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EXPERIMENTAL INVESTIGATION OF NEGATIVELY BUOYANT SEDIMENT PLUMES RESULTING FROM DREDGING OPERATIONS

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1. Introduction

Dredging is an activity often related to economical expansion projects along the world's coastlines and has been a strongly increasing for some years. In view of the increased attention to environmental impacts of coastal and offshore dredging operations, research in this field is on the rise.

In this context the effect of turbidity generated by dredging activities plays an important role. The sediments brought in suspension can generate effects ranging from reduced light penetration in the water column over burial of sea bed ecosystems to dispersion of toxic materials attached to polluted sediments (Dankers, 2002; Smith *et al.*, 2008). The dispersion of benthic material can have other impacts including siltation of still water bodies such as bays, docks or harbours.

Sediments in highly-concentrated suspensions are released from the often used Trailing Suction Hopper Dredgers (THSD) through an overflow of the hopper. Depending on sediment concentration and ambient current velocity (relative to the sailing vessel) the flow can either behave as a density-driven, negatively buoyant jet or as a plume mixing fast with the seawater and therefore losing its buoyancy. In the first case the dynamic plume sinks to the seabed while part of the sediment is mixed into the water column, in the second case almost all fine sediment is brought in suspension (Spearman *et al.*, 2007). Both cases lead to a large, non-buoyant, passive far-field plume with the potential to travel large distances due to advection with coastal or estuarine currents.

2. Methods

In a first step to investigate the behaviour of this type of density current, an experimental facility has been built to release scaled sediment plumes in the presence of cross flow (Figure 1). In a mixing tank fitted with a circulating pump a mixture of water and sediment is homogenised. Using a second pump, the mixture is fed to a constant head vessel located on top of the flume. The constant head vessel is designed to keep a constant water level by being overtopped and leading the excess mixture back to the mixing tank. The constant head vessel is connected to an opening in a polycarbonate plate situated at 4 cm below the water level in the flume. The constant level in the vessel, combined with an orifice in the pipe guarantees for a constant, known discharge of the mixture with controlled sediment concentration into the flume. Fine sediment (kaolin clay) with a narrow particle size distribution has been used in order to minimise the effect of settling and particle size distributions and thus simplify the interpretation.

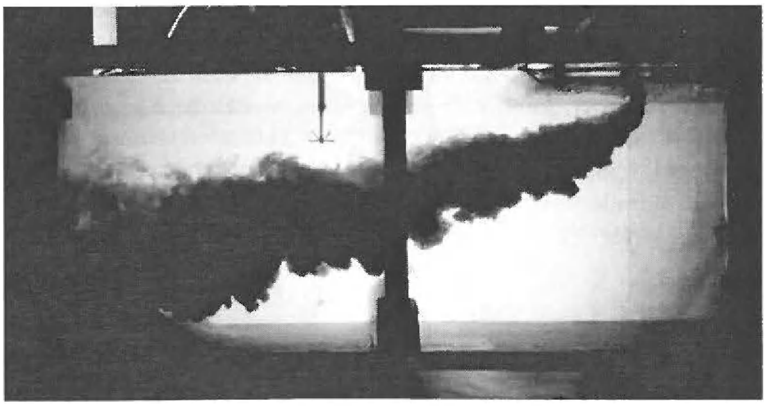

Figure 1. Image of a negatively buoyant sediment plume in cross flow.

High-frequency measurements of velocity components and sediment concentration are obtained using acoustic and optical backscatter equipment, still regarded as the best options to obtain information in highly turbid flows. The Acoustic Doppler Velocimeter (ADV) is used to provide data on mean and fluctuating velocity profiles by means of the Pulse Coherent Doppler technique. In this laboratory study, the instrument's acoustic backscatter intensity is calibrated to measure the time-averaged sediment concentrations in the plume as well as turbulent fluctuations of the concentration allowing for the determination of turbulent sediment and momentum fluxes (e.g. Shabbir and Taulbee, 2000). The optical backscatter signal of an Argus Surface Meter (ASM) has been calibrated for the response in kaolin clay suspensions and has been installed to obtain additional profiles of mean sediment concentration at a higher spatial resolution.

A background of diffused white light provides for using images as a shadowgraphy measurement of the obscuration due to sediment allowing for the determination of the average elevation of the concentration maximum at any distance from the source up to about 2 m (32 to 60 pipe diameters, depending on the pipe).

The influence of mass density of the released material, exit velocity, pipe diameter and background current velocity are investigated. A total of 34 different experiments have been executed with Richardson numbers ranging from 0.01 to 17 and background to outflow velocity ratios between 0 and 8.7. In this way, dynamically scaled conditions have been produced corresponding to the range of conditions occurring while dredging in marine and coastal environments. At this stage of the research, the influence of waves, air bubbles, propellers and intermittent discharges due to ship pitching are not taken into account.

3. Results and conclusions

In order to verify the measurement techniques a sediment plume has been released into still water, generating the well-known buoyant jet without cross-flow. Radial profiles of axial velocity and sediment concentration have been measured using the ADV and show good correspondence with the Gaussian profile described by self-similar conditions (Fisher, 1979; Lee and Chu, 2003). Furthermore, PLIF data of turbulent sediment concentration fluctuations (C_{rms}) by Papanicolaou (1988) have been compared and show good agreement in terms of the axial maximum and radial profile of C_{rms}/C_m, with C_m the maximum concentration.

The paths of the axis of the experimental buoyant plumes in cross-flow have been compared to integral laws by Fisher *et al.* (1979), showing relatively good agreement, proving that a turbulent plume of fine sediments behaves very similar to a two-liquid plume as long as particle settling velocity is small compared to advective velocities. An exception are the cases with a plume formed by low density material and high background flow velocity having a higher path and are therefore influenced by the wake of the schematised polycarbonate ship hull where shear flow induces increased vertical mixing and therefore a location of the plume axis closer to the surface compared to integral laws.

At relatively close distance to the exit pipe, the background flow is perpendicular to the plume. This effect produces the radially symmetric pipe-flow profile to deform into two counter-rotating vortices. With this structure, the plume adopts a larger surface area leading to higher mixing and dilution rates.

The experiments offer an extensive dataset on the mixing in this type of plumes, useful for calibration of a numerical model.

4. References

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