Advances in Bioresearch
Adv. Biores. 8 [Spl issue 1] 2016: 64-68

Print ISSN 0976-4585; Online ISSN 2277-1573
Journal's URL:http://www.soeagra.com/abr.html
CODEN: ABRDC3
ICV 86.92

Advances in Bioresearch

Full Length Article

Characterizes of Hydraulic jump in Stilling basins with adverse slope

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ABSTRACT
Hydraulic jump stilling basins are used as an energy dissipater structures downstream of gates spillways and weirs. The research shows that some changes in stilling basins can increase the efficiency of basins. For example using roughness or adverse slope. In the present study the effect of adverse slope in stilling basins is survey. The experimental research was set for determine the effect of adverse slope in stilling basins. To reach this goal, 3 discharge and 4 adverse slope was used in rectangular flume and for each test characteristic of hydraulic jump was defined. The amount of Froude Number was set from 4.85 to 9.48. The results showed that adverse slope, can decrease the cost of stilling basin. Also the result showed that optimized adverse slope in all tests was 0.0052 m/m. The maximum reduction compared with classic hydraulic jump was found in this slope. The amount of decreasing in hydraulic jump length, roller length and sequent depth was 44%, 53% and 20.5% respectively.
Keywords: Hydraulic jump, Stilling Jump

Received 17/07/2016 Accepted 16/11/2016
How to cite this article:
R Riazi, M Ashrafi. Characterizes of Hydraulic jump in Stilling basins with adverse slope. Adv. Biores., Vol 8 [Spl issue 1] 2016: 64-68. DOI:10.15515/abr.0976-4585. SI6468

INTRODUCTION

Hydraulic jump is generally used for the dissipation of excess kinetic energy downstream of hydraulic structures such as drops, spillways, chutes, and gates. The structures which are constructed at great costs downstream of these are called energy dissipation structures. The hydraulic jump which occurs in wide rectangular horizontal channels with smooth bed is defined as being a classical jump and has been widely studied by Peterka [1], Rajaratnam [2], McCorquodale [3] and Hager [4].
Some studies about hydraulic jump in adverse sloped stilling basins with smooth bed have been done like Govinda Rao and Rajaratnam [5], McCorquodale and Khalifa [6] and Abdel Gawad and McCorquodal [7].

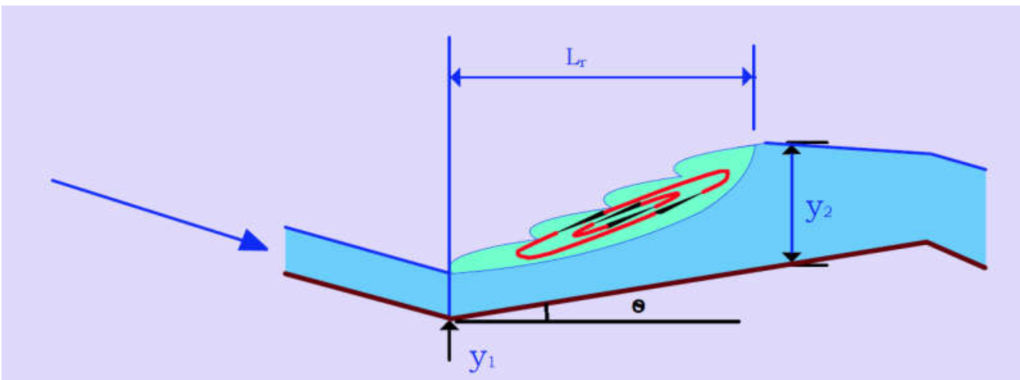

Figure (1) adverse slope hydraulic jump [8]

Some of researchers have offered relationships for determining specifications of adverse sloped jump. Govinda Rao and Rajaratnam [5] have studied specifications of submerged hydraulic jump in rectangular channels with adverse slope. They founded equation (1) by using continuity and momentum equations. They showed that adverse slope can change a classical free hydraulic jump to a submerged jump.

$$\frac{y_3}{y_1} = \left[(1+Sr)^2\emptyset^2 - 2Fr_1^2 + \frac{2Fr_1^2}{(1+Sr)\emptyset}\right]^{0.5} \quad (1)$$

In this equation, y_3= submerged depth on gate, y_1= depth of super critical flow, Fr_1= Froude number related to y_1, ø= sequent depth proportion in free jump, and S_r= submerging factor that can calculate by bellow formulas:

$$\emptyset = \frac{y_2}{y_1} = 0.5\left(\sqrt{1+8Fr_1^2} - 1\right) \quad (2)$$

$$Sr = \frac{y_4 - y_2}{y_2} \quad (3)$$

They also have offered bellow experimental formulas for energy dissipation and length of submerged jump:

$$\frac{E_L}{E_1} = \left[\left(\frac{y_3}{y_1}(1+Sr)\emptyset\right) + 0.5\mathrm{Fr}_1^2\left(1 - \frac{1}{(1+\mathrm{Sr})^2\emptyset^2}\right)\right]\left[\frac{y_3}{y_1} + \frac{\mathrm{Fr}_1^2}{2}\right] \quad (4)$$

$$\frac{L_j}{y_2} = 4.9Sr + 6.1 \quad (5)$$

Long et al. [9] adverse sloped hydraulic jump in rectangular channel with smooth bed. They considered specifications of this kind of hydraulic jump including profile of water surface; the distribution of velocity and Shear stress resulted from turbulence

Since the effect of optimized adverse slope in hydraulic jump not been considered yet, in this study this kind of hydraulic jump has been investigated.

MATERIALS AND METHODS

Dimensional analysis

The effective terms in adverse slope is:

$$f(y_1, y_2, L_j, L_r, g, \vartheta, \mu, \rho, V, q, s) = 0 \quad (6)$$

In this equation:

y_1 and y_2 are flow depths before and after jump respectively. L_j and L_r are hydraulic jump length and roller length respectively. g is the acceleration of gravity. ρ, υ are the mass density and viscosity of water respectively. μ is Viscosity. V, q, s are velocity, unit discharge and slope respectively.

Using Buckingham's theory, the following dimensionless relationship is thus obtained:

$$f\left(Fr_1, R_e, \frac{y_2}{y_1}, \frac{q}{Vy_1}, \frac{L_j}{y_1}, \frac{L_r}{y_1}, s\right) = 0 \quad (7)$$

In this equation Fr_1 and R_1 are, respectively the Froude and Reynolds values at the beginning of the jump. The value of the Reynolds number in these experiments was quite high. It means that viscosity has no effect and thus Reynolds number can be eliminated from analysis. As a result Eq (7) would change to Eq (8):

$$f\left(Fr_1, \frac{y_2}{y_1}, \frac{q}{Vy_1}, \frac{L_j}{y_1}, \frac{L_r}{y_1}, s\right) = 0 \quad (8)$$

Experimental methods

In this study, the tests were performed in a rectangular open channel about 40 cm wide, 50 cm deep and 12 m long. The side walls of the flume were made of glass.

Water was pumped from a storage tank to the head tank of the flume by a centrifugal pumps. The slope was made by a hydraulical jack.

The supercritical flow was produced by a sluice gate. Water entered the flume under this sluice gate with a streamlined lip, thereby producing a uniform supercritical flow depth with a thickness of y_1. In all experiments, the tailgate was adjusted so that the jumps were formed freely. The discharges were measured by a flow meter installed in inlet pipe. Values of y_1 and V_1 were selected to achieve a range of the Froude number, from 4.85 to 9.48.

In total, 45 tests was preformed for 5 different slopes in which 9 tests was preformed for horizental bed (s=0) and other test was stablished for s=0.0043, s=0.0047, s=0.0052 and s=0.0056. Also discharge was changed for each slope. The amount of discharge was stablished 14.47, 15 and 15.7 L/s for any of them. For each slope and each discharge, y_1 was set in 2, 2.3 and 2.6 cm.

Figure (2) model setup

Figure (3) Hydraulic jump wih adverse slope (Q=15L/s, Fr1= 5.74 and s=0.0043)

RESULT AND DISCUSSION

Length of the jump:

Fig 4 shows the relationship between the Froude number and the dimensionless length of the jump (L_j/Y_1) for tests. It shows that the same result can be observed for two adverse slope s=0.0052 and 0.0056. Also for all Froude number values, relative jump length increase with increasing Froude number. The results also show that the hydraulic jump length ratio (L_j/y_1) decreases maximum 43.87% in comparison with horizontal bed.

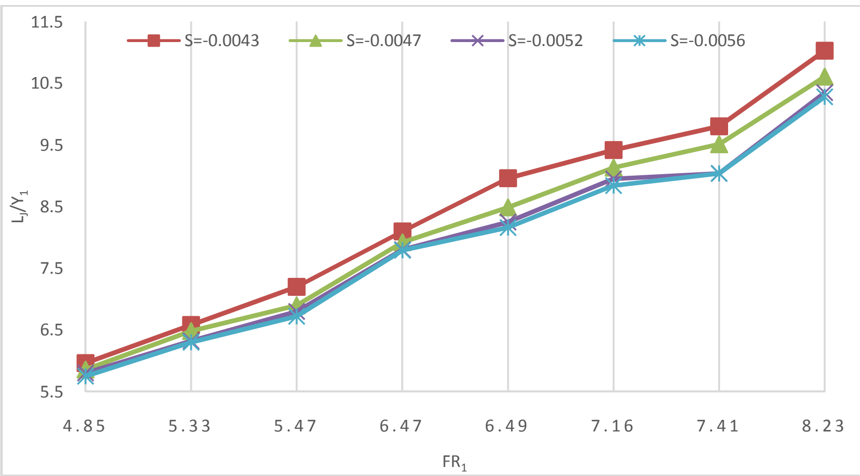

Fig 4. Relationship between L_j/Y_1 and Fr_1 in adverse slope

Length of the roller:

The experimental results on roller length corresponding to different values of the Froude number for each y_1 are plotted in Figure 7. It shows that for each Froude number ranged from 4.85 to 9.48, the length of the roller in horizontal bed is more than adverse slope. The experimental observations showed that adverse slope was more effective in low amount of Froude number. The results also show that the roller length ratio decreases maximum 52.94% in comparison with horizontal bed.

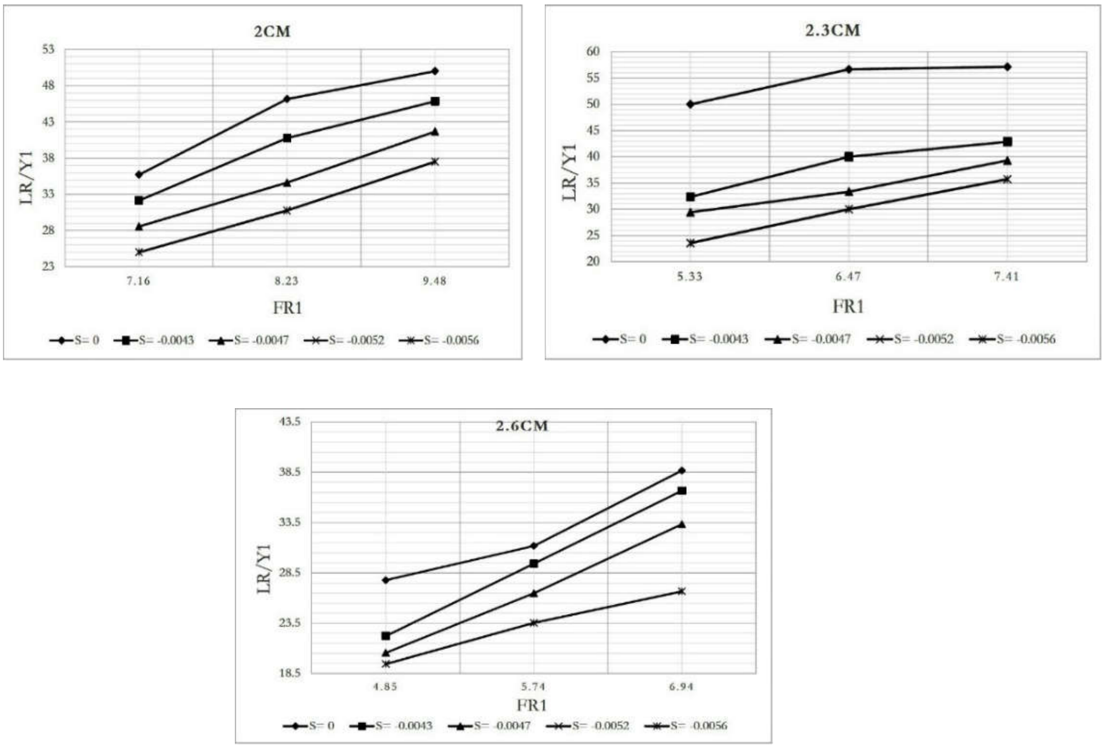

Fig 5. Relationship between L_r/Y_1 and Fr_1 in adverse slope for different Y_1

Sequent depth:

Figure 6 to 8 shows that the ratio of Y_2/Y_1 in adverse sloped bed is smaller than the same ratio of classic jump for each Froude number. The logic behind such a phenomena is that since the slope be toward start of jump, the jump cannot developed and kinematic energy is dissipate in to the gravity energy. Figure 6, 7 and 8 shows comparison of the sequent depth ratio obtained from our experimental tests.

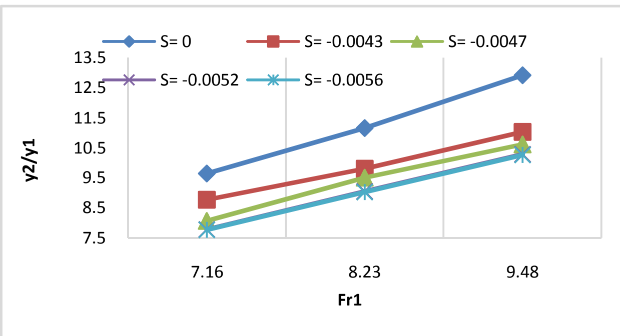

Fig 6. Relationship between Y_2/Y_1 and Fr_1 in adverse slope for Y_1=2 cm

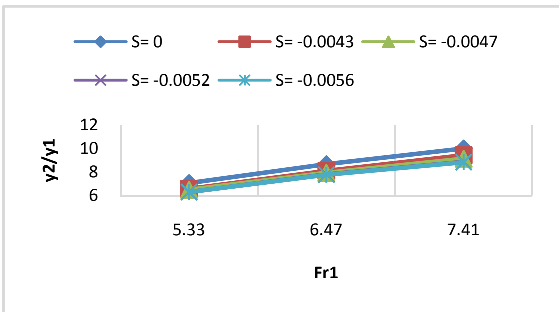

Fig 7. Relationship between Y_2/Y_1 and Fr_1 in adverse slope for Y_1=2.3 cm

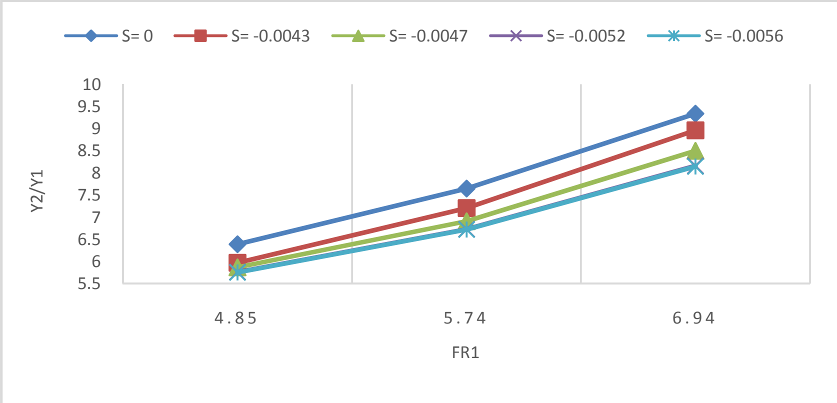

Fig 7. Relationship between Y_2/Y_1 and Fr_1 in adverse slope for y_1=2.6 cm

As it can be seen from this figure, our results are in agreement with the above mentioned occurrence for two adverse slope s=0.0052 and 0.0056. These results indicate that adverse slope more than 0.0052 has low effect in reducing the sequent depth of hydraulic jump. The results also show that the sequence depth ratio decreases 20.38% in comparison with horizontal bed.

CONCLUSIONS

In this study the effect of adverse slope in stilling basins hydraulic jump was surveyed. The result shows that:

- Adverse slope can effect on hydraulic jump characteristics. It decrease hydraulic jump length, roller length and sequent depth.
- The amount of decreasing in hydraulic jump length, roller length and sequent depth was 44%, 53% and 20.5% respectively.
- For two adverse slope s=0.0052 and 0.0056, the same results was obtained.
- Adverse slope more than 0.0052 has low effect in reducing the sequent depth, hydraulic jump length and roller length of hydraulic jump.

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