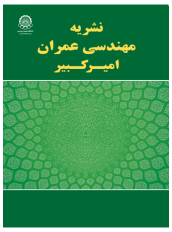

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Flow Characteristics and Pressure Parameters of Free and Submerged Hydraulic Jumps in the USBR Stilling Basins

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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 the bed of the USBR Type II stilling basin 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 bed of the basin 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 (CP^+), maximum negative pressure fluctuation coefficient (CP^-), total pressure fluctuation coefficient (CP) and skewness coefficient (A_d) were investigated. Pressure parameters are dependent on Fr1, the dimensionless position (Γ^*_X), and the submergence degree (S). The results showed that by reducing the Fr1 values, the parameter of εt decreased. The value of $\Phi^*_{X\max}$ in the USBR Type II basin decreased around 30% compared to the Type I basins in free jumps. The reduction of $\Phi^*_{X\max}$ in the submerged jump with S=1.4 was about 29% compared to the free jumps. The values of $CP^+_{\max}$ and $|CP^-|_{\max}$ coefficients in the submerged jump with S=1.4 in comparison with free jumps decreased about 15 and 17%, respectively.

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1. INTRODUCTION

Knowledge of pressure fluctuations along the 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 the USBR Type II stilling basin. The results were compared with others in terms of free jumps in the 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 pressures were measured with the pressure transmitters of the 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 the US30 series Datalogic with an accuracy of ±0.1 mm.

2.2. Statistical Pressure Parameters

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

$$\Phi^*_X = \frac{\sigma_X}{E_L} \times \frac{Y_2}{Y_1} \times \frac{1}{S} = f\left(\Gamma^*_X\right) \tag{1}$$

$$\Psi^*_X = \frac{P_X - Y_1}{Y_2 - Y_1} \times \frac{1}{S} = f\left(\Gamma^*_X\right) \tag{2}$$

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

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,

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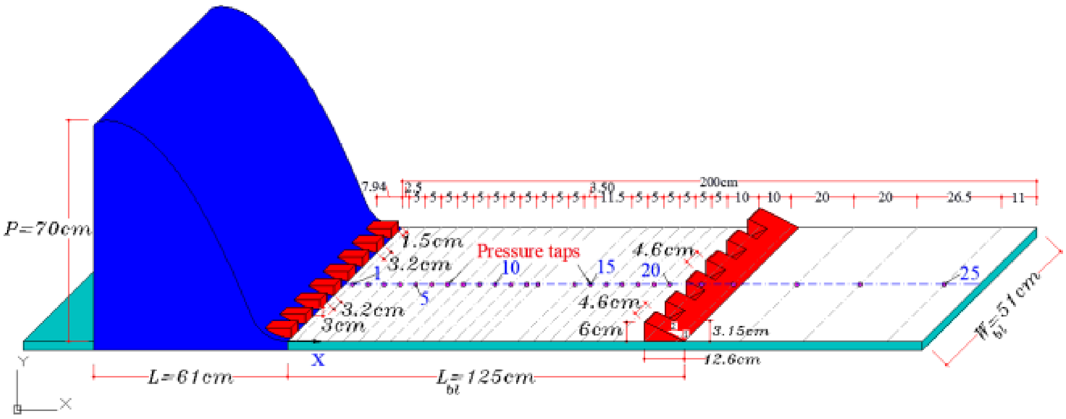

Fig. 1. Schematic view of the experimental setup

Table 1. Characteristics of free jumps in the 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

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. The parameter of N_1 parameter is the bed pressure at a given position and is 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), were used as follows:

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

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

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

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

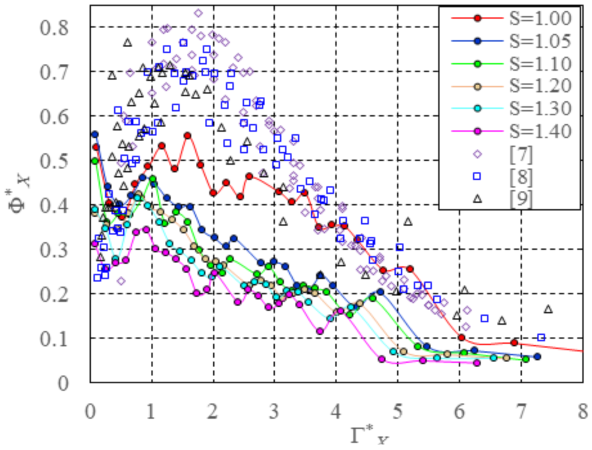

Fig. 2. Distribution of Φ^*_X with Fr1=7.12

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 spillway, with increasing the approach flow discharge (Q), the Froude number (Fr_1) decreased 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 parameter of Y_1 parameter has an important role in determining the Fr_1 values. For a given the values of Fr_1, the energy dissipation efficiency (ε_t) decreased linearly with increasing submergence. The average difference between the ε_t parameter in free and submerged jumps is about 16%.

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

The values of Φ^*_{Xmax} in the Type II basin are close to the spillway (Table 2). For free jumps, Φ^*_{Xmax} decreased about 30% in the Type II basin compared to the Type I basins. The

Table 2. Values of Φ^*_{Xmax} and Γ^*_{Xmax} 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

reduction of the values of Φ^*_{Xmax} in the submerged jump with S equal to 1.05 and 1.4 are about 13% and 29% compared to free jumps, respectively.

The results showed that at the position values 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 is 8.5 and 8, respectively. Thus, the length of the Type II basins was 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 decreased about 15% and 17%, respectively. The variations range of the values of C_P values in free jumps were in the range of 0.32 to 0.42. The A_d coefficient in the first zone of the Type II basin decreased around 55%–75% compared to the Type I basins.

4. CONCLUSIONS

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

i) For free jumps, as the value of Q increased, the value of Fr1 decreased at the downstream of spillway. In fact, the increase rate of the values of $Y1$ was more than the corresponding increase rate of the values of $V1$.

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

iii) With increasing the value of S, the jet mixing decreased, and the value of ε_t was reduced compared to free jumps. For submerged jumps, all of the flow turbulences were 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 variations, which is an advantage compared to free jumps. Further experiments are recommended for submerged jumps.

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