THEORETICAL STUDY ON NON-EQUILIBRIUM SEDIMENT TRANSPORT IN OPEN CHANNEL FLOW

Sumit Sen

Abstract

The thesis primarily focuses on investigating the transport problems of suspended sediments in turbulent flow through straight rectangular open channels with fixed height and cross-section. Several theoretical models are developed for the distribution of flow velocity and sediment concentration for both uniform and non-uniform particles under non-equilibrium condition, incorporating various turbulent phenomena.

A theoretical model is derived for the two-dimensional (2D) distribution of stream-wise velocity in steady, uniform, sediment-laden flow from the Reynolds-averaged Navier-Stokes (RANS) equation by incorporating the effects of sediment concentration and secondary current. The resulting second order partial differential equation (PDE) is solved numerically and compared with experimental data for both wide and narrow channels. The results indicate that the presence of sediment particles increases the magnitude of velocity and as a result, the cross-sectional velocity contours shifts towards the boundary wall with increasing sediment concentration. Additionally, an increase in the aspect ratio of the channel leads to a higher number of circular vortices in the secondary circulation.

A model for the steady 2D distribution of sediment concentration along the vertical and stream-wise direction is proposed in turbulent flow over erodible sediment beds. This model incorporates the effect of stratification and considers generalized boundary conditions. The governing PDE is solved using the spectral collocation method with second-kind shifted Chebyshev polynomial. The convergence of the method is gained by finding the spectral radius of the scheme. Furthermore, a generalized model is presented to study the steady 2D concentration distribution of coarse sediment, considering the effects of secondary current, hindered settling, lag velocity, fluid induced lift force and Reynolds normal stress gradient. The model also considers the sediment diffusivity as a combination of sediment diffusivity due to the sediment-turbulence interaction and drift diffusivity. The resulting non-linear PDE is solved numerically and validated with experimental data under far-field conditions.

To gain a better understanding of the sediment transport mechanism, simultaneous study of both flow velocity and sediment concentration is important as they are interconnected by particle-turbulence interaction. A coupled model of these two is formulated for vertical distribution in an unsteady, uniform sediment-laden flow, incorporating the effects of hindered settling and stratification. The numerical solution is compared with previous models and experimental data for both unsteady and steady flow conditions. It is observed that stratification effect results in a decrease in concentration but increase in velocity, while hindered settling leads to an increase in concentration.

All these aforementioned models are for uniform sediments; but natural flows contain non-uniform particles. Therefore, a model is formulated by modifying the RANS equation to study the unsteady transport of suspended sediments of various grain-sizes coming from erodible sediment beds. This model incorporates the hiding-hindering effect caused by the interaction between non-uniform sediments and utilizes the concept of mixing length. It is observed that the bimodal distribution of grain sizes evolves from one strong peak and one weak peak to two strong peaks as the height increases.

Keywords : Open channel turbulent flow, Stream-wise velocity, Sediment concentration, Uniform and non-uniform sediments, Secondary current, Stratification effect, Hindered settling.