20is%20a,occurs%20in%20the%20liquid%20surface.

[18] "Hydraulic jumps in rectangular channels", https://en.wikipedia.org/wiki/Hydraulic_jumps_in_rectangular_channels