Hydraulic Jump Over Strip Corrugations- a review

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Abstract

Hydraulic jump is a very important things in open channel flows such as streams and spillway and laboratory flumes. Detailed literature available of the hydraulic jump properties on rough and strip corrugation are presented here. Hydraulic jumps mainly used for the dissipation of kinetic energy at the downstream side of a spillway with the support of baffle blocks. In this paper comparison of different shapes of corrugations, which were investigated by many researchers and the best shape is being suggested. By the various researchers it is clear that the application of corrugated bed always gives better results than smooth bed and jump length and sequent depth also reduced on rough bed as compared to smooth bed. Hence the installation cost of stilling basin can be reduced

Keywords: *Hydraulic Jump, Rough bed, Smooth bed, Energy dissipation*

1. Introduction

Hydraulic jump is a phenomenon that occurs when the flow changes from supercritical to subcritical flow. It is a phenomenon in the field of open channel hydraulics, particularly in the open channel flow, such as spillways, channels, downstream of steep slopes in rivers, etc. Hydraulic jump phenomenon has been studied since two centuries, of which earliest being reported by G. Bidone [16]. Thereafter, several analytical and experimental works have been carried out by many researchers like Belanger, Darcy and Bazin, Gibson, Kennison, Woodward, Forster and Skrinde, and others. Early work on this concept was limited only to the study of the characteristics on horizontal smooth beds. Later, as an effective tool for energy dissipation, on the downstream side of the spillways and the topic of hydraulic jump has extended to the use of rough beds as rough beds due to the surface shear stress development while water flows over it. Further studies conducted on corrugated bed, by considering different conditions, reduced the hydraulic jump length and sequent depth as a result of roughness of the surface. A jump formation on smooth horizontal bed with wide rectangular cross section is referred as classical jump. Aspect of classical hydraulic jump was thoroughly investigated by eminent researchers like Paterka , Rajaratnam, McCorquodale and Hager .

Huges studied the effect of gravel bed and rectangular strip corrugations on the hydraulic jump properties and found that it improves the energy dissipating properties of the jump. Ali introduced a brass cube roughness in to the hydraulic jump and found that it will improve the efficiency of the stilling basin. After that many types of corrugations have been tried on the hydraulic jump phenomenon by different researchers all these years.

A generalized solution for hydraulic jump in smooth and rough bed has been suggested by Carollo. and further improvements have been done to that later. This paper gives a broad view of the hydraulic jump properties on strip corrugation and suggest the future scope of this topic in open channel flow.

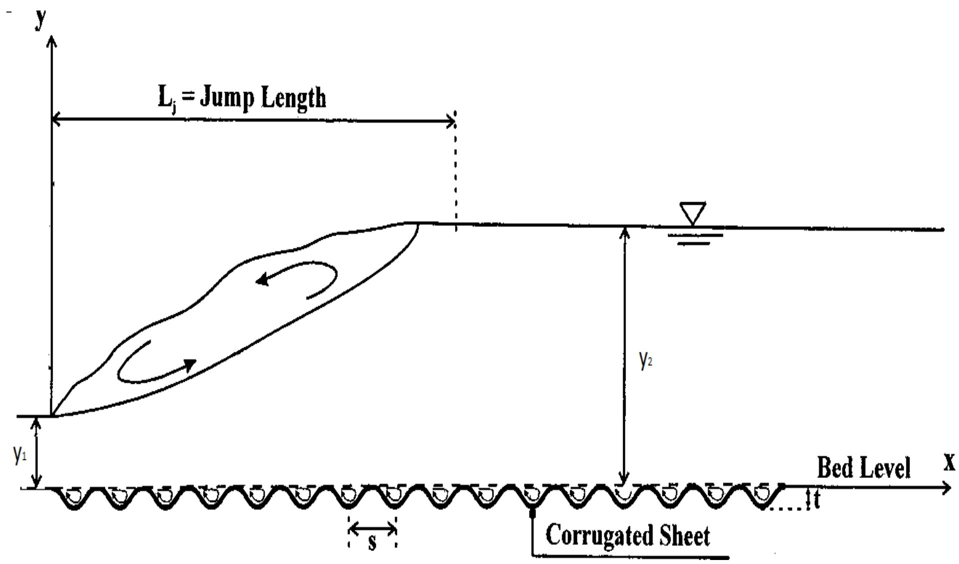

Figure 1. A hydraulic jump over rough bed

2. Various Properties of Hydraulic Jump

2.1. Tail water Depth

Hydraulic Jump length' L_j 'and tail water depth ' y_2 ' over corrugated rough beds mainly depend on the flow behavior and characteristics on the upstream, such as flow velocity flow depth ' y_1 ' fluid density' ρ', fluid viscosity'μ'acceleration due to gravity 'g', amplitude or height of corrugation't' and shape of corrugation's', thus the jump length or sequent depth of the jump can be expressed as

$$y_2 or L_j = f(y_1, v_1, g, \rho, \mu, t, s) \quad (1)$$

By applying Buckingham's pi theorem, equation (1) can be written as below

$$\frac{y_2}{y_1} or \frac{L_j}{y_1} = f\left\{F_r = \frac{v_1}{\sqrt{gy_1}}, R_n = \frac{\rho v_1 y_1}{\mu}, \frac{t}{y_1}, \frac{s}{y_1}\right\} \quad (2)$$

The Froude number and Reynolds's number in the expression are of upstream side. So, for large Reynolds's number, if viscous forces are neglected then the expression can be written as

$$\frac{y_2}{y_1} or \frac{L_j}{y_1} = (F_r, \frac{t}{y_1}, \frac{s}{y_1}) \tag{3}$$

Farhad Izadjoo and S. A.Ead concluded that, the effect of comparative roughness have small effect on the sequent depth ratio. Carollo et al. conducted study over naturally roughened bed. Their results concluded that the rough bed was more efficient for reducing the jump length and sequent depth ratio, which depends on both relative roughness of corrugation and the upstream Froude number. Different researchers have studied the difference between sequent depth y_2 and sequent depth y_2^* of classical jump on smooth bed based on a dimensionless depth deficit parameter D,

$$D - \frac{y_2^* - y_2}{y_2^*} \tag{4}$$

Where y_2^* is the tail water depth in a classical jump and y_2 is the tail water depth for any rough bed and it is detected that this parameter is similar to submergence factor of submerged hydraulic jump [17]. This depth deficit D denotes how much amount of depth is reduced in corrugated bed as compared to smooth bed.

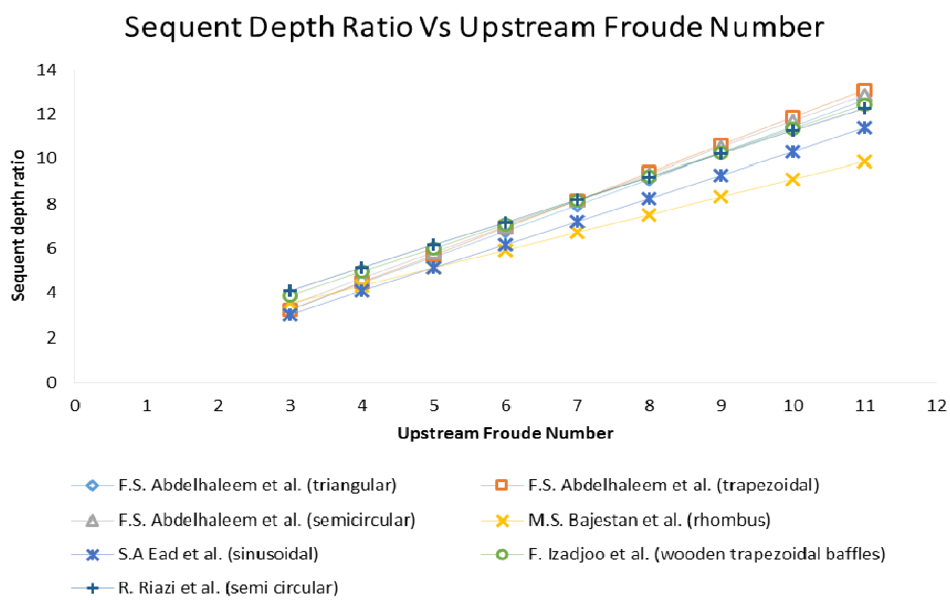

Figure 2. Comparison of results for sequent depth ratio from different researches

The experiments by S. A. Ead gave a D value of 0.25 for sinusoidal corrugations. Abdelhaleem originated that the D values were found as 0.14, 0.145 and 0.174 for the semicircular, trapezoidal and triangular corrugated beds correspondingly. These results were similar to the findings of Peterka [20]. The investigations by Izadjoo and Shafai Bajestan on trapezoidal corrugations resulted in D value of 0.20 and that of M.F. Bejestan and K. Neisi on Lozenge (rhombus) shaped corrugations resulted in 0.24.

The works by G. Ezihah et al. on U shaped corrugations also resulted in 0.20 D value. The works done by R.Riazi and S. Jafari on semicircular corrugations resulted in a D value of 0.18. Recently B. Ghorbani and M. Bazaz conducted experiments on triangular bed and got a D value of 0.14. In figure 2 it shows that the rhombus shape has given better results at higher Froude numbers but when the D value is compared the value of rhombus shape is less that of the sinusoidal shape. Hence concluded that the sinusoidal corrugated bed is the appropriate shape for reducing the tail water depth, this can be backed with the findings of Ming JyhChern and Sam Syamsun using smoothed particle hydrodynamics (SPH) model.

2.2. Jump Length

The corrugated beds have reduce the length of the hydraulic jump. To study the effect on length of the hydraulic jump and the relationship between dimensionless length ratio $\frac{L_j}{y_1}$ and Froude number has been studied by a number of researchers. As per Abdelhaleem et al the length of the jump can be reduced by 10%, 11% and 14% for semicircular, trapezoidal and triangular corrugated beds. The U shaped corrugated bed reduced the hydraulic jump length by 28% to 47% as found by Ezizah et al . The studies by S. A. Ead on sinusoidal corrugated bed showed a 50% reduction in the jump length. It is also observed that when the Froude number is very low say below 3.5 the effect of corrugations is not pronounced well . The investigations by H. M. A. Ahmed with triangular corrugated bed with spacing, resulted in a maximum reduction of 27.75% in jump length at optimal spacing. A recent research by B. Ghorbani and M. Bazaz on triangular corrugation showed a maximum of 29% reduction in length. The length of Hydraulic jumps on corrugated bed is always lesser than that on smooth bed. The studies by Ming Jyh Chern and Sam Syamsuri using SPH model suggested that the sinusoidal corrugated bed reduced the jump length by maximum amount. So sinusoidal corrugations can be treated as the best corrugation for limiting hydraulic jump length. The length of hydraulic jump determines the length of the apron at the downstream, so if the length reduces the cost of construction will be reduced and the best corrugation that can be given as if now is sinusoidal corrugations.

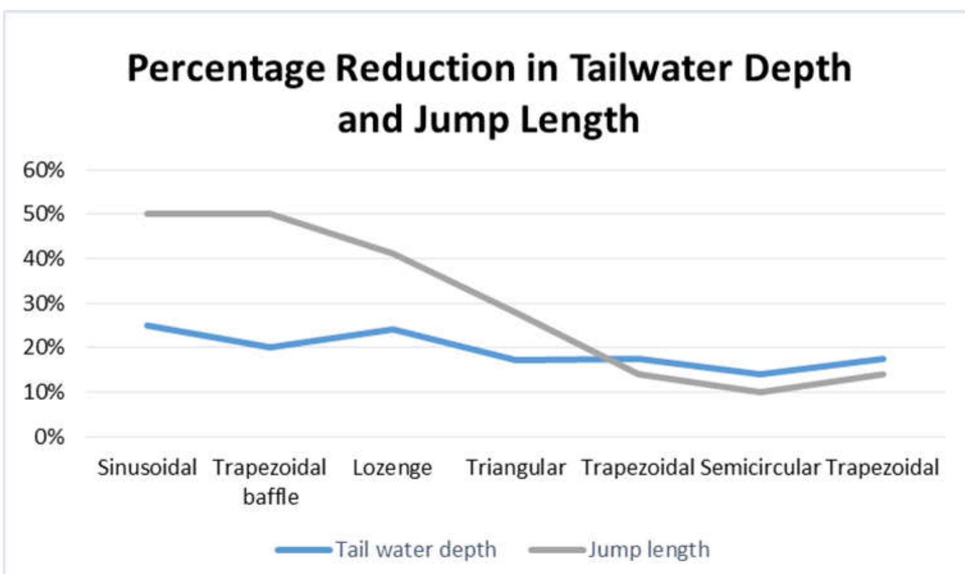

Figure 3. Comparison of different shapes in terms of tail water depth and jump length reduction

2.3. Bed Shear stress

Generally roughened & corrugated bed, are used for increasing the bed shear stress. If we use this on rough bed then sequent depth & length of jump will reduce. Succeeding momentum equation used for calculating the bed shear stress

$$F_T = (P_1 - P_2) + (M_1 - M_2) \tag{5}$$

Where P_1, P_2, M_1, M_2 are the integrated pressure and momentum at the sections before and after the hydraulic jump occur. Shear force index (ε) is calculated by following equation [13]

$$\varepsilon = \frac{F_\tau}{0.5\gamma y_1^2} \tag{6}$$

It was found that bed shear stress on triangular, rectangular& semicircular is 8, 9 and 11 times more than smooth bed. The characteristics of hydraulic jump were studied on rough bed for different. Froude number ranges from 3.8 to 8.6. During this range, results showed that shear stress is 10 times more than smooth bed. If we increase the bed shear stress then ratio of energy ($\Delta E/E_1$) will decrease. The range of comparatively loss of energy ratio for semicircular, trapezoidal and triangular corrugated bed were found as 14% to 64%, 15% to 65% and 16% to 66% and smooth bed ranges found to be from 10% to 62% .The studies using SPH method and shows that the maximum bed shear stress occurs in the sinusoidal bed case and trapezoidal and triangular are the second and third respectively. This is the reason why the length of the jump is least in the case of sinusoidal corrugated bed. Hence for energy dissipation corrugated & rough bed can be used at downstream hydraulic structure and it will reduce the cost of stilling basin.

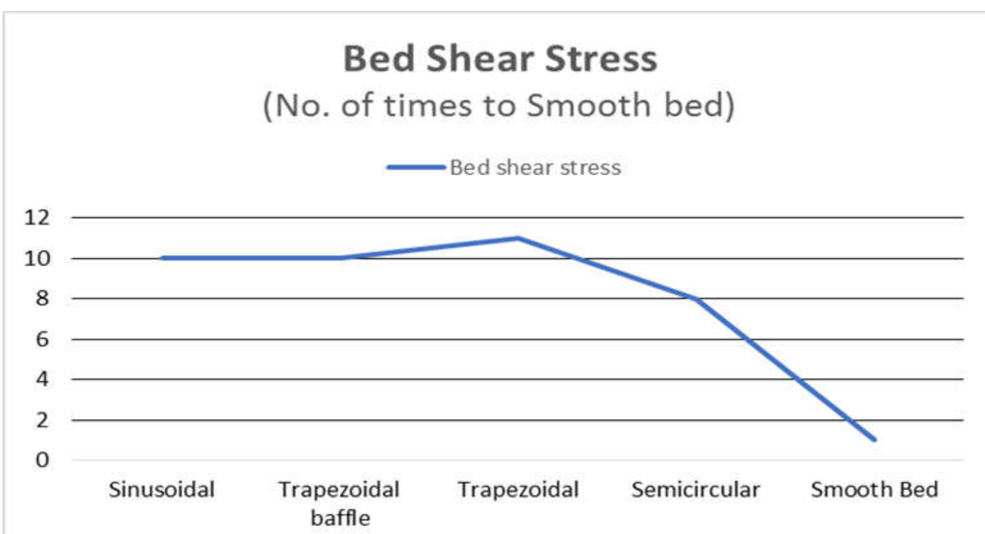

Figure 4. Comparison of different shapes in terms of bed shear stress

3. Conclusions

According to the review of properties of hydraulic jump over different types of corrugated bed, the following conclusions can be drawn:

1. Corrugated bed always results in the reduction of hydraulic jump length and sequent depth up to a limit of 50% and 25% respectively.
2. The effectiveness of corrugated bed is more pronounced in higher Froude numbers.
3. The reduction in length and sequent depth are due to the increase in bed shear stress, which is more in corrugated bed when compared with smooth bed.
4. From the investigations it is proved that corrugated bed can be used for energy dissipation at the downstream side much more effectively then smooth bed.
5. It is being found that sinusoidal type of corrugations is more effective than all other type of corrugations, even though some researchers state that shape doesn't have much role in controlling the jump

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Notations

L_j = length of jump

y_2 = tail water depth

v_1 = flow velocity

y_1 = upstream flow depth

ρ = fluid density

μ = fluid viscosity

γ = kinematic viscosity of water

g = acceleration due to gravity

t = amplitude or height of corrugation

s = shape of corrugation

F_r = Froude number

R_n = Reynold's number

ε = shear force coefficient

F_1 = Froude number on the upstream

D = Depth deficient parameter

L_r = roller length

F_τ = integrated bed shear stress, per unit width, over jump length

P_1 =hydrostatic force, per unit width, where jump starts

P_2 =hydrostatic force, per unit width, where jump ends

M_1 =momentum flux, per unit width, where jump starts

M_2 = momentum flux, per unit width, at section where jump ends