Density-Driven Currents and Deposition of Fine Materials

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Dredging is a key element in river, ports, coastal and offshore development. In general dredging is conducted for excavation at the river, lake or seabed, relocation of the material, maintenance of the navigation channels, mining underwater deposits, land reclamation or cleaning up the environment. Dredging activities always make changes to the environment, such as alteration of the coastal or river morphology, currents and wave climates, and water quality. Such changes may be considered improving or degrading to the environment. The type of material being dredged, type of the dredging equipment and the local conditions determine the level of environmental interference and the impacts caused by the dredging projects.

Sediment spillage from hopper overflow constitutes a source for sediment plumes and can also impact the turbidity of aquatic environments. The overflowing mixture is often different from the mixture pumped into the hopper (the inflow), because the mixture undergoes compositional transformation as a result of different timescales in the segregation of the various sediment fractions. A proper description of the compositional transformation during filling and subsequent overflow stages can be captured using a sediment budget approach, i.e., by using continuity equations for water and sediment phases. In the first part of this study, the compositional transformation and the bed height inside the hopper are obtained by solving these equations, considering monodisperse, bidisperse, and polydisperse mixtures, the former analytically. Although assumptions tied to the mathematical model are fulfilled best for hoppers rigged with a multiple-inflow system, the model accurately predicts measured concentrations in the final stage of overflow for single-inflow systems.

In the second part of this study, a 3 dimensional two-phase mixture method has been used to model the detailed processes involved in the highly concentrated mixture inside the hopper. The benefit of such model is that it takes into account important dynamic interactions and volume exchange effects due to the settling particles in the flow and the accretion of the bed layer inside the hopper. The model has been validated successfully with experiment and has been used to study different processes critical to overflow losses. The placement of the inlet pipes along the length of the hopper, which is primarily arranged to balance the load distribution in the hopper, has been studied from the perspective of dredging efficiency. The results show large influences from the arrangement of the inlet pipes on the sedimentation rates, and the overflow losses in the hopper. Natural seabed material is composed by many fractions and the size and type of sediments change along and into the seabed. Variations in the material entering the hopper have been studied by assuming fluctuating inflow concentrations. The fluctuations impose a mean net change on the overflow concentrations.

In the third part of this study, the above described CFD model has been used to model the detailed processes involved in nearfield entrainment, dilution and settling of the turbidity plumes. In order to resolve the entrainment and dilution mechanisms, the Large Eddy Simulation (LES) method has been implemented to directly solve the major flow structures and eddies responsible for the interactions between the mixture and the ambient fluid. The effects of governing parameters on the plumes behaviour have been studied, being in density driven or the mixing regime. The main parameters are the densimetric Froude number at the discharge point below the overflow pipe, velocity ratio between the overflow jet and the ambient current, and the water depth. The results from the CFD model have shown that presence of the dredgers propeller in the vicinity of the overflow plume increases the mixing rate, drag the plume towards the surface and retards its settling rate. The results from the polydisperse model show that the dispersity in size and weight of the sediment constituents affects the fate of overflow plumes, due to dynamic and kinematic interaction between the fractions. The numerical model is a perfect tool for conducting a parametrized study on the nearfield behaviour of the plume, which then provides boundary conditions for the larger scale farfield dispersion models.

In the last part of this study, the hydraulics of the classic dropshafts (being in close resemblance to the hopper overflow structures) has been studied for better understanding of the air entrainment process and the driving parameters. The air entrainment at hopper overflow structures results in further mixing and slower settling of the sediment plume due to the positive buoyancy effects of the entrained bubbles. A two-phase numerical model, based on the Volume of Fluid (VOF) method, has been established to simulate the process of overflow and the air entrainment in circular dropshafts, which has been verified successfully with the experimental data. The model has been used to simulate the performance of the so called Green Valve, as being a mitigation method in reducing the air entrainment in overflow pipes.

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Contributors: Saremi, S., Svenstrup Petersen, O., Christensen, E. D., Hjelmager Jensen, J.
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