World Journal of Environmental Biosciences

Available Online at: **www.environmentaljournals.org**

Volume 8, Issue 2: 21-28

ISSN 2277- 8047

Study of Simultaneous Effect of Sharp- Roughness and Positive Slope on Hydraulic Jump in Stilling Basins

Farshad Esmaeelzadeh Feridani[1], Roozbeh Aghamajidi[2]*

[1] *Msc of Remote Sensing & GIS, Shahid chamran university, Iran.*
[2] *Assistant professor, Islamic azad university, Sepidan branch, Sepidan , Iran.*

ABSTRACT

Hydraulic structures, e.g. stilling basins, mainly use hydraulic jump to dissipate energy at the downstream of spillways, chutes and gates. In the present study, the effect of a hydraulic jump was examined by using experimental tests. To this end, several tests (60 tests) were performed for inflow Froude numbers within the range of 4 to 12 in a flume with a width of 35 cm. In these tests, rhombic roughness was installed and tested changing bed slope from 0 to 0.3 percent, and the parameters such as flow rate, initial depth, sequent depth, jump length of water surface profile, water head over spillway, and upstream water head were carefully measured. Data analysis showed that rhombic roughness can reduce the jump length to sequent depth ratio up to 35.5%. For a constant rhombic roughness, y2 / y1 ratio increases by 6.5%, on average, with increasing Froude number. For a constant Froude number, Lj / y2 ratio decreases by 1.2%, on average, when a rhombic roughness is installed.

Keywords: *Hydraulic Jump, Stilling Basin, Spillway, Physical Model.*

Corresponding author: Roozbeh Aghamajidi
e-mail ✉ roozbeh 1381@yahoo.com
Received: 22 September 2018
Accepted: 28 March 2019

1. INTRODUCTION

Hydraulic jump is the most important type of variable spatial flows and occurs when the flow goes from supercritical to subcritical. This flow is accompanied by a sudden increase in free surface of water and an excessive depletion of kinetic energy. Hydraulic jump occurs when water flows under a gate or over a spillway, and when the channel slope suddenly changes from steep to gentle over a relatively short length. As a result of this flow, depth increases within short distances and flow rate reduces. This results in high turbulence on the water surface. Farther away from the starting point of the jump, towards downstream, intensity of this turbulence and water energy will be reduced. If roughness is uniformly distributed on the jump bed, the resulting jump is called hydraulic jump over a rough bed. There are several studies on the effect of roughness and positive slope on the hydraulic jump properties, some of which are referred here. Rajasthanam (1968) conducted the first systematic studies on the hydraulic jump over a rough bed and showed that roller length, Lr, and jump length, Lj, are significantly decreased over rough beds. Therefore, it seems that hydraulic jump over rough beds is remarkably superior to the classical one (Rajasthanam, 1968). Safranz (1927 and 1929) carried out the first systematic experimental study on classical hydraulic jump. Although, Hines (1920), Stevens (1925), Levy and Olms (1927), and their critics did not agree upon definition of a jump, but Safranz (1927) contains a summary of previous studies including Bidone, Darcy Bezan, and Freddie Merimam (1895). According to Consion, Safranz and Flash Bart (1929), calculation of corresponding depths using the momentum equation was accepted at the general level. During the second phase of study on jump, most of the studies and findings were obtained by the United States. In this regard, Bakhmatov (1932) studied open-channel flow, and Ross (1934) proposed the hypothesis of dimensionless numbers among which Froude number is an important indicator of hydraulic jumps. Hooke (1984) reported large jumps and shooting them, and Drummond (1935) proposed a simple design procedure. Bakhmatov and Matzke (1936) proposed dimensionless profiles of free water surface, experimental data of corresponding depths and jump length. The third study on design was conducted by Skubi (1939). Moore (1943) examined jump at the end of slope breakers, and different forms of jump and surface profiles. Bakhmatov and Matzke proposed the idea of velocity distribution based on Moore (1943). The fourth phase of hydraulic jump studies started during early seventies and includes advanced observational methods such as the hot-film (Rush 1970, Rush and Louth Hawks 1971 and 1972) and laser Doppler sensor. The first mathematical models of hydraulic jump were proposed by Ross (1970) Narayanan (1975) McChurchdale and Khalifa (1983) Madsen and Sondensen (1983), Sondensen and Madsen (1984), Qarangik and Chadori (1991), and a Boussinesq equation was used to simulate flow change from supercritical to subcritical. Mohammad Ali (1991) performed a series of tests on a bed roughed using cubic elements and showed that relative length of hydraulic jump over a rough bed increases by 27.4-67.4% relative to the classical state (Mohammad Ali 1991). Eid et al. (2000) conducted laboratory experiments to determine turbulent flow velocity field in a circular corrugated tube with a diameter of 62 cm, for three different slopes and different discharge rates. They concluded that the velocity at the boundary of corrugated tube is relatively low. In this study, they sought to investigate fish passage conditions through corrugated culverts (Eid et al. 2000). Kamanbedast and Aghamajidi 2011) tried to study effect of roughness on hydraulic behavior of ogee spillway There are many studies concerning the effect of roughness and positive slope on the hydraulic jump properties. However, the experimental model used in this study aimed to examine the effect of bed roughness on the hydraulic jump practically, to study the effect of positive slope on the hydraulic jump scientifically, and to analyze test results.

2. MATERIALS AND METHODS

Tests were performed in a lab flume of 8*0.35*0.4m with plexiglass bed and glass walls (Fig. 1) in the hydraulic laboratory of Islamic Azad University of Yasouj. A plexiglass reservoir with a capacity of 1 m^3 was positioned upstream and rhombic roughness was made of Teflon. In this study, a plexiglass ogee spillway was used according to USBR standard to create supercritical flow and initial depth of hydraulic jump. In order to prevent flow separation and cavitation phenomenon, the top of roughnesses was placed at the same level as the bottom of ogee spillway where the supercritical flow is generated. Characteristics of bed roughnesses are presented in table 1. Where, h_R denotes roughness height, w_R represents roughness width, and L_{RC} is roughness covered length.

Table 1: Characteristics of the used rhombic roughness

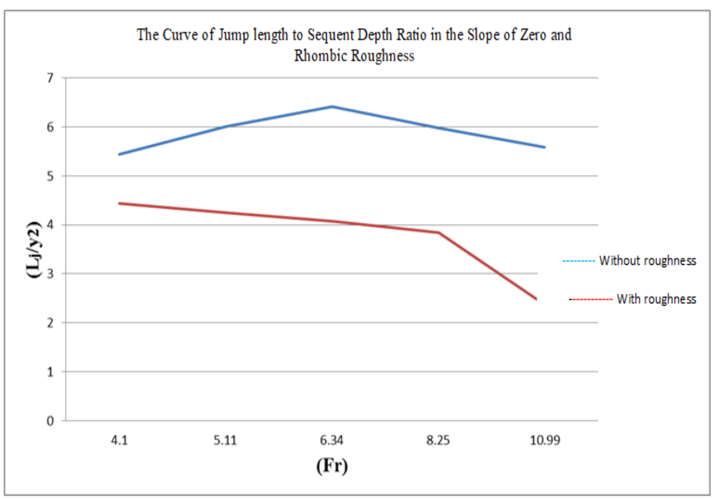
No.	Roughness shape	Roughness height (mm)	Roughness length along the flow (mm)	Roughness width (mm)
1	Without roughness			
2	Rhombic	16	16	22.6

Figure 1: Laboratory of flume

In order to measure the depths before and after jump accurately, the depth of three points, one point in the middle and two points along the channel wall, were measured and the mean value was considered as the depth of flow. In each test, the following parameters were measured: discharge Q, initial depth Y_1, sequent depth Y_2, tailwater depth TW, hydraulic jump length L_j, roller length L_r, and water head over spillway H, upstream water head, water surface profile of jump, opening of the downstream gate, and velocity depth profile of the jump in some tests. To achieve the results, 60 tests were performed and (F_r), ($^{y_2}/_{y_1}$) and ($^{L_j}/_{y_2}$) were calculated using the measured parameters. For each bed roughness size, 5 discharges, 5 Froude numbers (4.1 <F_r< 10.99), and 4 positive slopes (0, 0.1, 0.2 and 0.3) were tested.

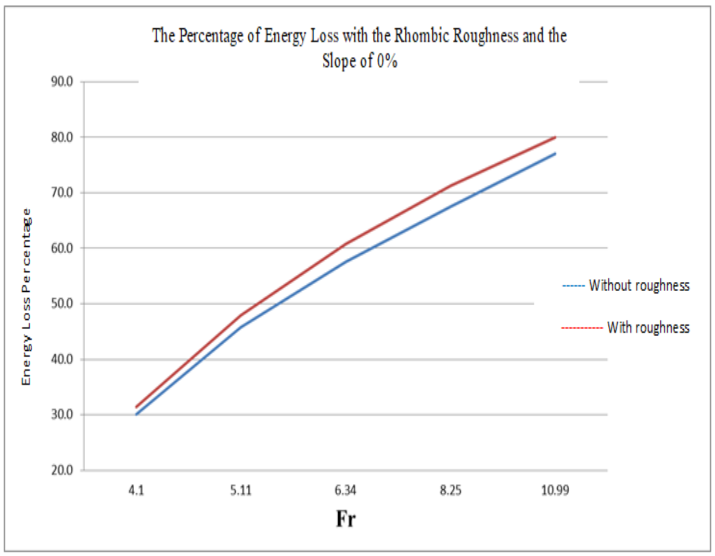
3. DISCUSSION AND CONCLUSION

Figure 2a, b, and c respectively present the curves of sequent depth to initial depth, jump length **to** sequent depth, and jump length **to** sequent depth versus corresponding initial Froude number for 0% slope.



a) Jump length to sequent depth ($^{L_j}/_{y_2}$) versus Fr

b) Sequent depth to initial depth ($^{y_2}/_{y_1}$) **versus Fr**

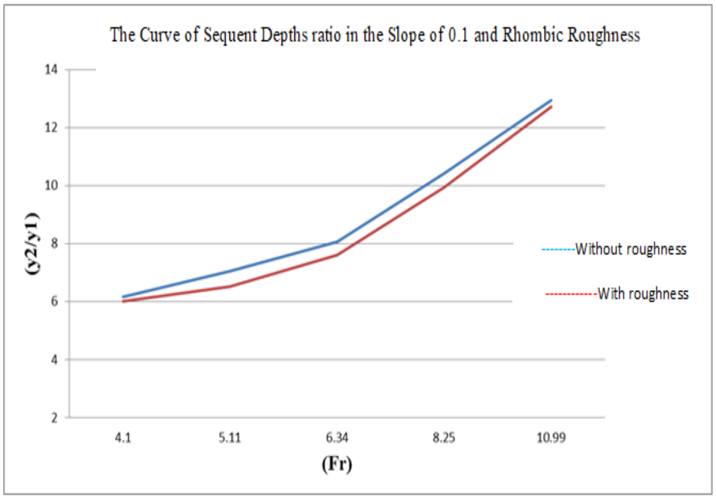


c) Percentage of energy loss versus Fr

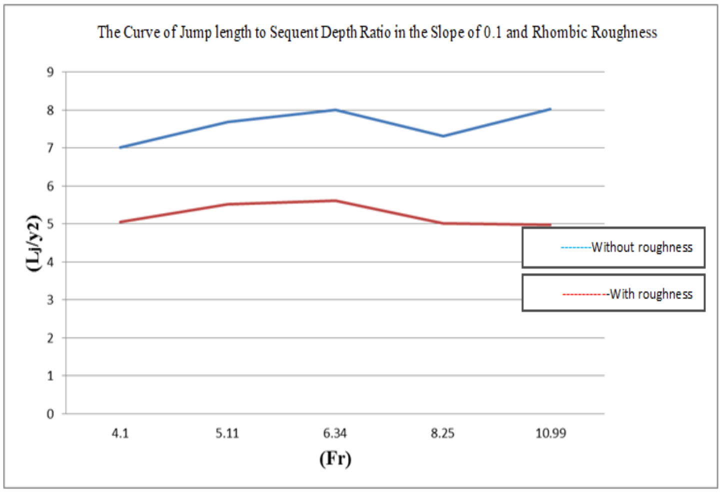
Figure 2: Test results for slope= 0% and rhombic roughness

The results show that in the case of rhombic roughness and 0% slope, ($^{y_2}/_{y_1}$) and ($^{L_j}/_{y_2}$) **reduced** by 9.6 and 35.5%, respectively (rounded to one decimal place). Percentage of energy loss reduced by 55.6 and 58.3% in the cases of smooth bed and rhombic roughness, respectively. For rhombic roughness, ($^{y_2}/_{y_1}$) increases with increasing Froude number. For a constant Froude number, ($^{y_2}/_{y_1}$) decreases when a rhombic roughness is installed. For a constant Froude number, ($^{L_j}/_{y_2}$) decreases when a rhombic roughness is installed. Percentage of energy loss increases when a rhombic roughness is installed.

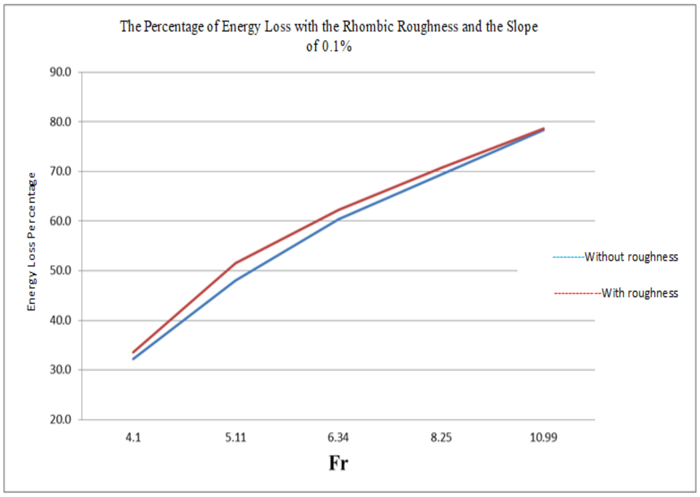
Figure 3a, b, and c respectively present the curves of sequent depth to initial depth, jump length **to** sequent depth, and jump length **to** sequent depth versus corresponding initial Froude number for 0.1% slope.



a) Jump length **to** sequent depth ($^{y_2}/_{y_1}$) **versus Fr**



b) Sequent depth to initial depth ($^{L_j}/_{y_2}$) versus Fr

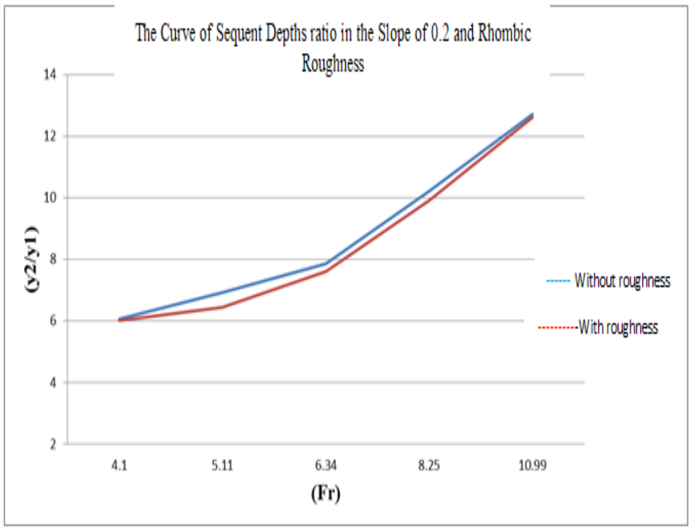


c) Percentage of energy loss versus Fr

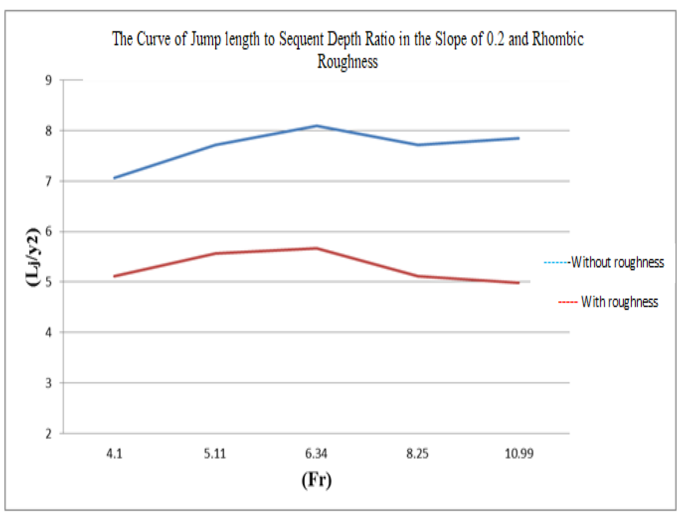
Figure 3: Test results for slope= 0.1% and rhombic roughness

The results show that in the case of rhombic roughness and 0.1% slope, $({}^{y_2}/_{y_1})$ and $({}^{L_j}/_{y_2})$ **reduced** by 4.1 and 31.2%, respectively (rounded to one decimal place). Percentage of energy loss reduced by 57.7 and 59.3% in the cases of smooth bed and rhombic roughness, respectively. For rhombic roughness, $({}^{y_2}/_{y_1})$ increases with increasing Froude number. For a constant Froude number, $({}^{y_2}/_{y_1})$ decreases when a rhombic roughness is installed. For a constant Froude number, $({}^{L_j}/_{y_2})$ decreases when a rhombic roughness is installed. Percentage of energy loss increases when a rhombic roughness is installed.

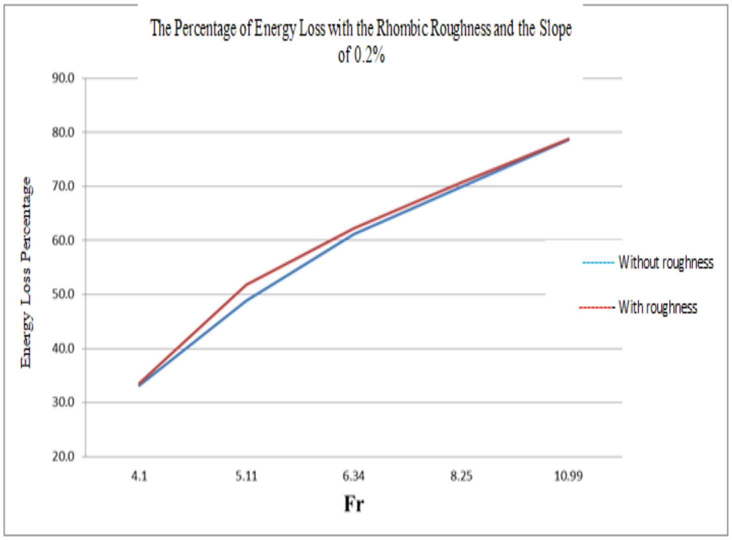
Figure 4a, b, and c respectively present the curves of sequent depth to initial depth, jump length **to** sequent depth, and jump length **to** sequent depth versus corresponding initial Froude number for 0.2% slope.



a) Jump length to sequent depth $({}^{y_2}/_{y_1})$ versus Fr



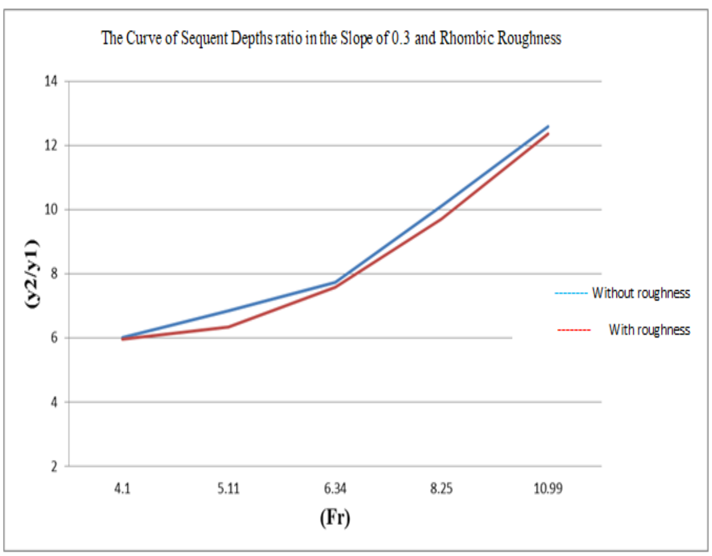
b) Sequent depth to initial depth $({}^{L_j}/_{y_2})$ versus Fr



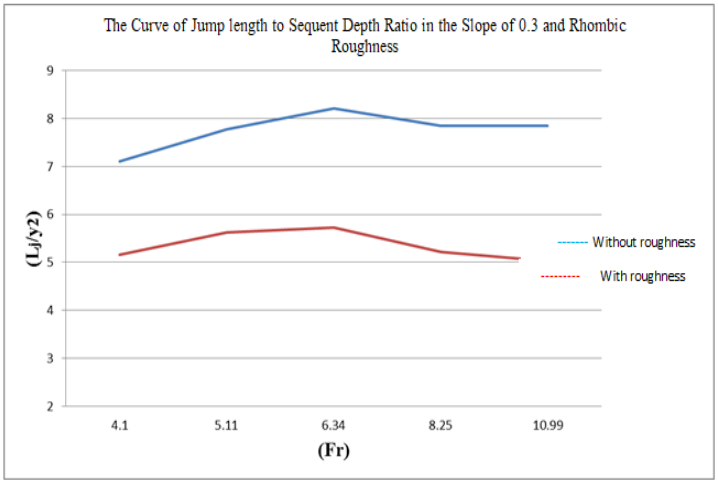
c) Percentage of energy loss versus Fr

Figure 4: Test results for slope= 0.2% and rhombic roughness

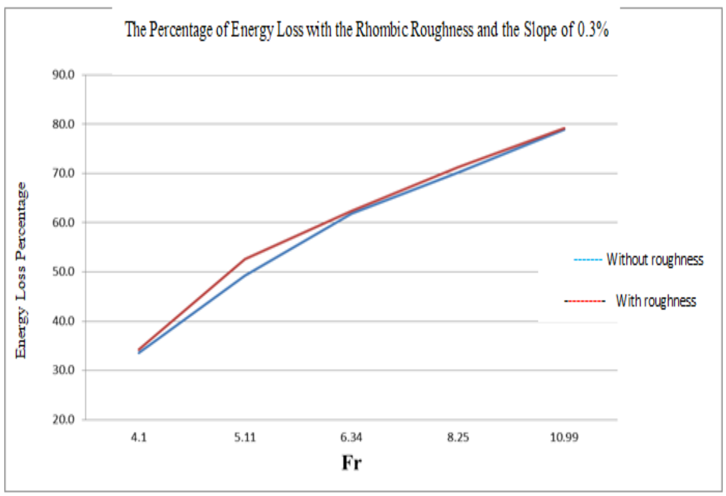
The results show that in the case of rhombic roughness and 0.2% slope, $(^{y_2}/_{y_1})$ and $(^{L_j}/_{y_2})$ reduced by 2.65 and 31.2%, respectively (rounded to one decimal place). Percentage of energy loss reduced by 58.4 and 59.5% in the cases of smooth bed and rhombic roughness, respectively. For rhombic roughness, $(^{y_2}/_{y_1})$ increases with increasing Froude number. For a constant Froude number, $(^{y_2}/_{y_1})$ decreases when a rhombic roughness is installed. For a constant Froude number, $(^{L_j}/_{y_2})$ decreases when a rhombic roughness is installed. Percentage of energy loss increases when a rhombic roughness is installed.Figure 5a, b, and c respectively present the curves of sequent depth to initial depth, jump length to sequent depth, and jump length to sequent depth versus corresponding initial Froude number for 0.3% slope.



a) Jump length to sequent depth $(^{y_2}/_{y_1})$ versus Fr



b) Sequent depth to initial depth $(^{L_j}/_{y_2})$ versus Fr



c) Percentage of energy loss versus Fr

Figure 5: Test results for slope= 0.3% and rhombic roughness

The results show that in the case of rhombic roughness and 0.3% slope, $(^{y_2}/_{y_1})$ and $(^{L_j}/_{y_2})$ reduced by 3.16 and 31.1%, respectively (rounded to one decimal place). Percentage of energy loss reduced by 58.7 and 60% in the cases of smooth bed and rhombic roughness, respectively. For rhombic roughness, $(^{y_2}/_{y_1})$ increases with increasing Froude number. For a constant Froude number, $(^{y_2}/_{y_1})$ decreases when a rhombic roughness is installed. For a constant Froude number, $(^{L_j}/_{y_2})$ decreases when a rhombic roughness is installed. Percentage of energy loss increases when a rhombic roughness is installed.

4. CONCLUSION

Hydraulic jump results in depletion of kinetic energy of water. Hydraulic structures, e.g. stilling basins, mainly use this property of hydraulic jump to dissipate energy at the downstream of spillways and diversion dams. Overall, the following results can be concluded from the present study. Rhombic roughness can reduce $(^{y_2}/_{y_1})$ by 2.65-9.6% (6.13% on average) compared a classical jump. The results showed that rhombic roughness can reduce $(^{L_j}/_{y_2})$ up to 35.5% compared to a classical hydraulic jump over a smooth bed. For rhombic roughness, $(^{y_2}/_{y_1})$ increases by an average of 6.5% with increasing Froude number. For a constant Froude number, $(^{y_2}/_{y_1})$ decreases up to 2 % when a rhombic roughness is installed. For a constant Froude number, $(^{L_j}/_{y_2})$ decreases by an average of 1.2% when a rhombic roughness is installed. Percentage of energy loss increases by an average of 1.7% when a rhombic roughness is installed.

REFERENCES:

1-kamanbedast (2014) The effect of surface roughness on discharge coefficient and cavitations of ogee spillways using physical models. Journal of Applied Science and Agriculture.p 2442-2448

1. Bakhmeteff, B.A. (1932): Hydraulics of Open Channels. McGraw-Hill: New York.
2. Bakhmeteff, B.A.; Matzke, A.E. The hydraulic jump in terms of dynamic similarity. ASCE Trans. 1936, 101, 630–680.
3. Drummond, G.B. (1935): The Design of Stilling Basins for Small Dams and Weirs. Agricultural Engineering 16(8): 319–320.
4. Ead S.A. Rajaratnam N. Katopodis C. and Ade F. (2000). "Turbulent open channel flow in circular corrugated culverts". J. Hydraulic Engineering, 126(10): 750-757.
5. Gharangik, A.M. & Chaudhry, M.H. (1991): Numerical Simulation of Hydraulic Jump. J. Hydraulic Engineering ASCE to be published.
6. Hinds, J. (1920): The Hydraulic Jump and Critical Depth in the Design of Hydraulic Structures.Discussions 1922, 88(22): 923–924.
7. Hughes, W.C, Flack. J.E. (1984). "Hydraulic jump properties over a rough Bed Journal of Hydraulic Engineering, ASCE, Vol. 110, No. 12, PP. 1755-1771".
8. Leutheusser, H.J. & Kartha, V.C. (1972): Effects of Inflow Condition on Hydraulic Jump. Proc. ASCE, J. Hydraulics Division 98(HY8): 1367–1385.
9. Levy, A.G. & Ellms, J.W. (1927): The Hydraulic Jump as a Mixing Device. J. American Water Works Association 17(1): 1–26.
10. Madsen, P.A. & Svendsen, I.A.(1983): Turbulent Bores and Hydraulic Jumps. J. Fluid Mechanics 129: 1–25.
11. McCorquodale, J.A. & Khalifa, A. (1983): Internal Flow in Hydraulic Jumps. Proc. ASCE, J. Hydraulic Engineering 109(5): 684–701.
12. Mohamed Ali, H.S (1991), "Effect of Roughened-Bed stiling Basin on Lengh of Rectangular Hydraulic Jump" Journal of hydraulic Engineering ASCE, Vol 117, No.1. PP.83-93.
13. Moore, W.L. (1943): Energy Loss at the Base of a Free Overfall. Trans. ASCE 108:1343–1392.
14. Narayanan, R. (1975): Wall Jet Analogy to Hydraulic Jump. Proc. ASCE, J. Hydraulics Division 101(HY3): 347–359.
15. Rajaratnam, N. (1968). "Hydraulic jump on rough bed" Trabsactions of the engineering institute of Canada, Vol. 11, No. A-2, PP.1-8.
16. Resch, F. (1970): Hot-Film Turbulence Measurements in Water Flow. Proc. ASCE, J. Hydraulics Division 96(HY3): 787–800. Discussion 1971, 97(HYl): 194–196: 1971, 97(HY8): 1238–1239.Google Scholar
17. Resch, F.J. & Leutheusser, H.-J. (1971): Mesures de turbulence dans le ressaut hydraulique. La Houille Blanche 26(1): 17–31.Google Scholar
18. Resch, F.J. & Leutheusser, H.-J. (1972a): Le ressaut hydraulique: mesures de turbulence dans la region diphasique. La Houille Blanche 27(4): 279–293.
19. Rouse, H. (1934): On the Use of Dimensionless Numbers. Civil Engineering 4(11): 563–568.
20. Safranez, K. (1927): Wechselsprung und die Energiev ernichtung des Wassers. Bauingenieur 8(49): 898–905.
21. Safranez, K. (1929): Untersuchungen über den Wechselsprung. Bauingenieur 10(37): 649–651; 10(38): 668–677.
22. Safranez, K., Unter.Wechse. (1929)341.
23. Scobey, F.C. (1939): Notes on the Hydraulic Jump. Civil Engineering 9(8): 467–469. Discussion 9(9): 565.
24. Stevens, J.C. (1925): Determining the Energy Lost in the Hydraulic Jump. Engineering News-Record 94(23): 928–929. Discussions 1927, 98(3): 126; 1927, 98(13): 538–539.
25. Svendsen, I.A. & Madsen, P.A. (1984): A Turbulent Bore on a Beach. J. Fluid Mechanics 148:73–96.