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ORIGINAL ARTICLE

The characteristics of submerged hydraulic jump in sloped stilling basins with rough bed

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ABSTRACT

In present study, the effect of reversed slope on hydraulic jump specifications in rectangular channel with rough bed was measured. Also the proportion of Sequent depths, the length of roller, the submerged depth on the gate, and energy dissipation are investigated. flume with 0.3 depth, 0.4 height and 8 meters length, was used for experiments. Experiments were performed in range of Frouden umber between 4.5-10.9. Reversed slope were set in zero, 1.8%,2.5%, 3.5% and 4 percents. The results show that energy dissipation increases up to 7 percent by increasing slope. Also they show that rough bed in submerged hydraulic jump can decrease the length of stilling basin.

Key words: Submerged hydraulic jump, reversed slope, submerged depth, Energy dissipation, Rough bed

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INTRODUCTION

Hydraulic jump can occur in two general kinds: free and submerged. In free hydraulic jump, Sequent depths and form of jump are visible. But, in submerged hydraulic jump, it is completely under the water (Figure 1). In free hydraulic jump, downstream depth (y_4) has no effect on flow that pass from the gate.If downstream depth increases without flow increasing, hydraulic jump moves upward gradually till jumpstart (y_1) began to cover by water. In this position wary amount of extra increase in downstream depth, causes the jump to be more submerged and if we want to fix flow intensity, the amount of upstream depth should be increased. It'scalled submerged jump. Free and submerged jump because of their usage in energy dissipation at down hydraulic structures as dams, spillways and… are important phenomenon in open channels.So it has been considered by many scientists and scholars. Rajaratnam [1] and Hager [2]were studied in classic hydraulic jump. Other studies in hydraulic rough bed by Leutheusser and Schiller [3],Gill [4], Hughes and Flack [5], Ead and Rajaratnam [6], Carollo et al [7], Izadjoo and Shafai Bejestan [8] and Pagliara et al. [9] proved that the roughness have remarkable effect on reducing the jump characteristics.These experiments were done in smooth and rough horizontal beds. Also, some studies about submerged hydraulic jump with horizontal bed have been done like Govinda Rao and Rajaratnam [10], McCorquodale and Khalifa [11] and Abdel Gawad and McCorquodal [12]. Some of them have offered relationships for determining specifications of submerged jump. Govinda Rao and Rajaratnam (1963) have studied specifications of submerged hydraulic jump in rectangular channels [10]. They founded equation (1) by using continuity and momentum equations :(fig 1)

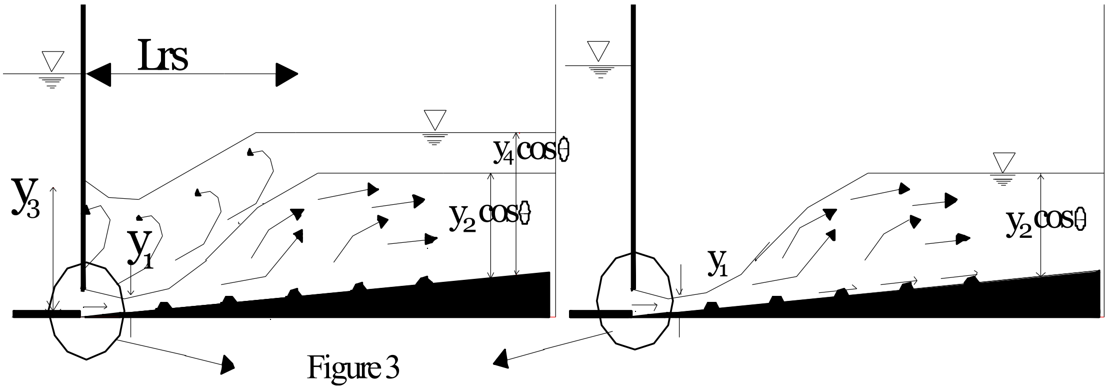

Figure 1- submerged and free hydraulic jump in lower part of sliding gate in rough bed with slope

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

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 Sr= 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:

$$\frac{E_L}{E_1}=\left[\left(\frac{y_3}{y_1}(1+Sr)\emptyset\right)+0.5Fr_1^2\left(1-\frac{1}{(1+Sr)^2\emptyset^2}\right)\right]\left[\frac{y_3}{y_1}+\frac{Fr_1^2}{2}\right] \quad (4)$$

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

Figure 1 shows variable of above equations. Long et al. (1990) studied submerged hydraulic jump in rectangular channel with smooth bed [13]. They considered specifications of submerged hydraulic jump including profile of water surface; the distribution of velocity and Shear stress resulted from turbulence. They divided jump in to three parts of developing, developed and improved (see figure 6). In this division, developing are forms %15 and developed are forms %85 of jump length. Also, the distance between gate and end of developed area is called hydraulic jumproller length (Lrs). The results of their experimental researches showed that in developed jump area, current specification, especially velocity distribution and turbulence extremity of the floware singular to each other. Abdel Aalal(2004) offered some continuity equations relative depth y_4/y_1 relative length of jump L_j/y_1, and relative drop of jump E_L/E_1[14]:

$$\frac{L_j}{y_1}=-0.862+3.59Sr+5.28Fr_1 \quad (6)$$

$$y_0=\frac{y_4}{y_1}=0.178+0.839Sr+0.701Fr_1 \quad (7)$$

$$\frac{E_l}{E_1}=-5.026-1.225Sr+19.44Fr_1-3.013Fr_1^{1.5} (8)$$

Since submerged hydraulic jump in rough-slope bed not been considered yet, in this study submerged hydraulic jump withsloped-rough bed has been investigated.

2: Materials and Methods

2-1- dimensional analysis of submerged hydraulic jump

Generally, specifications of submerged hydraulic jump in sloped bed depend on fallowing parameters:

$f(\rho,\mu,g,y_1,y_2,y_3,y_4,v_1,S)=0$

In this formula ρ= liquid special mass, μ= Kinematic viscosity, g= gravity Acceleration, y_1= first depth of classic jump, y_2= second depth of classic jump, y_3= submerged depth on the gate, y_4= second depth of submerged jump, v_1= velocity in start of jump, s= bed slope. By using principles of dimensional analysis, the extent of submerged jump length simplifies as follow:

$$f\left(\frac{y_4}{y_1},\frac{y_3}{y_1},\frac{y_2}{y_1},\frac{v_1}{\sqrt{(gy_1)}},s,\frac{y4-y2}{y2}\right)=0 \qquad (9)$$

$$\frac{y_3}{y_1}=f\left(\frac{y_2}{y_1},Fr_1,s,Sr\right) \qquad \textit{(10)}$$

Fr_1= Froude number in super critical area of jump. Other specifications of submerged jump, especially relative energy drop will be a function of above parameters.

2-2- Experimental setup

For this research a channel with metal frame, glass bottom and walls, was built. The flume was0.3 meters depth, 0.4 meters height and 8 meters length. For setting the downstream depth and also fixing the location of jump, a gate in end of channel was used. For measuring flow in system, a triangle weir with sharp edge and right angle was designed and made. For setting inlet flow, an electronic valve was installed at the inlet pipe. In this research downstream depth (y_4), submerged depth on gate (y_3), second depth of classic jump (y_2), depth on triangle weir and submerged jump roller length (Lr_S) were measured. The experimental results of Ead and Rajaratnam (2002) were used for comparison [6]. They founded that relative roughness(height roughness on depth of y_1) must be chosen from 0.25 to 0.5.So, in this research relative roughness equal 0.5 was chosen.Because the greatest $y_1$in this research was equal 2.2 cm,the radius of the roughness was selected 1.1 Cm. (fig.2) the bottom of flume in upstream should be equal to the highest point of the first roughness. In figure (2) W=2.2cm, H=1.1cm, M=5.3cm.

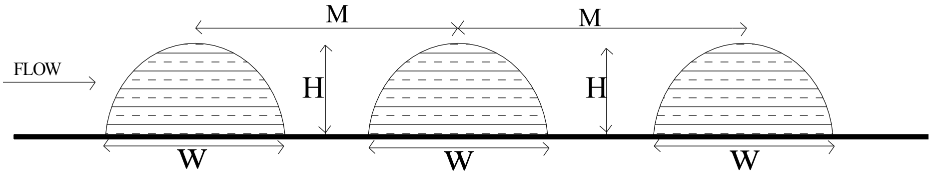

Figure-2 Roughness profile

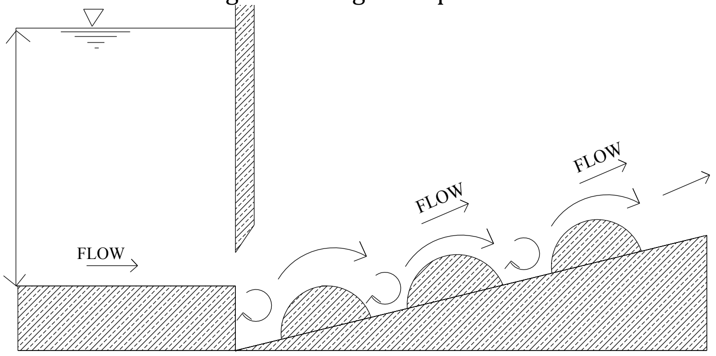

Figure-3 connection details of gate and bed in sloped-roughbed

Figure-4 zigzag arrangement of roughness in bed

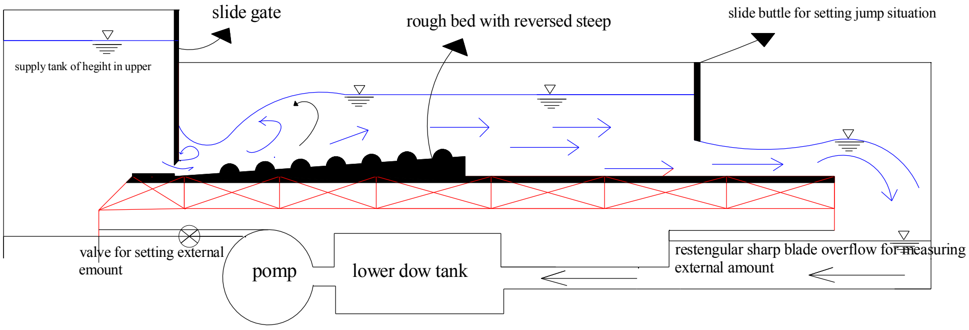

Figure-5 Schematic of the experimental setup

EXPERIMENTS

160experiments were conducted.80 experiments were conducted to smooth bed with slopes and 80 experiments were conducted to rough bed with slopes. The range of the experimental data were as follows: Froude numbers (4.50-9.0), y_1 (1.04, 1.34, 1.59, 2.2 Cm) and slopes (zero, 1.8, 2.5, 3.5 and 4 percents).

For making overcritical flow, a sliding gate made of Plexiglas was installed at the beginning of flume; roughness in bottom made from wood. The density was selected equal 17.2 percent. Since, for computing some of parameters (such as submerge ratio) we also need specifications of free hydraulic jump, first the jump develop freely and then parameters such as sequent depths were measured. After that the depth of tail gate was increased and submerged jump was preformed. After stabilization, specifications of submerged jump including submerged jump length, the depth of submerged on gate, and depth of (y_4) were measured.

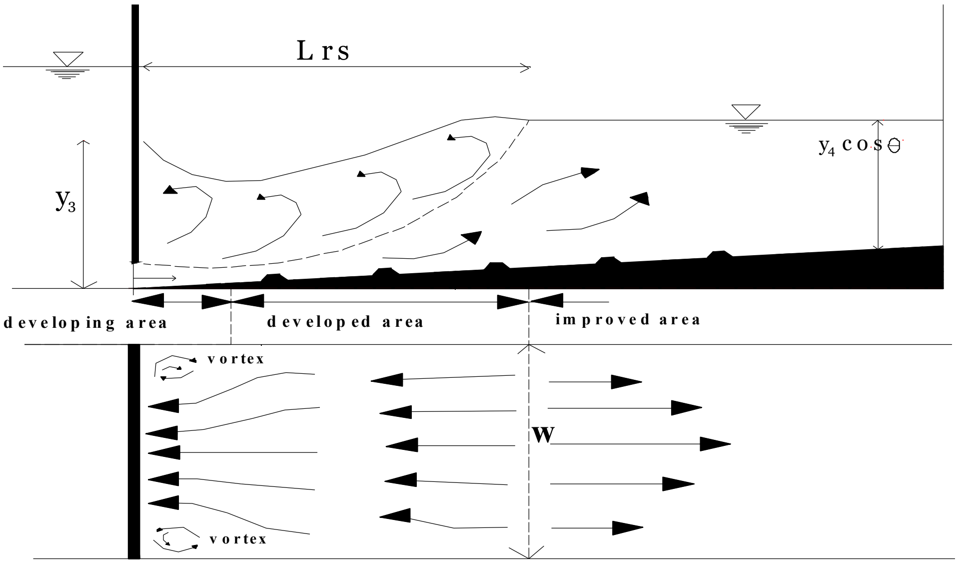

Figure-6 submerged hydraulic jump based on development of flow in slope bed with semicircle roughness

DISCUSSION

Firstly in horizontal bed, length of submerged jump and energy drop are defined. Then they measured in different steeps with semicircle roughness. In the following, observed changes in specifications of submerged hydraulic jump including relative energy drop, proportion of y_1 and y_2, and the depth of submerged on gate has been shown.

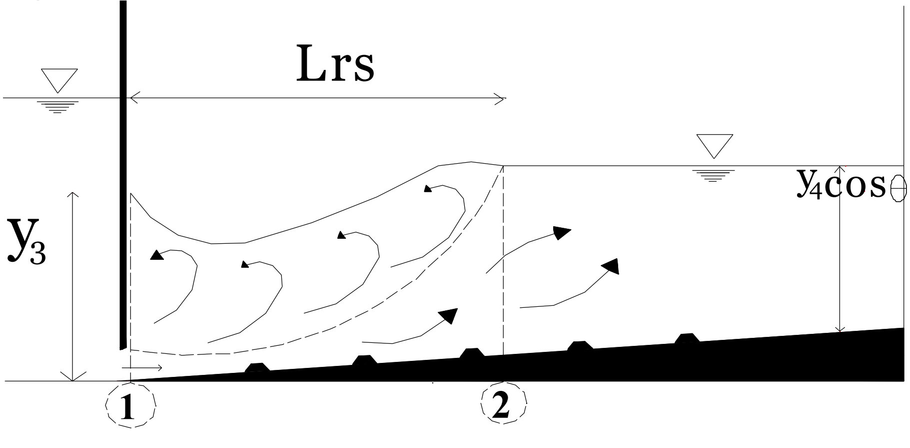

Figure-7 submerged hydraulic jump with sloped-rough bed

Relative energy drop

Relative energy drop is $\Delta E/E_1$, that in which ΔE is the difference between energy at the beginning of E_1 and the end of jump E_2(fig 7).So, energy in hydraulic jump calculated as follow: $E_1=y_3+\frac{v_1^2}{2g}$ and $E_2=y_4+\frac{v_4^2}{2g}$.

Figure 8 shows relative energy drops in different Froude number and different slopes. We can see that by increasing slope, energy drop will have increase up to 7 percent. Also the experimental equation of Govinda Rao and Rajaratnam (eq4) for horizontal bed has been compared with horizontal rough bed [10]. Closeness of result with Rajaratnam[1] experiments was observed.The difference between this two is due to roughness presence in this study.Itshows that steeped roughbed can help to improvement of hydraulic jump conditions.

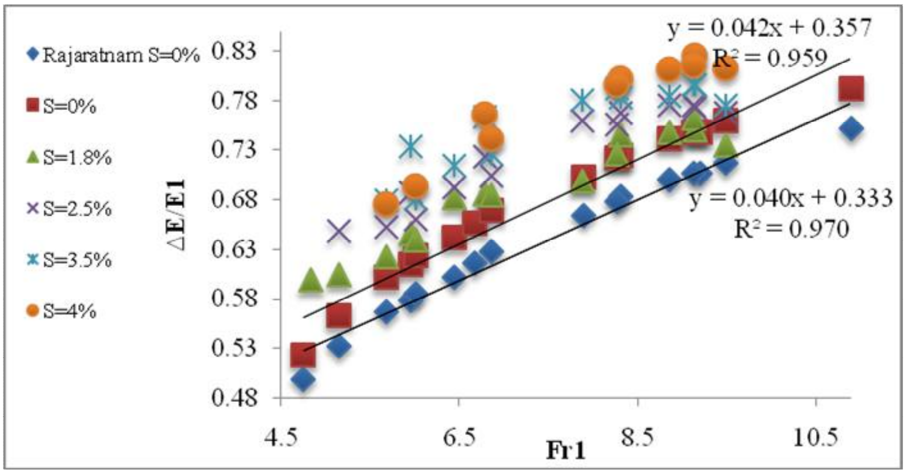

Figure8-relative energy drops in different Froude number and different slopes

The length of submerged jump

In Figure (9), relative lengths in submerged jump are shown. We can see the length of jump decreases up to %15 as the slope increases.

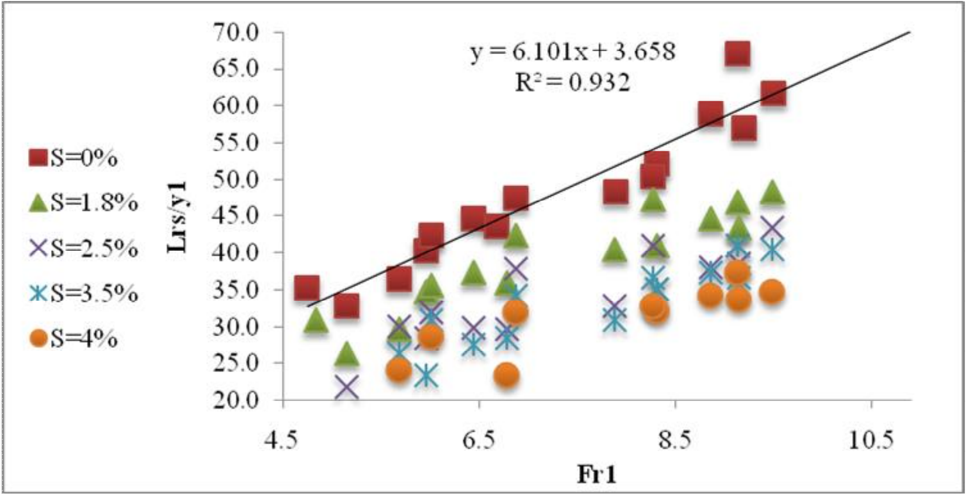

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Figure9-Lrs/$y_1$variation withFr_1

Proportion of conjugate depths

Before making submerged jump, first, jump is developed freely and conjugate depths of free jump were measured. The results are shown in figure 10. In this figure horizontal rough bed is compared with classic jump. The result shows that with increasing s, y_2/y_1will decrease. This decrease was up to %18.

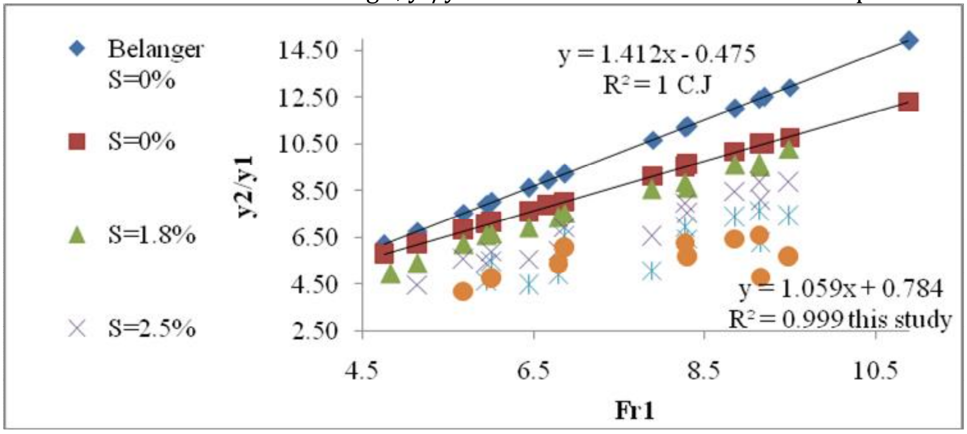

Figure 10- y_2/y_1variation with Fr_1

Finally, the data obtained with SPSS statistical software were reviewed and variation of y_3/y_1 to Sr, Fr_1 and s were obtained for smooth bed with slope. The final formula was obtained from output of software as follows:

This formula was influence for smooth bed with slope. The R square is 0.836.Comparison of above formula with results of experiment shows in figure 11. As can be seen in the figure, the results show relatively well correspondence with the experimental results.

$$\frac{y_3}{y_1} = 0.029\left[(1+S_r)\phi\right]^{1.97} + 0.801s^{-0.19} - 0.022SF^{2.025} + 1.327\left(\frac{F_r}{(1+S_r)\phi}\right)^{0.119} \quad [11]$$

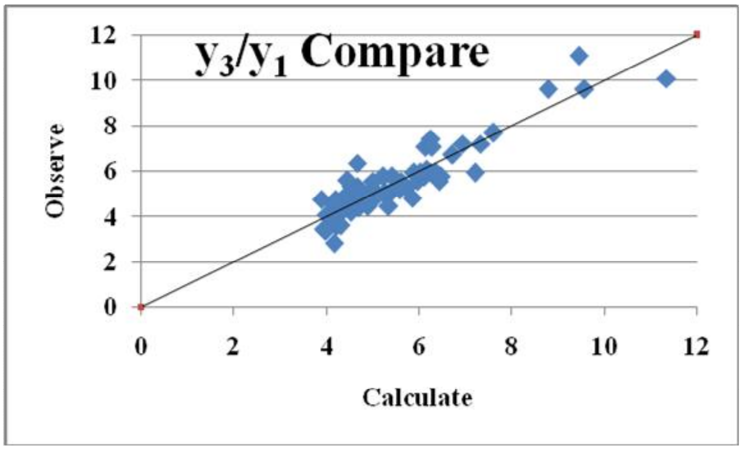

Figure 11- Comparison of calculated data from eq 11 with experimental results

CONCLUSIONS

In this study, the effect of slope on submerged hydraulic jump with rough bed specification was conducted. The roughness's have17.2 percent density and zigzag arrangement. In the whole expressed maters in pre-section it can be counted as below:

- With Increasing of slope in range of Froude number (4.5 – 10.9) energy to amount %7 decreases.
- With Increasing of slope from zero to %4, length of jump to amount %15 decreases.
- By increasing Froude number in every slope, the length of submerged jump increases up to %15.
- By increasing slope, the proportion of conjugate depths in classic jump decreases up to %18.

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