Large Eddy Simulation of Sediment Transport for the Pulsating Flow past a Cylinder over a Horizontal Bed

Efstratios N. Fonias
Dimokratis G. E. Grigoriadis
Computational Sciences Laboratory UCY-CompSci, Department of Mechanical and Manufacturing Engineering, University of Cyprus, Nicosia, Cyprus

ABSTRACT

In the present work, the suspended, pulsating incompressible flow past a submerged cylinder was examined by means of Large Eddy Simulations (LES). A layer of sandy inertial particles was allowed to move between the cylinder and the horizontal impermeable bottom. The particulate phase motion is modeled by means of the Maxey-Riley (1984) equation of motion, considering the Stokes drag and gravity as the significantly dominant forces exerted on the particles by the flow. For the interaction of the flow with particles, particles are allowed to affect the flow field and inter-particle collisions were also simulated, according to a hard sphere model. Solid boundaries were taken into account using the immersed boundary method. A three dimensional Cartesian grid with variable size is used for the spatial discretization, and a time-splitting scheme is used for the temporal discretization. The numerical method was validated against previously reported Direct Numerical Simulation (DNS). For the pulsating flow case, using a fixed cylinder, test cases for Keulegan–Carperter numbers equal to $4\pi$, $6\pi$ and $10\pi$ were examined. The particles that exit the domain are reintroduced from the periodic boundaries. Turbulent flow statistics were gathered and analyzed both for the flow variables and the moving particles. The impact of the interaction of the flow with the particles was examined in terms of sediment concentration so that the scouring effects could be thoroughly investigated.

KEY WORDS: LES; DNS; sediment transport; pulsating flow.

INTRODUCTION

Investigation of sediment transport has always been one of the most important fields of research concerning coastal flows. The significance of this phenomenon is apparent especially concerning its interaction with structures in terms of their foundation in the seabed. In the coastal environment, the forces exerted by the flow affect not only the structures, but also the seabed. In cases of a sandy seabed, the oscillatory flow can move the sediments and in some cases can gradually completely remove the soil underneath the structure resulting to structural failures or significant deformations.

The two basic mechanisms that distinguish the sediment motion, which are the bed load and the suspended load of sediments are in most cases treated separately. Theories on quantification of these processes are formed according to the research findings. The sediment motion has been thoroughly investigated through a number of experimental studies. The works of Ribberink and Abdullah (1994; 1995) investigated sediment transport for oscillatory flows over rippled and flat bed and validated existed formulas along with a more detailed system to distinguish sediment motions. Dohmen-Janssen et al, (2001) experimented on sediment motion and temporal evolution of bed morphology under oscillatory flow over horizontal bottom. All the experiments conducted until the present, mainly validated analytical equations and semi-empirical models to quantify sandy sediment motion under wave flow conditions (Thorner et al, 2002; O’Donoghue et al, 2006; van der Werf et al, 2006; Ribberking et al, 2008).

Numerical simulations have also demonstrated interesting results with respect to particle motion. Sediment transport can be simulated with either a Eulerian (Zedler and Street, 2001) or a Lagrangian (Chang and Scotti, 2003; 2006; Chang et al, 2013) approach. The present work is focused on the Lagrangian approach for particle motion, where particles are treated as spheres affected by the flow that exerts forces defining their motion. In coastal flows, the fluid-solid interaction is considered of high importance due to the fact that in most common cases, the sandy particles have relatively large size and inertia (compared to the fluid scales). Thus, there is a significant amount of inertial exchange among the fluid and particulate phase. In addition, the particle size makes the inter-particle collisions important for the accurate extraction of results in terms of flow variables and particle trajectories. Simulation of those phenomena is classified as “4-way coupling” regime of fluid-particle interaction and it is the most detailed way of describing dispersed phases within the carrier fluid. In that direction Dritselis and Vlachos (2008) and Vreman et al (2009) have worked on simulating particle motion within plane channel flows. In that direction, Large Eddy Simulations (LES) provide a very powerful way of accurate description of the flow so that the widest part of the flow scales can be simulated and consequently provide an accurate flow field for extracting information about the particles.