Journal of
Civil Engineering and Structures

Journal homepage: www.journalces.com

Original paper

Laboratory study on the effect of rough bed in the stilling basin hydraulic jump characteristics

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ARTICLE INFO

Article history:
Received 10 October 2024
Accepted 15 December 2024

Keywords:
Laboratory Study
Rough Bed
The Stilling Basin
Hydraulic Jump

ABSTRACT

One of the most important phenomena in hydraulic quick variable flow hydraulic jump in which the damage high energy, flow rate significantly decreases. In this study the effect of roughness and slope angle characteristics of hydraulic jump in spillway stilling basin has been investigated experimentally. For this purpose, 200 experiments land on the slopes numbers in the range of 1:1, 1:2 and 1:3 and 2<Fr<5.5 roughness of 11, 18 and 22 mm were used. Laboratory results showed that Froude numbers tested by reducing the amount of energy loss is higher tilt angle overflow. Compare the results on rough and smooth overflow with bed showed that the secondary depth, Froude number, hydraulic jump over the rough bed significantly reduced energy loss. Laboratory results of the present study compared with previous studies a good agreement for energy dissipation of hydraulic jump in a stilling basin is rough substrates. Finally relationships to get married depth relative energy loss in supercritical Froude number input was provided for jerks formed on the substrate roughness.

DOI: https://doi.org/10.21859/jces.9150

1. Introduction

Hydraulic jump phenomenon in downstream of hydraulic structures such as spillway and gates is the first time experimentally by Bidone (1818), have been investigated. This phenomenon is widespread by various researchers on the straight and horizontal rectangular channels with smooth floor (classical hydraulic jump) are studied. Belanger (1828), Provided Secondary classic jump in the area under the critical depth on a flat bed with a rectangular cross-section (a).This calculation is made for: A smooth substrate with a rectangular cross-section is calculated as follows:

$$\frac{y_2^*}{y_1} = \frac{1}{2}\left[\sqrt{1+8Fr_1^2} - 1\right] \quad (1)$$

In this regard, $Fr_1 = \frac{v_1}{\sqrt{gy_1}}$ is supercritical Froude number input, and y_1, v_1 are the depth and velocity of a supercritical average in the first of the jump and g is the acceleration due to gravity. Overview of hydraulic jump on smooth bed in Figure (1) is substantially y_1.And y_2^* represent the primary and secondary depth of hydraulic jump on smooth substrate and L_j, L_r thus represents length of the jump area and length of the roller area.

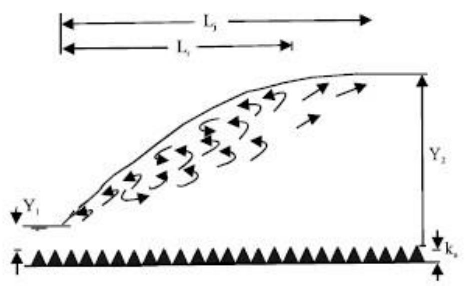

Fig 1. Overview of hydraulic jump on smooth bed.

Many researchers have done studies on the structure of the hydraulic jump including (Rajaratnam, 1965, 1967) and (Rajaratnam & Subramanya, 1968), (Sarma & Newnham, 1973), (Long et al., 1990), (Ead & Rjaratnam, 2002), (Chaurasia, 2003), (Ohtsu et al., 2003). Also (Wielogorski et al., 1970), and (Swamee et al., 2004) have studied interactions conjugate depths. (Safranez, 1929) and (Peterka, 1978) to determine the length of the jump and long jump and roll (Garg & Sharma, 1971) was the energy dissipation.(Narayanan, 1975), (Mccorquodale & Khalifa, 1983) and (Madsen & Svendsen, 1983) to model the hydraulic jump out and (Liu et

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Please cite this article as: Babaali, H.R., Alvandfar, R., Beiranvand, P., and Ahmadifard, M. (2025). Laboratory study on the effect of rough bed in the stilling basin hydraulic jump characteristics. *Journal of Civil Engineering and Structures*, 9(1), pp. 14-19.

al., 2004) evaluated the turbulence profile. The most common method for energy dissipation in the downstream spillway and gates the hydraulic jump. To control the jump downstream at this structure is the need for constructed stilling basin. One way to reduce the size of the pond measures such as building block or block foot shot mid-range jump is the more kinetic energy to waste. One of the processes that can be replaced by blocks is the use of floor roughness. Rough floor causes a volume control input and output does not equal amount of momentum and momentum output to the input resistance force roughness of less than momentum input. In recent years the rough elements in the basin floor is used. The researchers, including the effect of roughness on increasing efficiency and reducing the length of hydraulic jump stilling basins are examined [1-4]. Bed roughness can be in the form of stone China, sine waves, trapezoidal, rectangular and triangular channel width is on. Were the first researchers to experimental study of hydraulic jump in payments rough substrates. The results showed that mutations hydraulic formed on the rough bed made shorter jumps on flat substrates [5]. Demonstrated that supercritical flows downstream developed on rough bed, with a length less compared to smooth bed need [6], concluded that the roughness of bed, sequent depth and the jump length is reduced and the amount of reduction depends on the Froude number and relative roughness. Pagliara et al. (2008), no uniform roughness parameters were introduced and showed that the loss of hydraulic jumps properties in addition to the Froude number and relative roughness parameter depends no uniform roughness [7], So that the roughness is more uniform, the rate jumps will be more significant reduction Pagliara et al. (2012), showed that despite a protective stilling basin, steep rocks could play a key role in the phenomenon of energy dissipation [8]. Ahmad et al. (2010), energy dissipation by steep rocks with checkerboard layout using the overflow looked hemispherical stones. Results showed that energy drain on the slopes of the roughness, the more smooth overflows. Also the energy loss is a function of particle size rock slope [9]. The results Ortel et al. (2012), showed that the formulas proposed cross-stones on the slope between energy dissipation and the coefficients of the current regime makes rock slope design is better [10]. Pagliara et al. (2006), to determine the energy dissipation on rectangular channels with a slope of 1:4 and 1:12 in the presence of rock slope studied and compared the results with smooth mode. They stated that the energy dissipation is a function of the submerged rocks slope [11]. Brinkmeir et al. (2010), for the construction of new hydroelectric power station on shallow river Salzach design, rock slope due to a slight effect on river ecology, sustainable building bed and head suitable it as the best option introduced [12]. Pagliara et al. (2008), by creating roughness on the gradient expressed spillway by creating roughness relative increases in energy loss. The results showed that the secondary depth and length of the jump was performed on smooth substrate has higher rough bed (for the slope and Froude number are equal) and to compare the percentage of waste energy concluded that waste more energy in the rough than smooth substrate induction.

The results of this review indicated that the conjugate depth decreases due to the presence of its rough, this rate reduction fitted depends on the Froude number and form the lowest and the highest yield of the rough, the conjugate depth reduction were related to yield rough rectangular (D=0.21) and the triangular shape of roughness (D=0.27).According to the research carried out, operating with an effective bed roughness in cost reduction for depreciation for the basins to be fitted and major energy research in relation to the subject of the hydraulic jump on bed smooth or coarseness of detached taken while studying on the coarseness of the dense and coarse is very limited. On the other hand also has a significant impact on the reduction of substrate roughness profile has the energy to jump and depreciation. The main objective of this study was to examine the influence of roughness of the substrate and the angle of the slope of spillway on the hydraulic jump specifications such as conjugate for depth, the length of the jump, overall energy and depreciation to extract hydraulic jump about relationships and compare the results with other studies, the researchers fitted jeans on the bed.

2. Materials and methods

2.1. Dimensional analysis

Parameters can be studied into three general categories kinematics, dynamics and geometry divided. As kinematic parameters including: speed water for the shooting, gravity, hydraulic radius in the overflow level, dynamic parameters, including fluid density, specific energy primary before spillway and geometry parameters include specific energy level difference before and after the spillway, the water level at the foot of spillway, the height of the spillway, the slope of the spillway, the spillway roughness height which is equal to the diameter of the particles. The number of parameters affecting the energy dissipation high current, in turn, would be very difficult to make any influence and complicated, he adds. The number of parameters that have a greater impact on the rate of energy dissipation in previous studies, researchers from they were used as follows: velocity of water for the shooting, gravity, specific energy primary before spillway, different specific energy levels for before and after the spillway, the water level, the spillway height roughness, hydraulic radius cross-section of the spillway, the spillway slope. Buckingham theory we have:

$$f(v_1, g, \rho, E_0, \Delta E, y_1, R, K_s, D, S) \quad (2)$$

$$f\left(\frac{v_1}{\sqrt{gE_0}}, \frac{\Delta E}{E_0}, \frac{y_1}{E_0}, \frac{K_s}{E_0}, \frac{R}{E_0}, S\right) \quad (3)$$

By dimensional analysis and calculation of dimensionless parameters are:

$$\frac{\Delta E}{E_0} = f\left(Fr_1, \frac{K_s}{E_0}, S\right) \quad (4)$$

v_1 water velocity at the foot of the spillway, R the hydraulic radius cross-section of the spillway, g gravity, ρ density of the fluid, E_0 for initial specific energy, ΔE differences in specific energy levels before and after the spillway, y_1 water height, D Spillway height, S spillway slope, K_s Roughness height of the Spillway or equal to the diameter of particle(D_{50}).

2.2. Laboratory profile

In order to affect rough bed and spillway the tilt angle of the hydraulic parameters of an in vitro model was used in the hydraulic laboratory of Islamic Azad University, Khorramabad. To perform the experiment, the spillway with slopes of 1:1, 1:2 and 1:3 and the height of 130 mm in a flume with a length of 5 meters, width of 17 cm, height of 50cm and longitudinal slope 0.001 of Plexiglas with a thickness of 10 mm was used. Required water flume downstream of the reservoir parallel to the reservoir upstream transmitted by 3 pumps placed so that the maximum flow rate of each pump is 35 liters per minute (Figure 2).

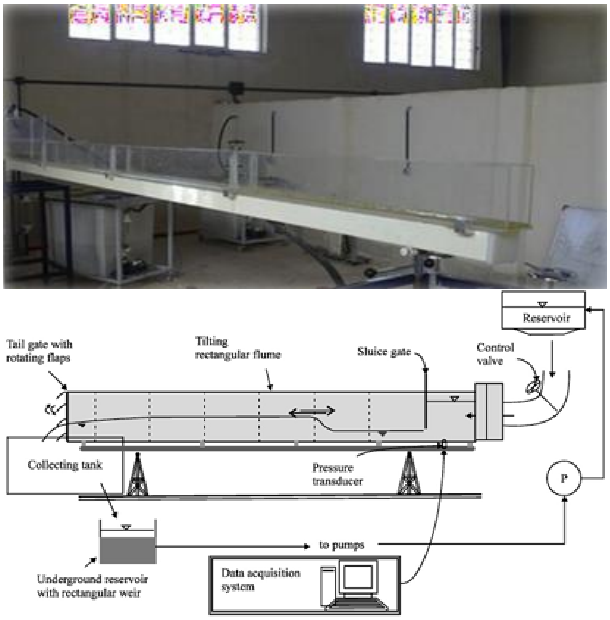

Fig 2. Longitudinal section of a laboratory flume used in this study.

The 200 Experiment with different flow rates in the range of 0.30 to 2 liters per seconds of 6 flow rate was used. In which to measure the depth bathymetry and currents in different sections of the square was used to measure the flow rate of the Spillway edge. After installing overflow flume used to calibrate it from a beaker with a given volume and hydraulic conductivity was set to 02/2. In Figure 3 flows rate curve - visible scale for the rectangular weir.

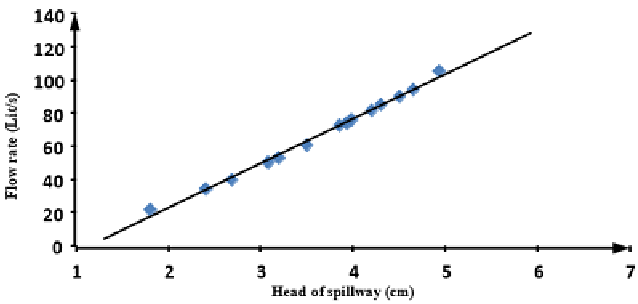

Fig 3. Flow rate curve - scale for rectangular weir.

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Froude numbers in the range of 2 <Fr <5.5 experiments and roughness of the grain size uniform (D_{50} = =18, 22, 11) on a flat-bed overflow with different slopes (1:1, 1:2 and 1:3) was conducted. In this study for creating rough, sand particles with uniform grain size using special glue and then glued on the sheet metal plate was placed inside the channel (Figure 4). The scope of the study variables in Table 1 is shown.

Fig 4. Sand with the grain size uniform.

Table 1. Variable.

Height of spillway (D:mm)	Slope of spillway (S)	Roughness (mm)	Flow rate (Lit/s)	Initial Froude number (Fr_1)	Parameter
130	1:1,1:2,1:3	11,18,22	0.3 - 2	2 - 5.5	Variation range

In all experiments, the initial depth and secondary depth, y_1, y_2 and jump length, Lj, was recorded during the experiments. In Figure 5 Hydraulic Jump on spillway with rough bed has been shown in the laboratory.

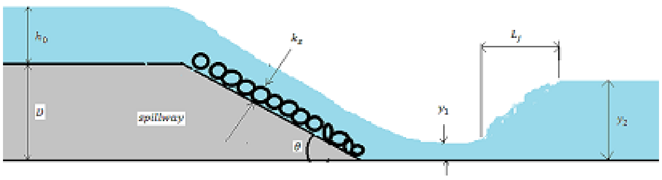

Fig 5. Hydraulic Jump on spillway on rough bed in the lab.

Geometry and hydraulic part of the experiments (gradient 1:2 with different roughness) on the table (2) is provided.

Table 2. Specifications of hydraulic jump in experiments conducted on rough ground with a slope of 1:2.

K_s(mm)	Q(L/s)	h_0(mm)	y_1(mm)	y_2(mm)	L_j(mm)	v_0(m/s)	v_1(m/s)	E_1(m)	E_0(m)	Fr_1
11	0.59	22	8	33	220	0.36	1.05	0.064	0.158	3.80
11	0.8	32	11	28	350	0.23	8	0.06	0.868	3.10
11	0.98	20	83	00	370	0.28	8.00	0.068	0.878	3
11	8.30	28	80	53	280	0.02	8.80	0.088	0.877	3
11	8.50	05	87	63	260	0.05	8.32	0.09	0.885	3.9
11	8.8	08	89	67	280	0.09	8.36	0.8	0.89	8.7
18	0.58	35	80	20	880	0.28	0.70	0.028	0.86	3.2
18	0.8	20	82	28	380	0.25	0.82	0.008	0.866	3.25
18	8	23	80	03	300	0.00	0.92	0.058	0.870	3.52
18	8.32	27	86	58	200	0.05	8.00	0.078	0.877	3.60
18	8.5	00	87	59	280	0.06	8.80	0.080	0.880	3.75
18	8.86	08	30	65	220	0.58	8.38	0.095	0.890	3.72
22	0.68	35	82	30	880	0.23	0.68	0.023	0.860	8.7
22	0.88	23	80	23	880	0.22	0.70	0.003	0.867	3
22	0.99	20	86	27	890	0.28	0.83	0.05	0.878	3
22	8.35	27	88	00	380	0.05	0.93	0.068	0.877	3.3
22	8.53	05	38	58	370	0.00	0.96	0.068	0.885	3.82
22	8.82	50	32	60	280	0.08	8	0.08	0.893	3.32

3. Results

To check the hydraulic jump characteristics on rough bed, Froude number, and length of the jump, jump the secondary depth and energy dissipation were evaluated. The spillway slope of 1:1 to 1:3 and Froude's numbers was 2 < Fr < 5.5.The results of this study are presented in two parts. The first part related to the comparison between proportions of hydraulic jump without a particle of sand for the next with uniform particle size and the second part to extract General hydraulic jump relationships and compare the results with other studies, the researchers fitted jeans on the bed.

3.1 Comparison between dimensionless ratios hydraulic jump for roughness uniform diameter

3.1.1 The effect of roughness uniform diameter of on the Froude number (Fr_1)

To investigate the effect of particle diameter rock slope on the Froude number jump start on the spillway of two dimensionless parameters ($\frac{h_0}{y_c}$) and (Fr_1) for different aggregation (Figure 6 and 7) were used.

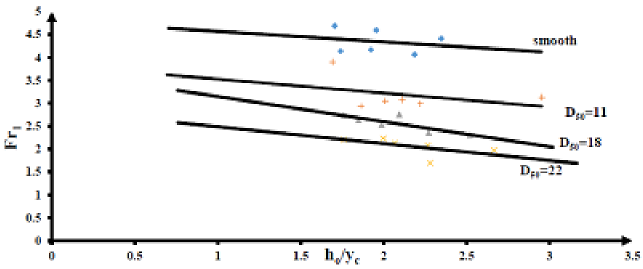

Fig 6. The relationship between ($\frac{h_0}{y_c}$) and (Fr_1) for particle diameter on the slope of 1:2.

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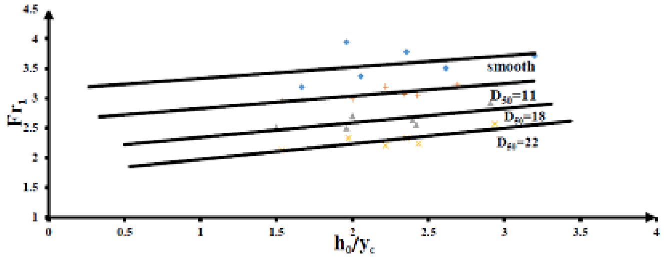

Fig 7. The relationship between $(\frac{h_0}{y_c})$ and (Fr_1) for particle diameter on the slope of 1:3.

According to the Figures (6 and 7) is observed that with increasing particle diameter (D_{50}) decreasing of Froude number to jump even higher.

3.1.2 The effect of roughness uniform diameter on energy loss ($\frac{\Delta E}{E_0}$)

The relative energy loss of hydraulic jump is, $\frac{\Delta E}{E_0}$ and ΔE is the special energy difference and are the first and the end of the jump respectively. G, energy dissipation rate was defined as the form below.

$$G = \frac{E_1 - E_0}{E_0} \quad (5)$$

In this study, the relative energy loss in smooth beds was also tested for different slopes of the graph in Figure (8) are shown.

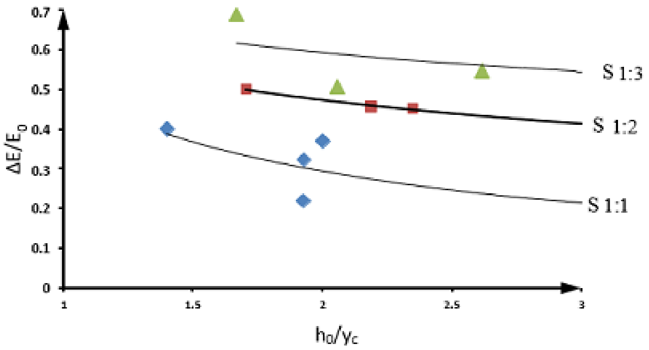

Fig 8. Changes in energy loss relative, $\frac{\Delta E}{E_0}$ of after spillway on $\frac{h_0}{y_c}$.

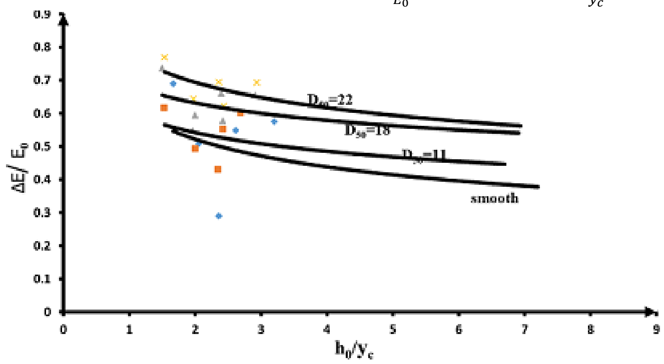

Fig 9. Changes in energy loss relative of $\frac{\Delta E}{E_0}$ in the rough bed for $\frac{h_0}{y_c}$ on the slope 1:3.

As shown in Figure (9) is made for $\frac{h_0}{y_c}$ the same, the energy loss increases with increasing particle diameter and the amount of these changes in numbers $\frac{h_0}{y_c}$ is minimal.

3.1.3 The effect of roughness diameter on the secondary depth of jump

Figure 10 dimensionless parameter $\frac{y_2}{y_1}$ for changes in particle diameter rock slope to the dimensionless parameter $\frac{h_0}{y_c}$ for the slope of 1:1 and 1:2 show.

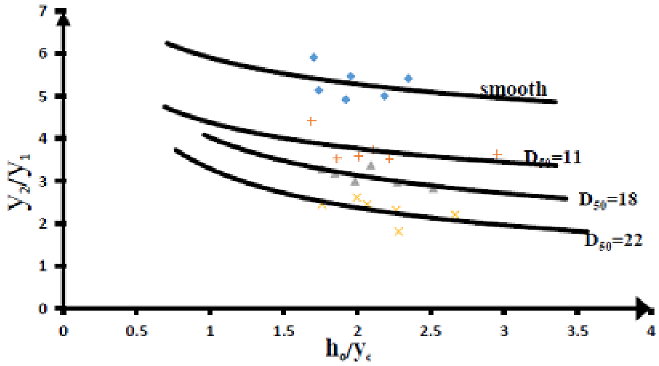

Fig 10. The effect of particle diameter (D_{50}) on the secondary depth jump $(\frac{y_2}{y_1})$ on a slope of 1:2.

As shown in Figure (10) is observed with increasing particle diameter (D_{50}) decreased the depth of the secondary hydraulic jump.

3.1.4 The effect of roughness on the particle diameter jump (L_j)

Dimensionless parameter changes $(\frac{L_j}{y_2})$ for changes in particle diameter roughness against dimensionless parameter $\frac{h_0}{y_c}$ for the slope of 1:1 in Figure (11) is visible.

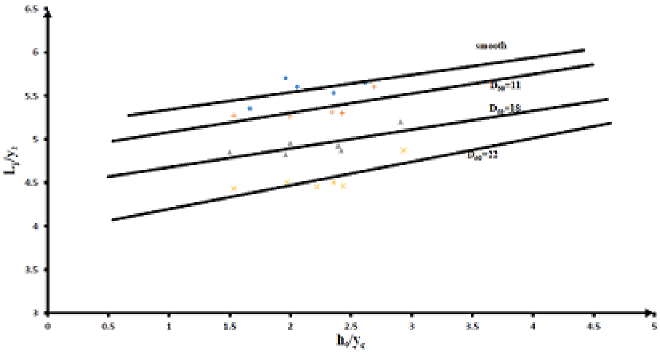

Fig 11. The changes in the relative length of hydraulic jump $\frac{L_j}{y_2}$ with increased roughness on the slope of 1:1.

As shown in Figure (10) is observed with increasing particle diameter (D_{50}) of secondary depth decreased during the hydraulic jump.

3.2 Comparison of our results with other studies, researchers, Compare $\frac{L_j}{y_2}$ (Observed in this study with observations USBR)

Given that studies in this area is very little and most studies have been conducted on the stilling basin or the effect of roughness of the channel bottom has been investigated.

The verify experimental conditions study with previous studies, comparisons between dimensionless parameter, jump length on depth secondary, $\frac{L_j}{y_2}$ observed in this study and USBR in Figure (12) shows given.

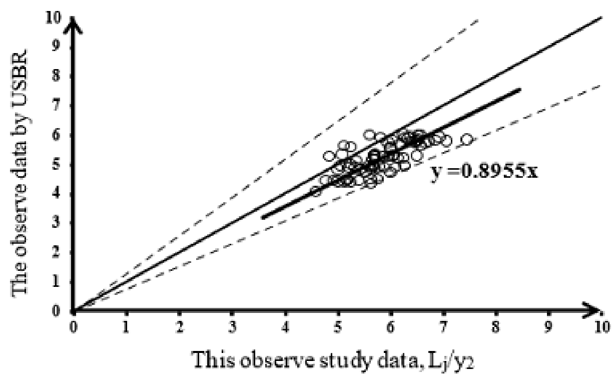

Fig 12. Comparison $\frac{L_j}{y_2}$ observational studies with USBR.

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Observations of this study with USBR As shown in Figure (12) is shown with respect to $\frac{L_j}{y_2}$ band to ensure 13 that are drawing a line 45 degrees, it can be concluded that the results are pretty close together that it confirms authenticity limitations of this study.

3.2.1 Compare $\frac{L_j}{y_1}$observed in this study with observations Silvester (1964)

Another comparison between $\frac{L_j}{y_1}$ observed in this study with empirical equation by Silvester (1964), based on the Froude number to jump to regard it as a relationship (6).

$$\frac{L_j}{y_1} = 9.75(Fr_1 - 1)^{1.01} \quad (6)$$

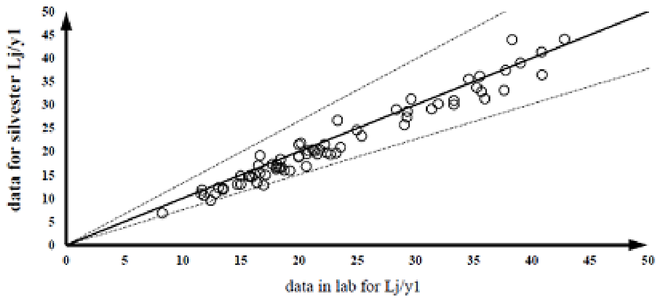

Fig 13. Comparison between ($\frac{L_j}{y_1}$) observational research with empirical equation (Silvester, 1964).

As shown in Figure (13) observed data differences observed in this study is very little with Silvester data.

3.2.2 Compare the relationship between Fr_1 and $\frac{y_2}{y_1}$ in this study, Belanger equation

Using experimental data specific relationship between and is defined by the results in Figure (14) shown in equation (7) is also extracted. Then taken to verify experimental data and the limitations of this study, the equation obtained by Belanger equation to equation (8) are compared.

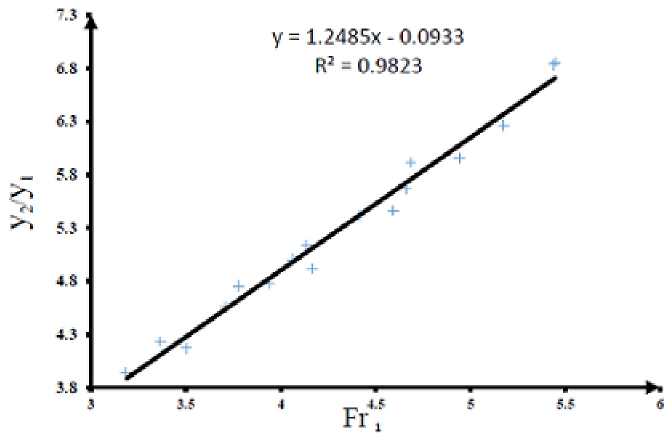

Fig 14. Relationship between (Fr) and ($\frac{y_2}{y_1}$) in this study.

As in Figure (14) is seen equation of this research is as follow:

$$\frac{y_2}{y_1} = 1.248Fr_1 - 0.093 \quad (7)$$

However, in order to compare the above equation 1 and 7 according to Table 2 for a number of different hypothetical landing $\frac{y_2}{y_1}$ for both the control connection.

Table 3. Data calculated from the formula (1) and (7).

Fr_1	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
$\frac{y_2}{y_1}$	2.37	3.07	3.77	4.47	5.17	5.8	6.6	7.3	8.0	8.7
$\frac{y_2}{y_1}$	2.4	3.02	3.65	4.3	4.9	5.5	6.1	6.8	7.4	8.0

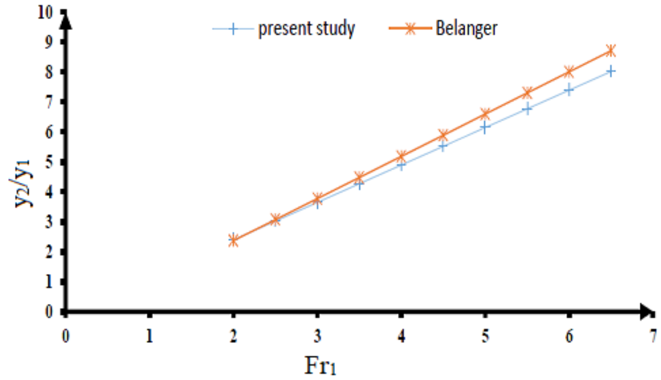

Fig 15. Comparison of the results obtained from the formula (1) and (7).

As shown in figure (15) is substantially different from the results obtained from the formula (1) and (7), this represents accuracy with minimal error.

3.2.3 Comparison of relationships between Fr_1 and $\frac{L_j}{y_1}$ other researchers

Figure (16) the relationship between the two dimensionless parameters, Fr1 and $\frac{L_j}{y_1}$, to verify vitro and in comparison with other studies, the researchers suggest.

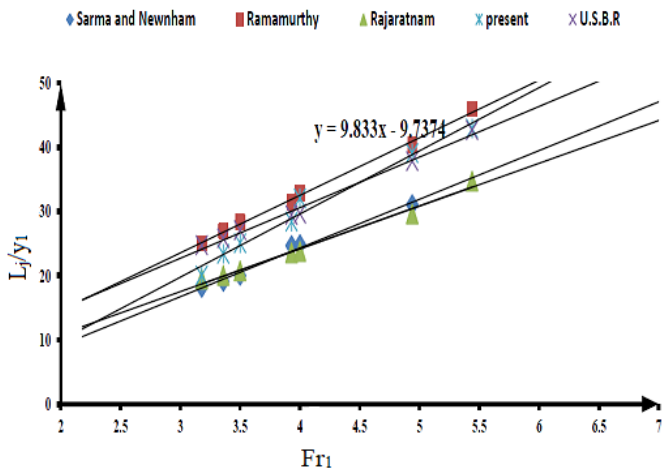

Fig 16. Comparison of relationships between (Fr1) and ($\frac{L_j}{y_1}$) in this study with previous studies.

As the figure (16) is shown the results of this study with previous studies are wide and its governing equation (8) is as follows:

$$\frac{L_j}{y_1} = 9.833Fr_1 - 9.733 \quad (8)$$

4. Conclusions

- 40% decrease in the slope of spillway; the energy loss is increased about 44%
- For increasing the roughness of the substrate particles, the dimensionless parameters$\frac{L_j}{y_2}$,$\frac{y_2}{y_1}$ and $\frac{\Delta E}{E_0}$ and Fr_1 are reduced.
- More energy loss by reducing the amount of slope overflow occurs, as for $\frac{\Delta E}{E_0} > 6$
- The changes in energy loss are independent of the parameters and simply tilt shift function slope of spillway
- The results of the present study compared with Silvester Research (1964) showed that the value of the parameter $\frac{L_j}{y_1}$ in this study, 4.7 percent more than the research Silvester (1964) is.
- It was also observed that the range of experimental data parameter $\frac{L_j}{y_1}$ in the present study compared with Silvester Research (1964), the band assures ± 14 percent.
- The results of the present study compared with USBR investigation showed that the value of the parameter in this study is 5.10% higher than USBR research. It was also observed

that the y_2 range of experimental data parameter $\frac{L_j}{y_2}$ in the present study compared with USBR research in certain bands ±13 percent.

Conflict of interest

There is not conflict of interest.

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Please cite this article as: Babaali, H.R., Alvandfar, R., Beiranvand, P., and Ahmadifard, M. (2025). Laboratory study on the effect of rough bed in the stilling basin hydraulic jump characteristics. *Journal of Civil Engineering and Structures*, 9(1), pp. 14-19.