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Hydraulic Jumps: Research, Regimes, and Applications

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Introduction

The phenomenon of hydraulic jumps has long been a subject of intense study within the field of fluid mechanics and hydraulic engineering due to its critical role in energy dissipation and flow control. Experimental investigations have been fundamental in unraveling the complex dynamics associated with these transitions. Early work has meticulously detailed the distinct regimes of hydraulic jumps, such as undular, oscillating, and steady states, along with their precise energy dissipation rates and empirical relationships for jump characteristics like length and sequent depths, all heavily influenced by the upstream Froude number [1]. Moving beyond rectangular channels, research has extended to trapezoidal configurations, highlighting the significant impact of channel geometry on jump stability and energy dissipation, leading to the development of validated computational fluid dynamics (CFD) models that accurately predict jump behavior [2]. Furthermore, the acoustic emissions generated by hydraulic jumps, particularly submerged ones, have been a focus, with studies quantifying noise generation and analyzing the turbulence structure downstream, establishing a link between acoustic intensity and energy dissipation rates [3]. The influence of surface characteristics, such as bed roughness, has also been thoroughly investigated, revealing how increased roughness significantly alters jump length, sequent depths, and energy dissipation efficiency, necessitating empirical formulas to account for these variations [4]. The interaction of hydraulic jumps with sediment transport, specifically the undular form, has been explored, quantifying increased bed scouring and sediment load, which is crucial for understanding alluvial channel dynamics and erosion potential [5]. Obstructions in waterways, such as floating debris accumulations, have been shown to modify upstream flow conditions, subsequently affecting jump location, length, and energy dissipation, providing vital insights for managing debris impacts on hydraulic structures [6]. The upstream flow conditions, particularly the velocity profile, have been experimentally examined for their impact on jump stability and characteristics, revealing that non-uniform velocity profiles lead to more erratic jump behavior and altered energy dissipation patterns compared to uniform flow [7]. Hydraulic jumps occurring over roughened spillway chutes exhibit enhanced energy dissipation compared to those on smooth surfaces, prompting the development of empirical relationships to predict this increased efficiency for spillway design [8]. The generation and propagation of waves associated with oscillating hydraulic jumps have been experimentally studied, identifying dominant frequencies and their relationship with jump oscillation amplitude and upstream Froude number, relevant for understanding wave dynamics in hydraulic structures [9]. Finally, hydraulic jumps within convergent-divergent channel sections have been characterized, focusing on how varying geometry influences jump formation, stability, and energy dissipation, leading to empirical relationships for complex flow control structures [10].

Description

The experimental investigation of hydraulic jumps has yielded a wealth of data concerning their fundamental characteristics and influencing factors. Studies have identified and categorized different jump regimes, including undular, oscillating, and steady jumps, and have precisely measured the rates of energy dissipation across these regimes. Crucially, empirical relationships have been developed that link jump length and sequent depths to the upstream Froude number, underscoring its critical role in jump stability and efficiency, which is vital for the design of efficient hydraulic structures [1]. Extending the understanding to non-rectangular channels, research has focused on trapezoidal configurations, where the influence of channel geometry on jump stability and energy dissipation is pronounced. These studies have resulted in validated CFD models capable of predicting jump location and sequent depths, showing strong agreement with experimental data, and providing practical guidelines for engineers managing open channel flows [2]. The acoustic aspects of submerged hydraulic jumps have also been a significant area of research, with advanced measurement techniques used to quantify the noise generated and analyze the associated turbulence structure. A notable finding is the established relationship between the intensity of acoustic emissions and the energy dissipation rate, offering insights for noise control in hydraulic infrastructure [3]. The effect of bed roughness on hydraulic jump characteristics has been experimentally demonstrated to significantly alter jump length, sequent depths, and energy dissipation efficiency. This has led to the proposal of empirical formulas that account for different roughness configurations, refining the understanding of flow in channels with non-uniform surfaces [4]. The interplay between undular hydraulic jumps and sediment transport has been quantified, revealing an increase in bed scouring and sediment load downstream due to the energy dissipation mechanism of the jump. These findings are essential for comprehending alluvial channel dynamics and predicting erosion potential in relevant environments [5]. Investigations into hydraulic jumps in the presence of floating debris accumulations have shown how such obstructions modify upstream flow conditions, consequently impacting the jump's location, length, and energy dissipation. This research is vital for managing debris impacts on hydraulic structures and understanding flow behavior in natural waterways with obstructions [6]. The influence of upstream velocity profiles on hydraulic jump stability and characteristics has been experimentally explored, revealing that non-uniform velocity profiles can lead to more erratic jump behavior and altered energy dissipation patterns compared to uniform flow, contributing to more accurate modeling in complex scenarios [7]. Hydraulic jumps occurring over roughened spillway chutes have demonstrated significantly enhanced energy dissipation compared to smooth chutes, leading to the development of empirical relationships that predict this increased dissipation efficiency, providing valuable design parameters for spillways aimed at reducing downstream erosion [8]. The phenomenon of wave generation and propagation downstream of oscillating hydraulic jumps has been experimentally analyzed, identifying dominant frequencies and their relationship with jump oscillation amplitude and upstream Froude number, which is relevant for understanding wave dynamics in hydraulic structures and their environmental impact [9]. Lastly, hydraulic jumps within convergent-divergent channel sections have been experimentally characterized, with a focus on how the varying channel geometry influences jump formation, stability, and energy dissipation, leading to empirical relationships between the Froude number and key jump parameters for the design of complex flow control structures [10].

Conclusion

This collection of research provides a comprehensive experimental and numerical understanding of hydraulic jumps. Studies have investigated jump regimes, energy dissipation rates, and the influence of upstream Froude number on jump characteristics and stability. The impact of channel geometry, including trapezoidal and convergent-divergent sections, on jump behavior has been explored, along with the effects of bed roughness and floating debris. Acoustic emissions and turbulence structures associated with submerged jumps have been analyzed. Furthermore, the research examines the interaction of hydraulic jumps with sediment transport and the generation of waves in oscillating jumps. The findings offer practical guidelines for the design and management of hydraulic structures, improving flow control and mitigating erosion and noise pollution.

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Conflict of Interest

None.

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