National Institute of Technology Rourkela

Synopsis Seminar

Seminar Title	: Experimental Investigation of Flow Dynamics and Bed Morphology in a Vegetated Channel
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Venue	: Civil Engineering Department Seminar Room
Date and Time	: 21 Apr 2025 (4.00 pm)

Abstract :

The presence of vegetation in an open channel flow can significantly affect the hydrodynamic behaviour of the flow and consequently sediment transport by obstructing the flow and changing the flow characteristics. Understanding the complex interactions between vegetation, turbulent flow, and sediment transport is critical for effective river management, ecological restoration, and sustainable hydraulic infrastructure design. This thesis presents a comprehensive experimental and numerical investigation into the three-dimensional (3D) hydrodynamics and bed morphology of narrow, vegetated open channels under a variety of vegetation conditions, submergence ratios, and flow regimes. The work focuses on exploring how channel geometry, vegetation, distribution, and submergence affect flow turbulence, momentum exchange, sediment transport, and bedform dynamics. Experiments were conducted for both artificial rigid vegetation in fully vegetated channel with fixed bed condition as well as natural vegetation (Vetiver grass) in partially vegetated channel with mobile bed channel. Experimental data were collected in the straight rectangular channel by using a 5 cm down-looking Acoustic Doppler Velocimeter (ADV) to analyse different flow characteristics and bed morphology data were collected by Laser meter after 24 hrs of experimental run.

Initial experiments in a narrow, mobile-bed channel with an aspect ratio of 4.615 reveal significant three-dimensional flow variations. Streamwise velocity was found to be higher near the center and free surface, while vertical velocity exhibited upward motion near the bed and downward motion near the surface. Ripple-type bedforms were dynamically generated under mobile bed conditions, shaped by local turbulence and sediment transport. Turbulent kinetic energy (TKE) and Reynolds shear stress (RSS) peaked near the bed and banks. Experimental results were validated against both analytical solutions and numerical simulations using the Realisable k-&epsilon turbulence model in ANSYS Fluent, demonstrating good agreement and highlighting the model's reliability in narrow-channel flow predictions.

Vegetation height is an important factor in influencing the flow characteristics in a vegetated flow. Further experiments investigated the influence of emergent rigid vegetation arranged in staggered patterns in fixed bed condition. The presence of vegetation reduced flow velocity and turbulence in the vegetated zones, while increasing momentum exchange and turbulence at the transition zones. Skewness and kurtosis analyses revealed complex asymmetries and intermittency in turbulent structures, particularly near and behind vegetation stems. Notably, three-dimensional turbulence properties such as intensity, TKE, and RSS varied spatially along both streamwise and transverse channel directions, with increased turbulence observed immediately downstream of vegetation due to wake effects.

Complementary numerical simulations captured key flow characteristics, including streamwise, transverse, and vertical velocity distributions, secondary currents, and turbulence dissipation. Results showed that streamwise velocity was highest in non-vegetated regions and vegetation gaps, while velocity deficits and transverse motions were most pronounced immediately behind vegetation stems. Statistical metrics such as the coefficient of determination and Nash-Sutcliffe efficiency confirmed the strong agreement between simulated and experimental data.

The study also explored the hydrodynamics of channels with partially vegetated mobile beds under diverse vegetation configurations, including natural emergent vegetation, double-layered submerged vegetation with submergence ratios of 61.53% and 30.77%, and vegetation of heterogeneous heights comprising 33.3% emergent, 33.3% just submerged, and 33.3% fully submerged stems. Across all configurations, vegetation acted as a flow obstruction, diverting momentum toward the non-vegetated side of the channel. This diversion intensified turbulence and shear stresses at the interface between vegetated and non-vegetated zones, contributing to increased bed erosion in the high-energy, non-vegetated regions. In contrast, within the vegetated zones, the drag induced by vegetation reduced streamwise velocity and turbulence, promoting sediment deposition and enhancing bed stability.

Quantitatively, the streamwise velocity on the vegetated side decreased by approximately 50-70% for emergent vegetation, 20-40% for heterogeneous vegetation, and 15-40% for double-layered submerged vegetation compared to their corresponding values on the non-vegetated side. The transition zone between vegetated and non-vegetated areas exhibited heightened turbulent intensity, turbulent kinetic energy (TKE), and Reynolds shear stress (RSS), primarily due to enhanced transverse momentum exchange. Secondary flow structures were also significantly influenced by the presence of vegetation. Helical motions emerged, indicated by negative streamwise-vertical RSS, while peaks in transverse-vertical RSS were observed near the non-vegetated bed.

This complex interaction between vegetation and flow dynamics resulted in spatially heterogeneous patterns of erosion and deposition. Flow diversion toward the non-vegetated side intensified scouring in high-energy

zones, particularly under emergent vegetation conditions. Meanwhile, the vegetated zones experienced decelerated flow and reduced turbulence, leading to sediment accumulation. The double-layered submerged vegetation scenario exhibited relatively lower erosion in the non-vegetated side, suggesting its potential effectiveness in stabilizing channel beds.

Overall, this thesis provides new insights into the three-dimensional turbulent flow behavior and sediment dynamics in vegetated open channels. It emphasizes the role of vegetation geometry, submergence, and spatial arrangement in shaping flow structure, energy dissipation, and morphological evolution. The findings contribute to advancing predictive modeling tools and offer valuable guidance for river restoration, erosion control, and ecohydraulic design in vegetated waterways.