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Effect of corrugated beds on characteristics of submerged hydraulic jump

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Jump efficiency and sequent depth

Abstract Hydraulic jump is generally helped in the dissipation of excess kinetic energy downstream of hydraulic structures such as gates, spillways, and weirs. This paper presents a comprehensive review of the available literature on the hydraulic jump properties on corrugated beds. In the present study the effect of spaced triangular strip corrugated bed on submerged jump characteristics has been experimentally investigated. Thirty experimental runs were carried out considering wide range of Froude numbers ranging from 1.68 to 9.29. Experiments were conducted for both smooth and rough bed. The results confirm that sequent depth and jump length were reduced by average values 15.14% and 21.03%, respectively, whereas, jump efficiency was increased by 50.31% at optimum spaced roughness compared to a classical jump respectively. Dimensionless relationships were deduced to predict the jump characteristics. Results of the present study were agreed satisfactorily with the previous studies.

1. Introduction

Hydraulic jump occurs when a high velocity supercritical flow drops to that of a subcritical flow, the rapid following flow is abruptly slowed and increases its height, converting some of the kinetic energy into potential energy. The condition of occurrence of a hydraulic jump is to change flow suddenly from supercritical flow (low depth with high velocity) to subcritical flow (high depth with a low velocity), Chow [1]. It also happens when slope changed from steep to mild slope. Hydraulic jump is a useful phenomenon in open channel hydraulic. It is generally used for the dissipation of excess kinetic energy downstream of hydraulic structures such as drops, spillways, chutes and gates, increasing weight on an apron and thus reduce uplift pressure under control structures,

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Nomenclature

b	The base width of corrugated bed,	t	The height of corrugated bed,
D	Dimensionless index,	v	Flow velocity before the jump,
E_1	Specific energy at the initial water depth of a hydraulic jump,	R	Reynolds's number,
E_2	Specific energy at the sequent water depth of a hydraulic jump,	y_1	Initial water depth of hydraulic jump,
F_r	Froude number at initial water depth,	y_2	Sequent water depth of hydraulic jump,
g	The acceleration of gravity,	y_2^*	Subsequent subcritical flow for classical jump,
H_u	Upstream water depth	y_3	Submerged water depth,
L_j	Hydraulic jump length,	ρ	Density of the fluid,
L_r	Roller hydraulic jump length,	ν	Viscosity of the fluid,
S	Strip corrugations wave length,	γ	Unit weight of water,
		η	Hydraulic jump efficiency.

also, it can be used as a mixed tool in water supply and aerate water for city water supplies.

Hydraulic jump is divided into two types according to their bed characteristics. The first type is a classical hydraulic jump with a smooth bed, and the second type is a forced hydraulic jump. The first type has been extensively studied by Peterka [2], Rajaratnam [3], McCorquodale [4], Hager [5] and Sholichin and Akib [6]. If $y_1$and v_1 are, respectively, the depth and mean velocity of the supercritical stream just upstream of the jump, with the Froude number $F_r = v_1/\sqrt{gy_1}$ where g is the acceleration due to gravity. The subcritical sequent depth $y_2\,j$ is given by the well-known Belanger equation:

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1+8F_r^2} - 1\right) \tag{1}$$

Hydraulic jump on rough beds has been also studied by many researches. Rajaratnam [7] carried out the first systematic studies on the hydraulic jumps over rough bed. He proved that the roller length L_r and the jump length L_j upon rough bed would decrease significantly in comparison to the smooth bed. Leutheusser and Schiller [8] also conducted studies upon the incoming jet over rough surfaces. They found that the existence of a developed supercritical flow downstream of the gates or spillways upon rough bed requires less length in comparison to smooth bed. Mahmoud [9] and Abdelsalam et al. [10] found that the optimal bed roughness intensity of cubic shape is 10% from both the hydraulics and economical point of view. Aboulatta [11] used the previous intensity to study the effect of location and length of roughened beds on flow characteristics.

Negm et al. [12] used two types of roughness element, they found that 13% and 16% roughness intensities provide the minimum relative jump length when hexagonal and cylindrical roughness elements were used for roughening the bed respectively. Alhamid [13] conducted experiments on a rough bed using cubic blocks. He concluded that 12% roughness intensity provided the optimal length of the basin for the flow conditions and roughness arrangement under consideration. Hughes and Flack [14] carried out experimental research on hydraulic jumps upon rough bed. They found that boundary layer roughness will definitely decrease the subcritical depth and length of the jump and the extent of this decrease are related to the Froude number and relative roughness of the bed.

Ead and Rajaratnam [15] performed an experimental study upon hydraulic jumps over round shape corrugated bed. Froude numbers ranging from 4 to 10 were taken into account and the value of the relative roughness was considered as being between 0.25 and 0.5.

They observed that the tailwater depth required for the hydraulic jump over corrugated bed is less than that required for jumps over smooth bed. It was also observed that the length of the jump is approximately half of that which occurs over smooth bed. Carollo et al. [16] measured the hydraulic jump characteristics on bed roughened by closely packed crushed gravel particles cemented to the bottom. They concluded that the boundary roughness reduces both the sequent depth and the length of a hydraulic jump and that the observed reductions were related to both Froude number and the degree of roughness. Pagliara et al. [17] studied the parameters that affect the sequent depth and the length of the hydraulic jump over homogenous and non-homogenous rough bed channels downstream of block ramps. They proposed a new relationship to determine the correction coefficient for the general jump equation for both uniform and non-uniform rough beds. Bejestan and Neisi [18] studied the effect of lozenge roughness shape on the hydraulic jump. They found that this shape reduces the tailwater depth by 24% and the hydraulic jump length by 40% compared with smooth bed Ead et al. [19] performed tests on the changing of the velocity field in turbulence flows under different characteristics. The hydraulic engineers take care in design calculation development, the size and location of a hydraulic jump, Streeter et al. [20]. More studies and researches on hydraulic jump have been done such as Bakhmeteff and Matzke [21] and Narasimhan and Bhargava [22]. They found that the length of a hydraulic jump increased as depth increases with the increase in Froude number.

El-Azizi [23] studied theoretically the effect of different intensities of bed roughness on the rectangular submerged hydraulic jump. It was noticed that, the theoretical curve for all verification cases is almost lower than the experimental one. In addition to the above, McCorquodale and Kalifa [24], Abdel Gawad et al. [25], Smith [26] and Ohtsu et al. [27] analyzed the submerged hydraulic jump formed in a radial stilling basin provided with sudden drop both theoretically and experimentally. Both the experimental results and the developed equations indicated that at a particular relative location of the drop, the relative water depth, relative energy loss and relative length of jump increase by increasing Froude number keeping the submergence unchanged. Ezizah et al. [28]