Editorial

Turbulence and Flow–Sediment Interactions in Open-Channel Flows

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Abstract: The main focus of this Special Issue of *Water* is the state-of-the-art and recent research on turbulence and flow–sediment interactions in open-channel flows. Our knowledge of river hydraulics is becoming deeper and deeper, thanks to both laboratory/field experiments related to the characteristics of turbulence and their link to the erosion, transport, deposition, and local scouring phenomena. Collaboration among engineers, physicists, and other experts is increasing and furnishing new inter/multidisciplinary perspectives to the research in river hydraulics and fluid mechanics. At the same time, the development of both sophisticated laboratory instrumentation and computing skills is giving rise to excellent experimental–numerical comparative studies. Thus, this Special Issue, with ten papers by researchers from many institutions around the world, aims at offering a modern panoramic view on all the above aspects to the vast audience of river researchers.

Keywords: turbulence; local scouring; erosion; transport; deposition; open-channel flows; laboratory experiments

1. Introduction to the Special Issue

The investigation of the interactions between flow and sediments in natural bed streams is one of the most fascinating research topic in the field of fluvial hydraulics, especially if the issues to be addressed are focused on the role of turbulence and its main characteristics in the sediment erosion, deposition and transport processes [1–5], as well as in the presence of vegetation [6]. Similarly, a comprehensive understanding of the flow dynamics in the near-bed flow zone is crucial for many different practical applications, such as bridge pier scour, pipeline scour, scour at bed sills, and other situations in which anthropization affects the behavior of water flow, turbulence, and sediment transport [7–10].

The Special Issue comprises ten original papers on turbulence and flow–sediment interactions in open-channel flows, which can be divided into two main categories: experimental [1–4,6–8,10] and field [5,9] studies. At the same time, among the experimental studies, it is possible to make another distinction on the basis of the instrumentation adopted. Indeed, two different sophisticated technologies were used to capture the instantaneous velocity field: the first one is based upon the Doppler shift effect (Acoustic Doppler Velocimeter, ADV) [2,6–8] and the second is an optical method of flow visualization (Particle Image Velocimetry, PIV) [1,3,4,10]. As regards the field studies [5,9], the Acoustic Doppler Current Profiler (ADCP) was employed, which is based on the Doppler effect as well as the ADV. From the viewpoint of turbulence analyses, all the contributions present in-depth and detailed statistical investigations. In fact, starting from the velocity fields, the researches were extended to the examination of vorticity, viscous and Reynolds stresses, turbulence indicators, turbulence intensity, turbulent length scales, turbulent kinetic energy and turbulent kinetic energy budget, and even to the study of wavelet spectrum, quadrant analysis and Reynolds stress anisotropy.

Thus, in order to provide a view of the key points of the contributions to this Special Issue, the papers were considered together and summarized in the following Section, according to the alphabetical order of the lead author.

2. Overview of the Contributions of the Special Issue

2.1. Kinematics of Particles at Entrainment and Disentrainment (Aleixo et al., 2020)

The objective of this study was the characterization of entrainment and disentrainment of sediment particles of uniform granular beds in turbulent open-channel flows, by performing laboratory experiments conducted by using a PIV system. The Authors demonstrated that sediment entrainment occurred at a wide range of turbulent flow velocities, with a prevalence of sweep and outward interactions. Specifically, four types of particle entrainment were identified: (i) that caused by hydrodynamic forces (Type A); (ii) that promoted by other sediments rolling or saltating near the particle at rest (Type B); (iii) that due to direct collisions between particles (Type C); and (iv) that due to simultaneous pickup of several sediments (Type D). As regards disentrainment events, it was found that negative values of instantaneous velocity fluctuations in streamwise direction were observed for the whole sample of particles. It was also revealed that the bed topography influenced the disentrainment events: sediments in motion tend to be trapped within pockets if bed depressions are found.

2.2. Hydrodynamic Structure with Scour Hole Downstream of Bed Sills (Ben Meftah et al., 2020)

In this study, experimental measurements of the scour hole downstream of bed sills with non-cohesive sediments was investigated. The flow field was measured within the equilibrium scour hole using an ADV. It was found that the flow in the scour hole can be characterized by three distinct regions: (i) a free entering jet flow; (ii) a second region located near the scour bottom, extending upstream owing to eddies generated by the jet diffusion; and (iii) a third less-turbulent region, localized downstream and characterized by an almost unidirectional flow in the streamwise direction. Furthermore, the phenomenological theory of turbulence was applied to predict the maximum equilibrium scour depth. With this approach, a new scaling of the maximum scour depth at equilibrium was obtained, which was validated using the experimental data.

2.3. Flow–Sediment Turbulent Ejections: Interaction between Surface and Subsurface Flow in Gravel-Bed Contaminated by Fine Sediment (Bustamante-Penagos and Niño, 2020)

This study is related to experiments on a surface alluvial stream polluted with fine sediment percolated into the bed. PIV measurements were performed and velocity data were analyzed by scatter plots, power spectra and wavelet analysis of turbulent fluctuations, finding changes with and without the presence of these fine deposits. Specifically, the results revealed that the sediment ejections change the patterns of turbulent structures and the distribution of the turbulence interactions, implying that the flow does not have a typical rough-wall open-channel flow turbulence. Additionally, the sediment ejections increase the energy both in the production zone and inertial subrange.

2.4. Wavelet Coherency Structure in Open Channel Flow (Chen et al., 2019)

In this study, based on PIV data, the wavelet coherency analysis was applied to catch the coherent structures in a steady open-channel flow. As a result, it was demonstrated that the high value peaks in the pre-multiplied wavelet power spectrum curves stand for the energetic scales in the signal, and the high value areas in the local wavelet spectrum give both the scales and the time instants of energetic motions. The methodology can also detect the scale and the occurrence time instants of energetic motions and the inner structure of them. Furthermore, it was found that the wavelet coherency analysis supports the hairpin packets model in open-channel flows.

2.5. Bedform Morphology in the Area of the Confluence of the Negro and Solimões-Amazon Rivers, Brazil (Gualtieri et al., 2020)

The aim of this study was the investigation of the bedforms observed in the area of the confluence of the Negro and Solimões/Amazon Rivers (Brazil), whose morphology was acquired with an Acoustic Doppler Current Profiler (ADCP). The results showed that wavelength and wave height of the bedforms

increased as the river discharge increased. Furthermore, the dunes were characterized by low-angles and, while several dunes were in equilibrium with the flow, several largest bedforms were found to be probably adapting to discharge changes in the river.

2.6. Man-Induced Discrete Freshwater Discharge and Changes in Flow Structure and Bottom Turbulence in Altered Yeongsan Estuary, Korea (Kang and Lee, 2020)

Using ADCP measurements in the Yeongsan estuary (Korea), this study aimed at examining the flow field resulting from the opening of the dam gate and the release of water with different properties, such as salinity, temperature and flow rate. Specifically, comparisons between the bottom turbulent kinetic energy (TKE) and the suspended sediment concentration (SSC) were performed. As a result, it was demonstrated that the surface freshwater discharge from the dam gate affects the behavior of water flow, bottom turbulence and sediment transport in the study area.

2.7. Turbulence Characteristics before and after Scour Upstream of a Scaled-Down Bridge Pier Model (Lee and Hong, 2019)

This study aims at understanding the near-bed turbulence characteristics and the resulting sediment transport around a pier, by using an ADV in laboratory experiments on scaled-down bridge pier models. Velocities and turbulence intensities as well as bed elevations before and after the scour were measured with an ADV. The results show that the mean flow variables are not sufficient to characterize the complex turbulent flow field around the pier leading to the maximum scour, because of unsteady flows. Instead, the quadrant analysis of velocity fluctuations revealed that bursts and sweeps are the primary forcing function for creating the scour hole at initial stage.

2.8. Turbulent Flow Field around Horizontal Cylinders with Scour Hole (Penna et al., 2020a)

This study presents the results of an experimental investigation on scoured horizontal cylinders, varying the gap between the cylinder and the bed surface. A PIV system was used to measure the flow field in a vertical plane at the end of the scouring process. The results revealed that suspended and laid on cylinders behave differently from half-buried cylinders if subjected to the same hydraulic conditions. In the latter case, vortex shedding downstream of the cylinder is suppressed by the presence of the bed surface that causes an asymmetry in the development of the vortices. This implies that strong turbulent mixing processes occur downstream of the uncovered cylinders, whereas in the case of half-buried cylinders they are confined within the scour hole.

2.9. Anisotropy in the Free Stream Region of Turbulent Flows through Emergent Rigid Vegetation on Rough Beds (Penna et al., 2020b)

In this study, an experimental investigation, based on ADV measures, was performed to characterize the free stream region of turbulent flows through emergent rigid vegetation on rough beds, focusing on turbulence anisotropy. Specifically, the anisotropy invariant maps (AIMs) were determined at different positions within the vegetation array along the flume centerline. The results showed that the combined effect of vegetation and bed roughness causes the evolution of the turbulence from the quasi-three-dimensional isotropy to axisymmetric anisotropy approaching the bed surface. Thus, as the effects of the bed roughness diminish, the turbulence tends towards an isotropic state. Furthermore, it was revealed that also the topographical configuration of the bed surface has a strong impact on the turbulent characteristics of the flow.

2.10. Turbulence in Wall-Wake Flow Downstream of an Isolated Dunal Bedform (Sarkar et al., 2019)

The objective of this study was the analysis of the turbulence in wall-wake flow downstream of an isolated dunal bedform, on the basis of laboratory experiments performed with an ADV. The results revealed that the near-wake flow is featured by sweep events, whereas the far-wake flow is controlled by the ejection events. Downstream of the dune, the turbulent kinetic energy production and dissipation

rates, in the near-bed flow zone, are positive. Then, they decrease up to the lower-half of the dune height; beyond that, they increase again. Conversely, in the near-bed flow zone the TKE diffusion and pressure energy diffusion rates are negative; they attain their positive peaks at the crest. Finally, it was found that, below the crest, turbulence has an affinity towards a two-dimensional isotropy, whereas, above the crest, the anisotropy tends to reduce to a quasi-three-dimensional isotropy.

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