PERFORMANCE OF HYDRAULICS JUMPS OVER ROUGH BEDS

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Abstract

A hydraulic jump phenomenon is one of the most common phenomena in open channels. It is a process of transition of a supercritical flow into a subcritical flow by dissipating a large amount of energy. The available knowledge on the behavior of hydraulic jump is only for smooth, horizontal channel beds and very limited studied have been reported in literature on the performance of hydraulic jumps on rough beds which is the real situation in the field. This research attempts to investigate the characteristics of hydraulic jumps formed on rough, horizontal channel beds under different flow conditions. A series of laboratory experiments were carried out in a rectangular flume which consists of artificially roughened beds formed by placing rectangular wooden strips in specific intervals. The hydraulic jump parameters such as, initial water depth, sequent water depth, and flow rate were measured for different bed roughness by changing the roughness density (width of roughness element / Spacing) 8% to 37.5%. The analysis of experimental data showed that the rough bed reduces the distance to the jump from the gate than in those smooth beds while creating a high energy loss. Existing equations to describe the behavior of hydraulic jump on rough beds were not in agreement with our experimental results as most of them were derived by keeping the roughness density constant therefore a new theoretical equation was developed using dimensional analysis, a better correlation was found among hydraulic jump parameters that include the roughness density to represent bed roughness.

$$\frac{y_2}{y_1} = \frac{0.8568\left(1\text{-}0.05\times\frac{t}{y_1}\right)\times Fr + 0.3378}{1\text{-}|0.23\text{-}d|}$$

where, y1, y2, t, d, Fr are initial depth, sequent depth, height of roughness element, roughness density and Froude number, respectively. It was found that maximum effect of roughness elements occurred at a roughness density of 0.23. The results of this study confirm the effectiveness of rough beds for energy dissipation below hydraulic structures

.**Keywords:** *Hydraulic Jump, Rough Bed, Sequent Depth Ratio, Froude Number, Roughness Density*

1. Introduction

Hydraulic jump phenomenon is one of the most common phenomena in open channels. It is a process of transition of a supercritical flow into a subcritical flow by dissipating a large amount of energy. The hydraulic jump has attracted researchers' broad attention over many years not only because of its importance in designing stilling basins or its use as an energy dissipater, but also for its complexity.

According to the published documents and text books, the characteristics of hydraulic jumps over smooth horizontal as well as over smooth sloping channel beds have been well established. At the same time, number of investigations have been carried out to identify characteristics of hydraulic jumps occur over rough horizontal beds, and their results still exist only in journal papers. However the most of the research works are not complete and the derived equations deviate from one research to the other. Hence further investigations have to be carried out to get a clearer knowledge about the characteristics of hydraulic jumps occur over rough horizontal beds.

The present study attempts to find out the effect of artificial roughness with four types of roughness elements having length of 30 cm and cross sections of 0.5×0.5 cm^2, 0.8×0.8 cm^2, 1.2×1.2 cm^2 and 1.5×1.5 cm^2 on hydraulic jumps characteristics. The main objective of the study is to investigate the change in hydraulic jump characteristics compared to hydraulic jumps on smooth beds and to derive equations to relate the jump characteristics on rough beds with the parameters of bed roughness.

2. Literature Review

Eq. (2.1) has been widely used to study the hydraulic jumps formed on smooth, horizontal channel beds and not much theories have been established for rough channel beds.

$$\frac{y_2}{y_1} = \frac{1}{2}\left[-1 + \sqrt{1 + 8 \times Fr_1^2}\right] \qquad \text{……Eq. (2.1)}$$

Where, y_1 is the initial water depth and y_2 is the sequent depth and Fr is the upstream Froude number.

For rough beds Rao et.al, (1966) proposed a modification to above equation by incorporating a coefficient to Froude number to represent the effect of roughness. Subsequently Carollo and Ferro, 2007 estimated the value of this coefficient as 7.42 based

on detailed analysis carried out. Carollo and Ferro (2007) further improved the equation by introducing a term (t/y_1) where t height of roughness elements next to the Froude number which was obtained from results of dimensional analysis and empirically.

However, these modifications to the Eq. (2.1) were not very successful as roughness density (spacing) was not incorporated in the equations. Hence, a detailed study of the hydraulic jumps characteristics on rough beds is necessary to formulate proper relationship to describe the jump characteristics on rough bed.

3. Methodology

3.1 Experimental Set-up

Laboratory flume of 12 m long, 0.3 m wide and 0.3 m high was used for the study (Figure 3.1). The flow was controlled by a valve at the flume. A V-notch was attached to the flume to measure the flow rate.

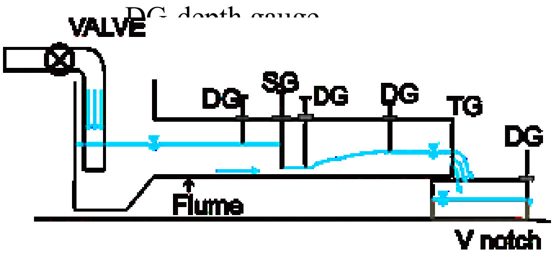


Figure 3.1: Schematic diagram of the experimental set-up

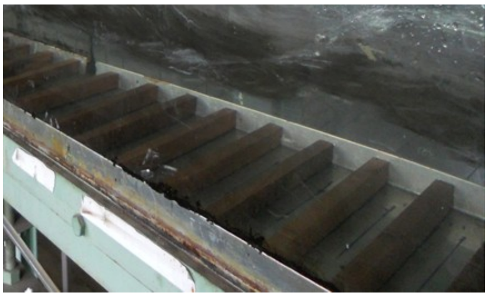


Figure 3.2: Roughened bed

The channel bed was roughened by fixing rectangular strips as shown in Figure 3.2. Three types of artificial wooden strips having sizes (*t*) of 0.8, 1.2 and 1.5 cm were used. The spacing (*s*) between the roughness elements were also changed as 4, 6, 8 and 10 cm.

3.2 Procedure

For each roughness element and its spacing, the dischargers ranging from 5 *l/s* to 25 *l/s* were passed in the channel to form hydraulic jumps. The parameters y_1 (Initial Depth), y_2 (Sequent Depth) and flow rate were measured in each experimental run.

4. Results and Discussion

4.1 Results

The parameters such as Sequent depth ratio (y_2/y_1), Froude number, Energy loss, and Jump efficiency were calculated and plotted in non-dimensional form to observe the relationship with the bed roughness. Figure 3.1 shows a comparison between computed y_2/y_1 using equations suggested by different researchers and observed y_2/y_1. It can be seen from the figure that the existing formulations derived for hydraulic jumps on rough beds were not in agreement with the observed data.

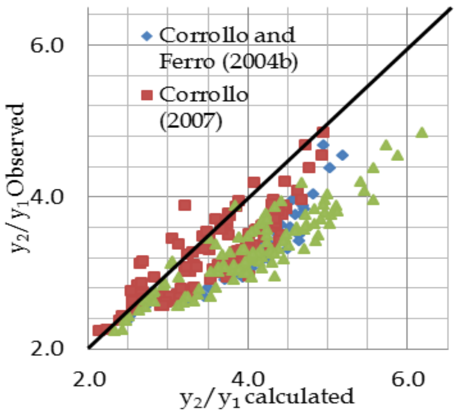


Figure 4.1: y_2 /y_1 observed verses y_2 /y_1 calculated

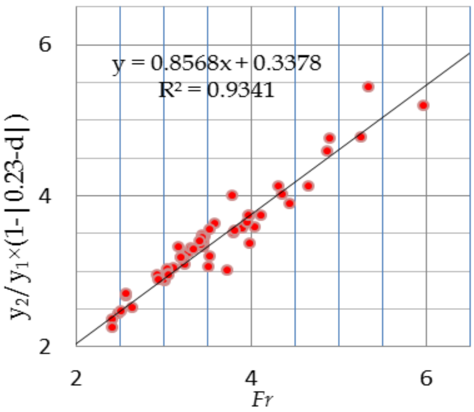
4.2 Data analysis

The main drawback of the available formulations was identified as the lack of a term representing the roughness density, as most of these equations were developed using experimental studies with only one type of roughness spacing.To identify better correlations various graphs were plotted in non-dimensional form obtained from the dimensional analysis (See Eq. 4.1).

$$\frac{y_2}{y_1} = f_2\left(Fr, \frac{t}{y_1}, \frac{s}{y_1}\right) \quad \text{.........Eq. (4.1)}$$

A new parameter called 'roughness density' (d = width of roughness element / Spacing) was incorporated into the analyses to represent roughness spacing. Figure 4.2 illustrate the relationship between $y_2/y_1 \times (1-|0.23-d|)$ observed verses y_2/y_1 calculated and Froude number, This shows better correlations among the parameters of the hydraulic jumps on rough beds. Accordingly the Eq. 4.2 was obtained.

$$\frac{y_2}{y_1} = \frac{(0.8568\,Fr + 0.3378)}{(1-|0.23-d|)} \quad \text{.........Eq. (4.2)}$$



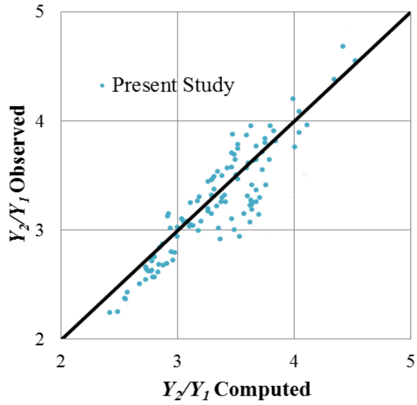


Figure 4.2: $y_2/y_1\times$ (1-|0.23-d|) observed verses calculated for 1.5 cm roughness element

Figure 4.3: Prediction of y_2/y_1 y_2/y_1 for all the results using Eq. 4.3

To include the effect of elements size into the above equation, the parameter t/y_1 was used. A new equation (See Eq.4.3) was developed by incorporating t/y_1 with coefficients found using experimental results.

$$\frac{y_2}{y_1}=\frac{\left(0.8568\left(1\text{-}0.05\times\frac{t}{y_1}\right)Fr+0.3378\right)}{(1\text{-}|0.23\text{-}d|)} \qquad \text{......Eq. (4.3)}$$

This equation provides a better relationship between the hydraulic jump characteristics and properties of roughened bed for all the experimental data collected. See Figure 4.3.

5. Conclusions

By analysing nearly 140 experimental runs, a new equation was formulated to relate the sequent depth ratio with the initial depth and Froude Number in a more accurate manner than in previous studies by considering both effects of roughness height and roughness density. Further experiments are recommended to study the applicability of proposed equation for a higher range of Froude numbers and different shape of roughness elements.

The applicability range of Froude number for proposed equation covers 2-5 and the shape of roughness elements was limited to rectangular shape. Further experiments are recommended to study the applicability of proposed equation for other Froude numbers and different shape of roughness elements.

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