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Hydraulic Jumps on Adverse Slope in Two Cases of Rough and Smooth Bed

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Abstract: One of the most frequently encountered cases of rapid varied flow is the hydraulic jump. It occurs when a supercritical flow has to change into subcritical flow. Nowadays jump study upon sloping beds, especially adverse slopes, is important because of the length of jump and the energy loss. In this research jump study has been done upon four adverse slopes -0.00125, -0.0025, -0.00375 and -0.005 in two cases of rough and smooth bed. The results showed that the Sequent depth ratio and the length of jump upon smooth bed has been more than rough bed for the same slopes and Froude numbers. Also comparison with percentage of the energy loss, more energy loss has occurred upon rough bed than smooth bed.

Key words: Energy loss, hydraulic jump, length of jump and sequent depth

INTRODUCTION

One of the most frequently encountered cases of rapid varied flow is the hydraulic jump. If a supercritical open channel flow changes into sub critical flow, the transition is associated with the formation of a hydraulic jump (Hager, 1992). Hydraulic jumps were extensively studied because of the frequent occurrence in nature and its use as an energy dissipate in outlet works of hydraulic structures (Carollo *et al.*, 2007).more studies has done upon horizontal bed in this field. The most important application of the hydraulic jump is in the dissipation of energy below spillways and weirs. So that objectionable in the downstream channel is prevented. The hydraulic jump is also used in municipal water supply systems to mix chemical as well as to remove air pockets. 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 (Peterka,1958; Rajaratnam, 1976; McCorquodale, 1986; Hager, 1992).

Besides, naturally many of the hydraulic events occur upon rough beds. So that many researches has been done in this subject. Rajaratnam (1968) carried out the first systematic studies on the hydraulic jumps over rough bed. Leutheusser and Schiller (1975) also studies upon the incoming jet over rough surfaces. Mohamad Ali (1991) performed a series of experiments upon rough bed. Ead *et al.* (2000) performed tests on the changing of the velocity field in turbulence flows under different characteristics. The information concerning the effects of boundary roughness on the hydraulic jump is incomplete (Hughes and Flack, 1984; Ead and Rajaratnam, 2002; Carollo and Ferro, 2004a, b).

But nowadays, jump study upon adverse slopes seems to be important because of its economic justification. According to the classification of Kindsvater (1944) and Rajaratnam (1966),Jumps forming on an adverse slope are F jumps. The writers investigated a new type of jump, called the B – F jump, where the jump begins on a positive slope and ends on the adverse slope. Rouse (1938) stated that a hydraulic jump on an adverse slope is impossible to control but Stevens (1944) predicted the sequent depth of the F jump for any slope. Abdul and Rajagopal (1972) studied the F jump with negative slopes up to − 0.025. They concluded that jumps on negative slopes steeper than S = − 0.025 are almost impossible to control. McCorquodale and Mohamed (1994) investigated F jumps on negative slopes for − 0.10, − 0.167, and − 0.20 using a gate at the basin end for tail water control. Abrishami and Saneie (1994) studied F jumps with negative slopes up to − 0.025. In these works, no analytical method was elaborated to predict the sequent depth ratio. Hence, in this research, Hydraulic jump's parameters upon the adverse slope bed, in two cases of smooth and rough, were determined in order to examining the effect of roughness on jump's characteristics and comparison with smooth bed.

Experimental setup: The experiments were carried out using a rectangular laboratory flume of the University of Tehran. The flume was 5 m long, 0.2 m wide, and 0.15 m deep; it was connected to a hydraulic circuit allowing for a recirculation of discharge. The walls and the bed of the flume were made of Plexiglas's sheet (Fig. 1). The experiments were carried out for both smooth and rough beds. Water was supplied by pomp from an underground storage tank in the laboratory. The flow depth h was measured by a point gauge. The runs were carried out for selected values of the flow depth h_1 and the Froude number Fr_1; the jump was set within the experimental measuring reach using the downstream gate. For each run, the discharge Q, the flow depths h_1 and the jump length Lj were measured. Discharge was measured with weight method. Discharge varied from 8 to 15 L / s. the experiments were carried on rough bed which was

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covered by cylindrical plastic with the height of 0.3 mm (Fig. 2). Bottom slopes of -0.00125, -0.0025, -0.00375 and- .005was used to generate adverse slope.

MATERIALS AND METHODS

Sequent Depth Ratio: Hydraulic jump on adverse beds occurs, as shown in Fig. 3. This is a rare type of jump, and no adequate experimental data are available at the present moment.

For the analysis of the jump upon adverse slope, a rectangular channel of unit width is assumed. Considering all effective forces parallel to the channel bottom, the momentum equation may be written:

$$\frac{\gamma q}{g}(\beta_2 V_2 - \beta_1 V_1) = P_1 - P_2 - w\sin\theta - F_f \tag{1}$$

Where $P_1 = 1/2\gamma D_1^2 \cos\theta$, $P_2 = 1/2\gamma D_2^2 \cos\theta$,β_1 and β_2 may be taken as unity, and $q = VD.F_f$ is equal to friction force. If the surface profile of the jump is a straight line, the weigh of water in the jump can be computed. The discrepancy between the straight-line and actual profile and the effect of slope may be corrected by factor . Thus,

$$w = \frac{1}{2}\gamma KL(D_1 + D_2) \tag{2}$$

Substituting Eq. (2) in Eq. (1), letting, $Fr_1 = \frac{V_1}{\sqrt{gD_1}}$ and simplifying,

$$\frac{D1}{D2}\left(\frac{2Fr_1^2}{\cos\theta} + \frac{KL\sin\theta}{D_2 - D_1}\right) = \frac{D_2}{D_1} + 1 \tag{3}$$

With assumption:

$$G1 = \frac{Fr_1}{\left(\cos\theta + \frac{KL\sin\theta}{D_2 - D_1}\right)^{0.5}}$$

The solution of Eq. (3) is apparently:

$$\frac{D_2}{D_1} = \frac{1}{2}\left(\sqrt{1 + 8G_1^2} - 1\right) \tag{4}$$

Since $D_1 = Y_1 \cos\theta$ and, $D_2 = Y_2 \cos\theta$ Eq. (4) may also be written

$$\frac{Y_2}{Y_1} = \frac{1}{2}\left(\sqrt{1 + 8G_1^2} - 1\right) \tag{5}$$

Energy loss: The loss of energy in the hydraulic jump is equal to the difference in specific energies before and after the jump. It can be shown that the loss is $\Delta E = E_1 - E_2$, where upon adverse slope:

$$\Delta E = (D_1\cos\theta - D_2\cos\theta) + \frac{V_1^2 - V_2^2}{2g} - L_j\sin\theta \tag{6}$$

Where L_j is equal to length of jump. The ratio $\frac{\Delta E}{E_1}$ is known as the relative loss efficiency. The ratio of the specific energy after the jump to that before the jump is

Fig 1: Schematic sketch for experimental arrangements

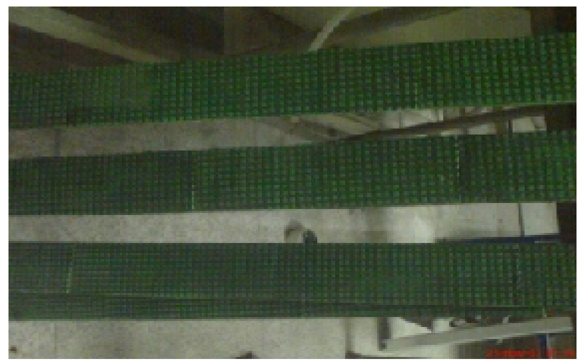

Fig 2: shape of roughness used in the experiment

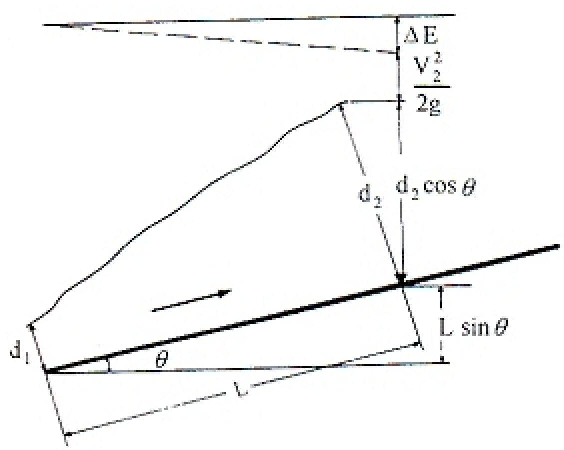

Fig 3: Sketches of hydraulic jump upon adverse slope

defined as the efficiency of the jump. It can be shown that the efficiency is:

$$\frac{\Delta E}{E_1} = \frac{1-\frac{D_2}{D_1}+\frac{V_1^2-V_2^2}{2gD_1\cos\theta}-\frac{L_j\tan\theta}{D_1}}{1+\frac{V_1^2}{2gD_1\cos\theta}} \qquad (7)$$

This equation indicates that the efficiency of a jump is a dimensionless function, depending on the Froude number of the approaching flow.

Length of the jump: So far, no Analytic relationship has been done about length of the hydraulic jump upon adverse slope. In this research, for examination of the length of jump changes, relationship between the Froude numbers and the dimensionless length of jump has studied.

RESULTS AND DISCUSSION

Sequent Depth Ratio: Fig. 4 shows relationship between the ratio of D_2/D_1 and the Froude number on adverse slope upon smooth bed. Results showed that ratio D_2/D_1 of increases with increasing the Froude number for each adverse slope, and also this ratio increases with decreasing the adverse slope for the same Froude number. this trend exists as well as for the rough bed exactly. (Fig. 5). But, just as it is apparent in Fig. 6 the value of ratio D_2/D_1 upon smooth bed is more than rough bed for the same slope.

Length of the Hydraulic jump: It can be concluded from Fig. 7 that for each slope when the Froude number increases, the ratio of L_j/D_1 increases. Also this trend observes for rough bed that that ratio of L_j/D_1 increases with increasing the Froude number for each adverse slope (Fig. 8). Comparison between the ratio of L_j/D_1 for both rough and smooth bed, It can be concluded that for a constant Froude number, the value of the ratio L_j/D_1 over smooth bed is more than this value in rough bed for the same adverse bed slope. (Fig. 9).

Energy loss: Results showed that as whole, there was upward trend in the dimensionless ratio of $\Delta E/E_1$ for two cases of rough and smooth bed and four slopes. So that, at first, for each two cases, there was rapid increase in the ratio of. $\Delta E/E_1$Since then, with increase in the Froude number (more than 7), the ratio of $\Delta E/E_1$ lean to remaining steady. But compression between rough and smooth bed, more energy loss has occurred over rough bed than smooth bed (Fig. 10).

CONCLUSION

This paper introduced a new study on the hydraulic jump on a rough bed. A laboratory investigation assessed the effect of a rough bed on the properties of a hydraulic

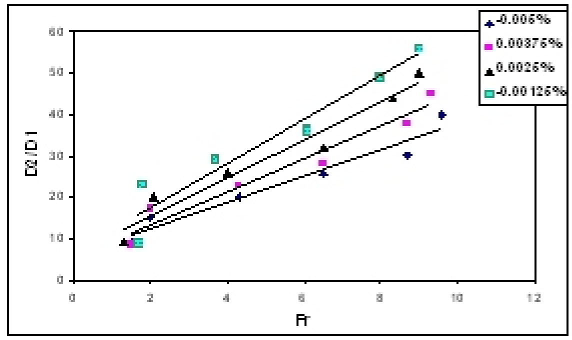

Fig 4: Variation of sequent depth ratio with inflow Froude number over smooth bed

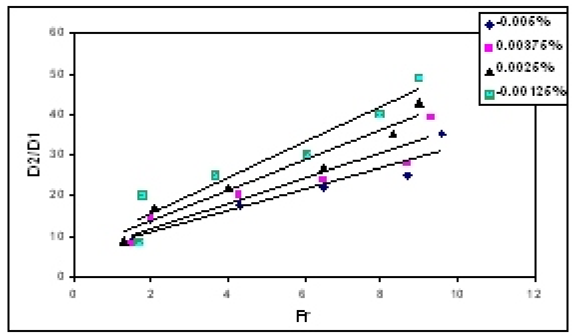

Fig 5: Variation of sequent depth ratio with inflow Froude number over rough bed

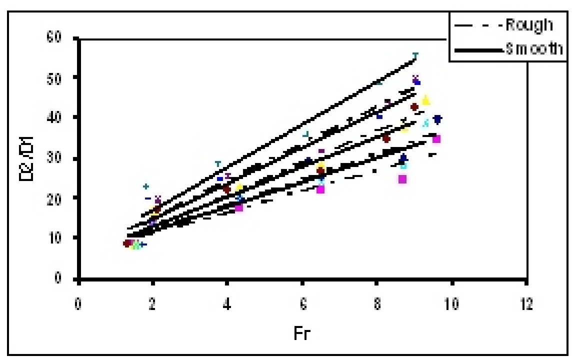

Fig 6: Comparison between the measured values of$\Delta E/E_1$ sequent depth ratio and inflow Froude number for each two cases of rough and smooth bed

jump, namely the sequent depth ratio and roller length. Hydraulic jump characteristics were measured in a horizontal rectangular flume in which the bed was artificially roughened. Observations showed that for jumps in which the gravity force component was opposite to the direction of the flow, the surface roller became unstable and jump on the adverse slope tended to move downstream. Both Sequent Depth Ratio and length of jump on rough bed was less than smooth bed. On the other hand the more energy loss occurred on rough bed than smooth bed.

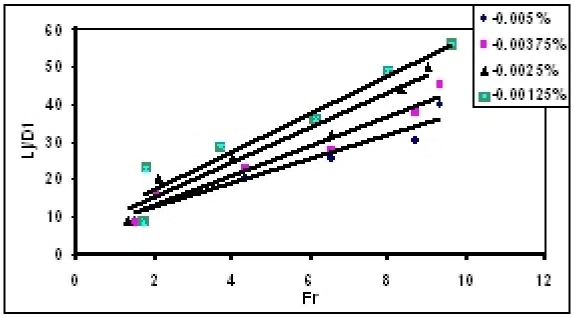

Fig 7: Variation of L_j/D_1 with inflow Froude number over smooth bed

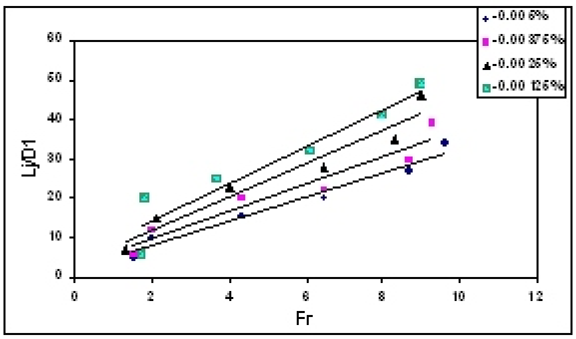

Fig 8: Variation of L_j/D_1 with inflow Froude number over smooth bed

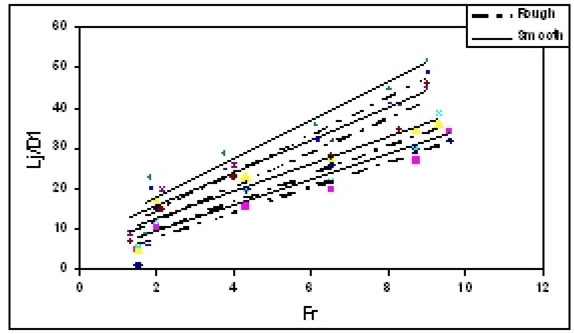

Fig 9: Comparison between the measured values of a L_j/D_1 and inflow Froude number for each two cases of rough and smooth bed

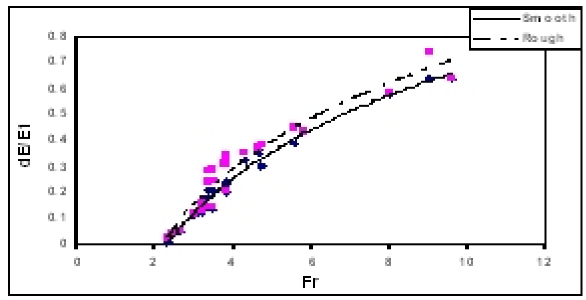

Fig. 10: Comparison between the measured values of a L_j/D_1 and inflow Froude number for each two cases of rough and smooth bed

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