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Numerical Simulation of Effect of Expansion Angle and End-sill Location on the Hydraulic Jump in Gradually Expanding Stilling Basins

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ABSTRACT: Expanding stilling basins not only are effective energy dissipators, but also appropriate translations between hydraulic structures. Hence, the present study aims at numerical simulation of the effect of end-sill location on the energy dissipation. Doing so, Fluent software was employed and hydraulic jump under two divergence angels and four end-sill locations in the range of 4 to 8 Froude number was examined. According to the results, for larger expansion angles, the sequent depth and jump length are lower and energy dissipation is much more. Moreover, as the end-sill closes to the basin's entrance, the lower sequent depth, shorter jump, and less energy dissipation are observed. For very close locations more instability in the flow surface are seen. Results showed that for a given expansion angel, improving the location of the end-sill can decease 20% the conjugate depth, enhance 90% the amount of energy dissipation, and reduce 26% the jump length.

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1- Introduction

Expanding stilling basins are widely used because they can serve as translation between upstream and downstream structures with different cross sections [1]. Many researchers were interested in such stilling basins. Hager [2] gathered and evaluated some of these investigations. Khalifa and McCorquodale [3] stated that in contrary to the convenience basins, expanding walls reduce the jump length up to 70% and increase the energy dissipation up to 15%. The optimum height and position of the blocks were investigated by Nettleton and Mc-corquodal [4, 5]. Rageh [6] showed the effects of continues end-sill on the performance of radial hydraulic jump. Keeping the performance, he could shorten the basin length by 25%. In another experimental investigation Verma et al. [7] evaluated the expansion angle and inverse bed slope on the hydraulic jump. Results revealed that by 8% increase in bed slope, the sequence depth and jump length reduces by 47% and 35%, respectively and energy dissipation increases by 20%, as well. On the other hand, 10% increase of expansion angle can reduce 51% sequence depth and 35% jump length and can also enhance 23% energy dissipation. Omid et al [8] and Esmaeili Varaki [9] were also assessed the gradually expansion of guide walls and bed slope of the stilling basin on the hydraulic jump parameters, simultaneously. They developed several equations for estimating those parameters.

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2- Methodology

According to the previous researches [1, 2, 9], the following equation can represent the hydraulic jump in a gradually expanding stilling basin of rectangular cross section:

$$F_1(\theta, y_1, y_2, v_1, v_2, \mu, g, L_j, \rho, S_0, \Delta E, d_s)=0 \tag{1}$$

where expansion angle $\theta=(B_2-B_1)/L$; B_1 and B_2 are basin width in the entrance and exit section, respectively; L is basin length; S_o bed slope, y_1 and y_2 are water depth before and after jump, respectively; v_1 and v_2 are flow velocity before and after jump, respectively; μ is dynamic viscosity of fluid; g is gravity acceleration; L_j is jump length; ρ is water density; ΔE is change in the energy; and d_s is distance of end-sill to the basin entrance. Applying ∏-Buckingham theorem with ρ, g, and y_1 as the repeating parameters.

$$F_2(y_2/y_1, L_j/y_1, Fr_1, Fr_2, Re, \Delta E/y_1, ds/y_1, \theta, S_0)= 0 \tag{2}$$

For a turbulent flow on a horizontal bed, the jump parameters can be estimated from Equations 3 to 6.

$$y_2/y_1=F_3(Fr_1, ds/y_1, \theta) \tag{3}$$

$$\Delta E/y_1=F_4(y_2/y_1,Fr_1,ds/y_1,\theta) \quad (4)$$

$$L_j/y_1=F_5(y_2/y_1,Fr_1,ds/y_1,\theta) \quad (5)$$

$$Fr_2=F_6(y_2/y_1,Fr_1,ds/y_1,\theta) \quad (6)$$

Dianat [10] conducted many test on a physical model (Figure 1) located in faculty of mechanic of Shiraz university and gathered valuable data which we have used in our research.

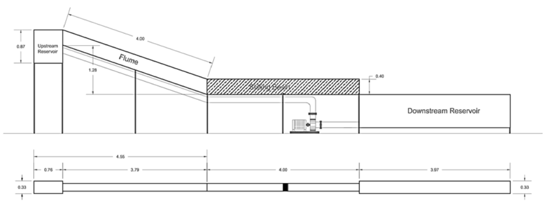

Figure 1. Schematic of the physical model in this research

In this investigation two expansion angles of 5-20 (B_1-B_2) and 10-20 have been examined where the basin is 4 m long (Figure 1).

3- Results and Discussion

For numeric simulation, Fluent software which has widely been used for flow modeling in the stilling basins was applied. Software was adjusted according to Applying mixed rectangular meshes of 20×20 mm^2 and 40×40 mm^2, the software was implemented for one case of the experiments (Q=6 lit/s, 5-20 expansion, d_s=3.5m, and free flow at the end of channel). Table 1 shows the verification results of the numerical simulation.

Table 1. Verification of the numerical results

parameter	Experiment [26]	Numeric results	AE (%)	RMSE (m)/(m/s)
y_1	0.02	0.018	-10	0.002
y_2	0.07	0.085	21.43	0.015
v_1	1.82	2.18	19.79	0.36
v_2	0.42	0.4	-4.72	0.02

Then the model was implemented with different Q and d_s values for two considered expansions and depth, velocity, and jump length were recorded. Table 2 shows the obtained results from different runs.

Table 2. The results for different

$\Delta E/y_1$	L_j/y_1	Fr_2	y_2/y_1	Fr_1	d_s/y_1	tan θ
17.96	30.00	0.384	6.00	6.82	100	0.019
16.56	40.53	0.278	7.11	6.75	131.5	0.019
9.72	38.50	0.242	7.00	5.63	150	0.019
10.61	42.63	0.213	7.89	5.97	184.2	0.019
7.42	20.00	0.268	6.67	5.15	166.7	0.019
5.93	27.06	0.247	6.59	4.82	147.1	0.019
12.29	43.89	0.245	7.22	6.14	138.9	0.019
23.49	26.00	0.416	6.25	7.64	125	0.019
17.57	21.20	0.392	6.00	6.79	100	0.019
10.84	20.00	0.249	7.33	5.90	83.3	0.019
10.79	42.78	0.264	7.22	5.88	111.1	0.013
10.27	43.89	0.234	7.78	5.86	138.9	0.013
8.78	49.44	0.204	8.33	5.71	166.7	0.013
5.69	43.33	0.181	8.61	5.19	194.4	0.013

Applying data of Table 2 to the general form of a multivariate linear relation ($y=a_0+a_1x_1+a_2x_2+\ldots+a_nx_n$), equations 3 to 6 could be rewritten as the following equations:

$$\frac{y_2}{y_1}=8.735-0.095Fr_1+0.011\frac{d_s}{y_1}-146.82\tan\theta \quad (7)$$

$$\frac{\Delta E}{y_1}=-16.187-1.292\frac{y_2}{y_1}+6.072Fr_1+0.006\frac{d_s}{y_1}+0.391\tan\theta \quad (8)$$

$$\frac{L_j}{y_1}=-68.979+9.799\frac{y_2}{y_1}+4.314Fr_1+0.058\frac{d_s}{y_1}-2.696\tan\theta \quad (9)$$

$$Fr_2=0.592-0.075\frac{y_2}{y_1}+0.048Fr_1+0.0002\frac{d_s}{y_1}-5.803\tan\theta \quad (10)$$

4- Conclusions

This research shows that expansion and distance of end-sill to entrance section (ds) are very important. Considering a fixed expansion angle, end-sill location can enhance the energy dissipation by 90% and reduce jump length by 26%. Based on the experimental and numerical data several equations were developed for estimation of jump parameters like sequence depth, energy dissipation, jump length, and Froude number at jump downstream.

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