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Research Article

Analysis of the effect of roughness height and spacing on hydraulic jump characteristics in the stilling basin downstream of an ogee spillway

Mohammad Hossein Ahmadi[1], Amir Vakili[1], Roozbeh Aghamajidi[2]

1 Department of Civil Engineering, Beyza Branch, Islamic Azad University, Beyza, Iran.

2 Department of Civil Engineering, Sepidan Branch, Islamic Azad University, Sepidan, Iran.

Email Corresponding Author: Mohamadh.ahmadi@iau.ac.ir

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Abstract

Introduction

In hydraulic engineering, the management of energy dissipation downstream of spillways is crucial to prevent erosion, scouring, and structural damage. Hydraulic jumps are a common phenomenon used to dissipate energy in stilling basins. However, the efficiency of hydraulic jumps can be significantly influenced by the characteristics of the channel bed, particularly the presence of roughness elements. This study investigates the impact of roughness height and spacing on the characteristics of hydraulic jumps downstream of an ogee spillway.

The ogee spillway is widely used in dam structures due to its efficient flow control and energy dissipation capabilities. However, the high velocity of flow downstream of the spillway necessitates effective energy dissipation mechanisms to prevent damage to the channel bed and surrounding structures. Traditional stilling basins rely on hydraulic jumps to dissipate energy, but their performance can be enhanced by introducing roughness elements on the channel bed.

This research employs numerical simulations using the FLUENT software and the Volume of Fluid (VOF) method to model the flow patterns and hydraulic jump characteristics. The study aims to determine the optimal roughness height and spacing to minimize the length and secondary depth of hydraulic jumps, thereby improving the efficiency of energy dissipation in stilling basins.

Materials and Methods

The study utilized numerical simulations to analyze the effects of roughness on hydraulic jump characteristics. The FLUENT software was employed, and the Volume of Fluid (VOF) method was used to model the two-phase flow. The computational domain included an ogee spillway and a stilling basin with triangular roughness elements on the bed.

The mesh was generated using the Quad Pave method, with triangular elements near the roughness and quadrilateral elements elsewhere. A mesh sensitivity analysis was conducted, and a grid with 33,652 nodes was

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selected based on the lowest error (2.3%) compared to experimental data. Boundary conditions included velocity inlet at the upstream, pressure outlet at the downstream, and wall conditions for the channel boundaries. The RNG turbulence model was chosen for its accuracy in predicting flow behavior. The simulations were validated against experimental data, and the results showed excellent agreement, with a maximum error of 0.02%.

Results and Discussion

The results demonstrated that the introduction of roughness elements significantly reduced the length and secondary depth of hydraulic jumps. As the roughness height increased, the relative secondary depth decreased, and the hydraulic jump length shortened. This is attributed to the interaction of the flow with the roughness elements, which disrupts the flow pattern and enhances energy dissipation.

The optimal spacing between roughness elements was found to be 2 cm, which provided the most efficient reduction in hydraulic jump length and flow regulation. Closer spacing increased the turbulence and shear stress on the bed, leading to faster energy dissipation. However, spacing beyond 2 cm resulted in less effective energy dissipation.

The study also examined the impact of the Froude number on hydraulic jump characteristics. As the Froude number increased, the hydraulic jump length decreased, and the relative depth increased. This trend was consistent across all roughness configurations.

Conclusion

The study concludes that the use of roughness elements on the channel bed significantly improves the performance of hydraulic jumps in stilling basins. Increasing the roughness height reduces the length and secondary depth of hydraulic jumps, while a spacing of 2 cm between roughness elements provides optimal energy dissipation.

These findings have important implications for the design of stilling basins and energy dissipation structures in hydraulic engineering. By incorporating roughness elements, engineers can enhance the efficiency of energy dissipation, reduce the risk of erosion, and improve the stability of hydraulic structures. Future research could explore the effects of different roughness shapes and configurations to further optimize the design of stilling basins.

Conflict of Interest

The authors declare no conflict of interest regarding the authorship or publication of this article.

Data availability statement

The data and results used in this research will be available through correspondence with the author.