Chapter 1

Introduction

1.1 General

Turbulent flow in open channels is a subject of considerable interest in hydraulic engineering. Although a large number of experimental and theoretical studies have been conducted so far, still there remain many problems awaiting proper understanding. Loose boundary streams are concerned with open-channel flows in which the geometry of a channel is determined by the flow of water it carries. Loose boundary streams include flow and sediment transport in channels with erodible beds, such as rivers, streams, unlined canals, coastal zones and estuaries. Incipient motion of bed particles, sediment transport resulting in erosion and deposition, flow subjected to seepage, flow past protrusions as a pebble cluster are some common phenomena of loose boundary streams.

Study of entrainment threshold of sediment is one of the classic problems of sediment transport in theory and practice. It represents the difference between bed stability and bed mobility. Entrainment of sediment motion is a basis for the analysis and design of stable river beds, hydraulic structures and sewerage systems, etc. It plays an important role in computing the bedload transport rate because a lot of bedload formulae are based on the critical bed shear stress. Because of its wide applications, incipient motion is a subject of great interest to the researchers. The condition being just sufficient to initiate sediment motion is termed threshold or critical condition. The condition for threshold motion is usually expressed is terms of critical shear stress. The problem may also be viewed either as the minimum shear stress required to move a given particle, or as the largest grain size that can be moved by a given shear stress. Near-bed turbulence characteristics in flows over a sediment bed modify significantly with the threshold of sediment particles. Although a large number of studies have been carried out on this aspect, a very few of them are well-focussed on the near-bed flow characteristics.

Wall-wake flow downstream of a sphere is a representative example of the flow around a bluff-body or flow past a protrusion. The study of wake flow downstream of a bluff-body is a matter of considerable interest due to its significance in many practical situations. The wake flows downstream of a bluff-body in shallow flows have importance to study several environmental and geophysical fluid flow situations such as fish habitat structures, short submerged horizontal cylinders and pebble clusters. A wake is the region of disturbed flow downstream of a solid body immersed in a stream or the flow region behind a solid body moving through a fluid, caused by the flow of the fluid around the body. It is a narrow elongated region, consists of large and small eddies, which interact with each other in their unruly motion. Depending upon the size and shapes of the bluff-bodies and flow conditions, wakes are sustained for some distances downstream of the body and a gradual recovery of the undisturbed boundary layer takes place with a further increase in downstream distance. The main characteristic of wake flows is the existence of turbulent wake with recirculation, which has a dominant effect on the drag and lift of the body. Flow around bluff-bodies is also an important aspect of aerodynamics. However, limited studies have so far been carried out to investigate the characteristics of flow past a protruding particle in open channels. Spheres, cylinders and hemispherical objects are examples of some commonly used protruding particles in many experimental studies. An appropriate characterisation of such flows is an essential prerequisite to understand the hydrodynamics and turbulent mixing processes over gravel-beds.

In most of the studies of turbulent flow in open channels, researchers have used the traditional time-averaged hydrodynamic equations which are also known as the Reynolds averaged Navier-Stokes (RANS) equations. Some recent studies showed that the RANS holds good only for flows over hydraulically smooth bed. But, for flows over hydraulically rough bed, in particular, near the bed, the time-averaged equations are not sufficient to give satisfactory solution. In fact, near the rough bed, the flow is highly spatially heterogeneous due to the irregular bed topography composed of discrete particles of various shapes and orientations which often create the inconvenience of using the RANS. To solve these problems to a more satisfactory level, the RANS equations should be supplemented by the spatial-averaging method. The spatial-averaging method

produces modified momentum and continuity equations of the flow variables which are already averaged in time (ensemble) domains and make the parameters double-averaged. The spatial-averaging explicitly define important additional terms like form-induced stress, form drag and viscous drag terms and provides a details understanding of turbulence characteristics over the rough bed.

1.2 Scope of the Present Work

Time-averaged turbulent flow characteristics, spectral analysis, anisotropy, third-order correlation of velocity fluctuations, turbulent kinetic energy, energy budget and bursting analysis are performed under immobile and entrainment threshold conditions for noncohesive sediments.

The flow profiles and the defects of time-averaged streamwise velocity, Reynolds shear stress and turbulence intensities are investigated at the downstream of a wall-wake. A detailed study on higher-order moments of velocity fluctuations, turbulent kinetic energy, energy budget and contributions of various bursting events towards Reynolds shear stress are analyzed. A theoretical solution for the similarity of the velocity defect in steady-state wall-wake flows is also established.

Spatially-averaged flow fields, quadrant analysis, turbulent kinetic energy and energy budget are studied in flows over a gravel-bed.

1.3 Objectives of the Present Investigation

- To study the influence of an entrainment threshold of noncohesive sediments on the near-bed turbulence characteristics.
- To investigate the turbulent wall-wake flows downstream of a spherical obstacle placed on a rough gravel-bed.
- To investigate the spatially-averaged turbulent flow characteristics in flows over a gravel-bed.

1.4. Structure of the Thesis

The thesis is divided into seven chapters. An introduction to the turbulence characteristics at sediment threshold, wall-wake flows downstream of a protrusion and spatially-averaged flow in open channel along with the objectives of the investigations are outlined in Chapter 1. Reviews of relevant literature are given in Chapter 2. In Chapter 3 experimental set-up and procedures for different experiments are described. Theoretical analysis, experimental results and discussions on the response of near-bed turbulence characteristics over a sediment bed with entrainment of sediment particles are presented in Chapter 4. The details of the experimental study for the turbulence in wall-wake flow downstream of a sphere placed on a rough wall are analyzed in Chapter 5. The spatially-averaged turbulent flow characteristics in the vicinity of the gravel-bed are studied in Chapter 6. The conclusions from the present investigation are outlined in Chapter 7.