Investigation of Flow Characteristics and Pressure Parameters of Free and Submerged Hydraulic Jumps in USBR Stilling Basins

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ABSTRACT

In this study, flow characteristics and pressure parameters of hydraulic jumps have been investigated in a laboratory flume**.** The results for different incident Froude numbers (Fr_1), at the downstream of an Ogee spillway on a typified USBR II stilling basin bed were compared with the USBR Type I basins. Dimensions of the Ogee spillway and stilling basin were designed according to the USBR criteria. The pressure data of the points on the basin bed were recorded using pressure transmitters with 20 Hz frequency. Experimental parameters including flow depths and velocities at the beginning and endpoint of free jumps (Y_1, Y_2, V_1 and V_2), and submerged jumps (Y_3, Y_t, V_3 and V_t) were measured. In the present study, dimensionless parameters of energy dissipation efficiency (ε_t), mean pressure head (Ψ^*_X), standard deviation of pressure fluctuations (Φ^*_X), maximum positive pressure fluctuation coefficient (C_P^+), maximum negative pressure fluctuation coefficient (C_P^-), total pressure fluctuation coefficient (C_P) and skewness coefficient (A_d) were investigated. Pressure parameters are dependent on Fr_1, the dimensionless position (Γ^*_X), and the submergence degree (S). The results showed that by reducing the Fr_1 values, the ε_t parameter decreases. The Φ^*_{Xmax} value in the USBR Type II basin decreases around 30% compared to the Type I basins in free jumps. The reduction of Φ^*_{Xmax} values in the submerged jump with S=1.4 is about 29% than free jumps. The $C_P{}^+{}_{max}$ and $|C_P^-|_{max}$ coefficients in the submerged jump with S=1.4 in comparison with free jumps decrease about 15 and 17%, respectively.

KEYWORDS

Ogee spillway, pressure coefficients, standard deviation of pressure fluctuations, submergence degree, USBR stilling basin.

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1. Introduction

Knowledge of pressure fluctuations along hydraulic jumps, which can occur within the stilling basin is essential for the design of energy dissipation structures. Some pressure parameters within the USBR Type II basin have been studied in references [1, 2]. In the present study, pressure parameters of free and submerged jumps have been investigated downstream of an Ogee spillway on the bed of a USBR Type II stilling basin. The results were compared with others in terms of free jumps in Type I basins.

2. Methodology

2-1. Experimental Setup

The experiments were carried out in a laboratory Plexiglas-walled flume with 10 m length, 51 cm width, and 60 cm height at the hydraulic laboratory of the University of Tabriz, Iran. Instantaneous pressure were measured with the pressure transmitters of Atek BCT 110 series with an accuracy of ±0.5%. The data acquisition frequency of 20 Hz with a duration of 90 seconds was used for each test at each pressure tap. According to Figure 1, the dimensions of the spillway and the stilling basin were designed according to USBR criteria [3, 4]. Flow depths were measured using an ultrasonic sensor of US30 series Datalogic with an accuracy of ±0.1 mm.

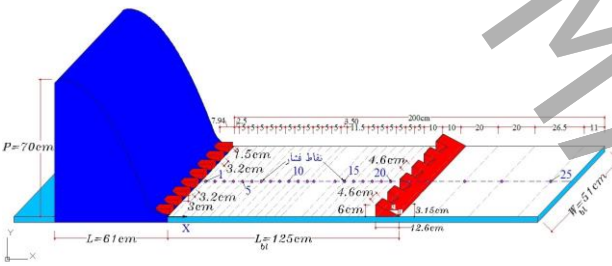

Figure 1. Schematic view of experimental setup

2-2. Statistical Pressure Parameters

The pressure parameters in hydraulic jumps is presented as follows [5]:

$$\Phi_X^* = \frac{\sigma_X}{E_L} \times \frac{Y_2}{Y_1} \times \frac{1}{S} = f(\Gamma_X^*) \tag{1}$$

$$\Psi_X^* = \frac{P_X - Y_1}{Y_2 - Y_1} \times \frac{1}{S} = f(\Gamma_X^*) \tag{2}$$

$$\Gamma_X^* = \frac{X}{Y_2 - N_1} \times \frac{1}{\sqrt{S}} \tag{3}$$

where Φ^*_X is the dimensionless standard deviation of pressures, Ψ^*_X is the mean pressure head, σ_X/E_L is the ratio of pressure fluctuations to energy dissipation, Y_2/Y_1 is the ratio of sequent depths of hydraulic jumps, S is the submergence degree (Y_t/Y_2), Y_t is the tail-water depth in submerged jumps, P_X is the mean pressure at the longitudinal position X, Γ^*_X is the dimensionless position of pressure tap, and X is the longitudinal position of the pressure tap from the beginning of the basin. N_1 parameter is the bed pressure at a given position, and equal to Y_1. Cos (θ), where θ is the angle of the spillway chute to the horizon [6].

Pressure coefficients including maximum positive pressure fluctuation coefficient (C_P^+), maximum negative pressure fluctuation coefficient (C_P^-), total pressure fluctuation coefficient (C_P), and skewness coefficient (A_d), are used as follows:

$$C_P{}^+ = \frac{P_{\max} - P_X}{E_1} \tag{4}$$

$$C_P{}^- = \frac{P_{\min} - P_X}{E_1} \tag{5}$$

$$C_P = C_P{}^+ + \left|C_P{}^-\right| \tag{6}$$

$$A_d = \sum_{i=1}^{n} \frac{(P_i - P_X)^3}{n\,\sigma_X^3} = f(\Gamma_X^*) \tag{7}$$

where P_{max} and P_{min} are the maximum and minimum pressures of the measured data series, respectively,and n is the total number of data.

3. Results and Discussion

At the downstream of spillways, with increasing the approach flow discharge (Q), the Froude number (Fr_1) decreases for free jumps (Table 1). Therefore, with increasing Q, the increase rate of the supercritical depth (Y_1) is more than the corresponding increase rate of the incident velocity (V_1). As a result, the Y_1 parameter has an important role in determining the Fr_1 values. For a given value of Fr_1, the energy dissipation efficiency parameter (ε_t) decreases linearly with increasing submergence. The average difference between the εt parameter in free and submerged jumps is about 16%.

Table 1. Flow characteristics under different conditions of free jumps of the USBR Type II basin

Q (L/s)	V_1 (m/s)	Y_1 (cm)	Fr_1	Y_2 (cm)
33.0	3.84	1.68	9.46	19.69
43.0	3.86	2.18	8.34	22.44
47.5	3.87	2.41	7.96	23.57
52.7	3.88	2.66	7.59	24.70
55.0	3.88	2.78	7.44	25.33
60.4	3.89	3.04	7.12	26.60

Figure 2 shows that for a given Froude number, the Φ^*_X value decreases as the S value increases. The Φ^*_X values in the USBR Type II basin are compared with others [7-9] in the Type I basins.

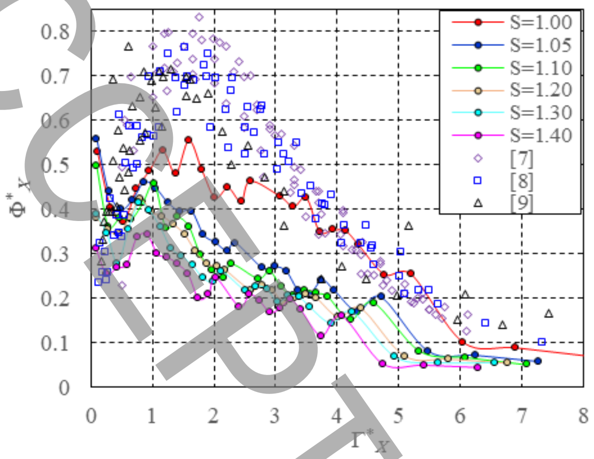

Figure 2. Distribution of Φ^*_X parameter with Fr_1=7.12

The Φ^*_{Xmax} values in the Type II basin are close to the spillway (Table 2). For free jumps, Φ^*_{Xmax} decreases about 30% in the Type II basin compared to Type I basins. The reduction of the Φ^*_{Xmax} values in the submerged jump with S equal to 1.05 and 1.4 are about 13% and 29% than free jumps, respectively.

Table 2. Φ^*_{Xmax} and Γ^*_{Xmax} values in different conditions

Flow conditions	Φ^*_{Xmax}	Γ^*_{Xmax}
S =1.00	0.46–0.58	1.22–1.70
S =1.05	0.35–0.56	0.87–1.18
S =1.10	0.38–0.50	0.89–1.22
S =1.20	0.40–0.44	0.81–1.31
S =1.30	0.37–0.48	0.78–1.04
S =1.40	0.34–0.40	0.84–1.00
[7]	0.73–0.83	1.40–2.00
[8]	0.69–0.76	1.85–2.04
[9]	0.65–0.77	0.61–1.70

The results show that at the position of $\Gamma^*_X \approx 6$, the Ψ^*_X values are approximately equal to 1. According to [8, 9], the hydraulic jump endpoint in Type I basins are 8.5 and 8, respectively. Thus, the length of Type II basins is reduced about 27% compared to Type I basins. $C_P{}^+{}_{max}$ and $|C_P{}^-|_{max}$ coefficients in the submerged jump with S=1.4 compared to free jumps decrease about 15% and 17%, respectively. The variations range of the C_P values in free jumps are 0.32–0.42. A_d coefficient in the first zone of the Type II basin decreases around 55%–75% compared to Type I basins.

4-Conclusions

Several findings of the pressure patterns within a USBR Type II basin in free and submerged jumps, and compared with Type I basins are provided as follows:

i) For free jumps, as the Q value increases, the Fr_1 value decreases at the spillway downstream. In fact, the increase rate of Y_1 is more than the corresponding increase rate of V_1.

ii) For free jumps, the Φ^*_{Xmax} values decrease about 30% in the Type II basin compared to Type I basins. The reduction of the Φ^*_{Xmax} values in submerged jumps is about 13%–29% compared to free jumps.

iii) With increasing the S value, the jet mixing decreases, and the ε_t value is reduced compared to free jumps. For submerged jumps, all flow turbulences are not contained in the basin. There is a residual amount of pressure fluctuations beyond the end sill. This is an unfavorable feature, and a longer basin is necessary for submerged jumps. Submerged jumps are less sensitive to tail-water fluctuations, which is an advantage than free jumps. Further tests are recommended for submerged jumps.

5. References

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