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Simulation for the convective descent phase of dredged-sediment releases in the seawater by a two-fluid model

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The harbour structures are often located in shallow areas, especially in estuaries. It is then necessary to perform dredging to allow ships accessing to the docks. The dredged sediment is released over a predefined deposit zone. During the release, the sediment cloud, of which the concentration can be initially more than 350g/l, contains a lot of contaminants and then will impact to the environment. The purpose of this work is to numerically study the process of dredged sediment with the help of a two-phase model [4]. The simulations are performed in the configuration of the experiments of Villaret et al. [6].

Key words

Dredged sediment release, sediment transport, two-phase flow modelling, fine sand

I INTRODUCTION

The process of dredged-sediment disposal generally follows three different steps [1]: (i) convective descent during which the sediment falls under the influence of gravity; (ii) dynamic collapse, occurring when the descending cloud or jet impacts the bottom (iii) passive transport-dispersion, commencing when the sediment transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the disposal operation.

Previous numerical studies have shown the limits of the “*passive scalar*” approach in simulating dredged sediment disposal [2]. This is due to the very high concentration of the sediment cloud. In recent work, Freson et al. [3] has used a bi-specie model, which is based on a degeneration of the two-phase model, and considers the sediment-water mixture. Interesting results were obtained for the falling phase whereas the bottom transport phase remains still problematic.

The purpose of this work is to study the convective descend step using a two-phase model [4]. This model has been applied [5] to the experimental configuration of Villaret et al. [6]. The process of dredged-sediment disposal is studied with different values of the current, the sediment diameter, and the initial sediment concentration.

II GOVERNING EQUATIONS

The two-phase flow model is based on the Eulerian-Eulerian (or two-fluid) description. The model is fully described in [4]. Herein we briefly recall the basic equations with special closures for

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the sediment dumping case. The governing equations (1) are written for each phase. The subscript k could be “ f ” for fluid and “ s ” for solid phase:

$$\left\{ \begin{array}{l} \frac{\partial(\alpha_k)}{\partial t} + \vec{\nabla} \cdot (\alpha_k \vec{u}_k) = 0 \\ \frac{\partial(\alpha_k \vec{u}_k)}{\partial t} + \vec{\nabla} \cdot (\alpha_k \rho_k \vec{u}_k \otimes \vec{u}_k) = \frac{1}{\rho_k} \vec{\nabla} \cdot (\alpha_k (-p_k \bar{I} + \bar{\tau}_k + \bar{\tau}_k^{Re})) + \alpha_k \vec{g} + \frac{1}{\rho_k} \vec{M}_k \end{array} \right. \quad (1)$$

where α_k , \vec{u}_k and ρ_k stand for the volume fraction, velocity and density of phase k respectively, \vec{g} is the acceleration of gravity, M_k the inter-phase momentum transfer, p_k the pressure of phase k , $\bar{\tau}_k$ (or $\bar{\tau}_k^{Re}$) the viscous (or Reynolds, respectively.) stress tensor. The sum of volume fractions, α_k , is obviously equal to 1. In this model, the viscous stress tensor is considered as a function of shear-stress tensors. It is worth noting that viscosity coefficients used for the solid stress are weighted by an amplification factor β , which accounts for the non-Newtonian behaviour of sediment flows. This is depending on the inter-particle distance, which depends itself on the maximum volume fraction $\alpha_{s,max}$ (close to the packing concentration, whose value is equal to 0.625 for non-cohesive spherical and mono-dispersed solid particles). Different turbulent closures are available in the present version of the code: the reader can find a detailed presentation in [7].

III STUDY CONFIGURATION AND SET UP

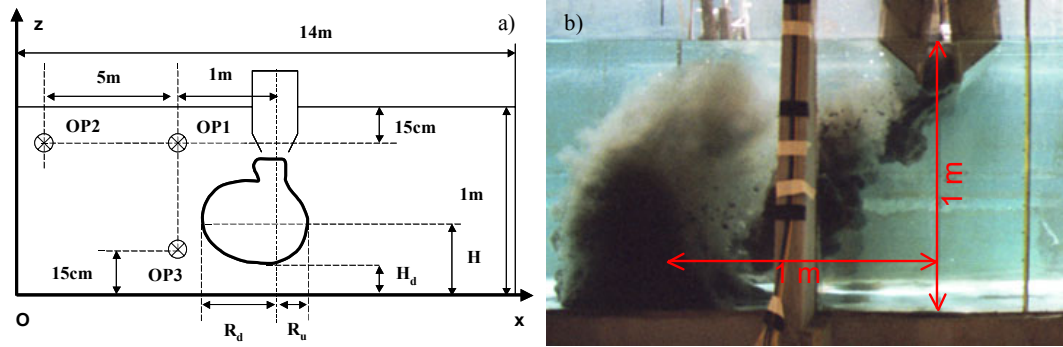


Figure 1: Definition sketch: a) location of optical sensors (OP) for turbidity measurements; b) mud dumping [6]

Villaret et al. [6] realised a laboratory experiment of sand release in a straight channel of 72 m long, of 1.5 m wide and of 1.5 m height. A specifically designed recipient (maximum capacity of 60 liters) is placed at 15 cm below the free-water surface. The ambient current is maintained with the help of a hydraulic pump. The sand-water mixture is initially filled-up in the recipient at a given concentration. Then the bottom of recipient is suddenly opened (Figure 1b) and the measurement (photo-camera and concentration) starts simultaneously. Table 1 gives an index of the different testing conditions.

Table 1. Testing conditions and nomenclature: W_{inj} is the injection velocity from the recipient, D_p the sediment particle diameter (90 μm), ρ the dry density of the solid (2650 kg/m^3), C_m is the concentration of the mixture (450 g/l), V_r the volume of dumped material (60 l), U_c the ambient velocity [6].

Tests	e6	e11	e12	e13	e14	e15	e16	e17	e18	e19	e20
W_{inj} (m/s)	0.6	0.79	0.89	0.79	0.89	0.79	0.89	0.79	0.89	0.79	0.89
D_p (μm)	90	90	160	90	160	90	160	160	90	160	90
C_m (g/l)	350	450	450	450	450	450	450	450	450	450	450
V_r (l)	45	60	60	60	60	60	60	60	60	60	60
U_c (cm/s)	0	0	0	10	10	15	15	20	20	25	25

IV TWO-PHASE MODELING & RESULTS

The 2-D X/Z computation domain extends over 14m in the x -direction (centred at the release location) and over 1m on the vertical one (z -ascendant coordinates). A regular mesh of 61x1401 nodes as well as a time step of $\Delta t=0,001$ s are used. The numerical parameters are set in Table 1. The lateral ends are considered as open boundaries. At the injection location (inlet diameter equal to 10 cm), the fluid and sediment fluxes are imposed following a Poiseuille profile with a given maximum velocity (W_{inj}).

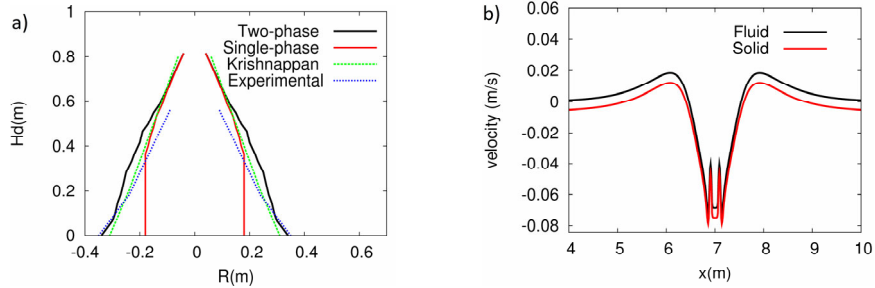


Figure 2: Test 11: a) numerical and experimental radius of the sediment cloud; b) vertical velocity profile at $z=-0.83$ m

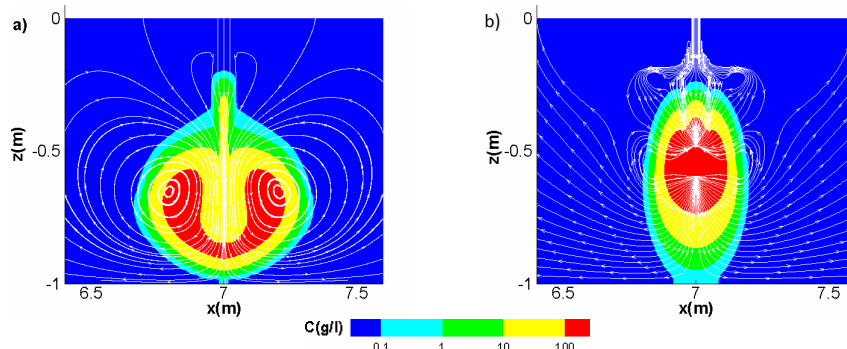


Figure 3: Simulation results for test e11: a) by two-phase approach; b) by single-phase one

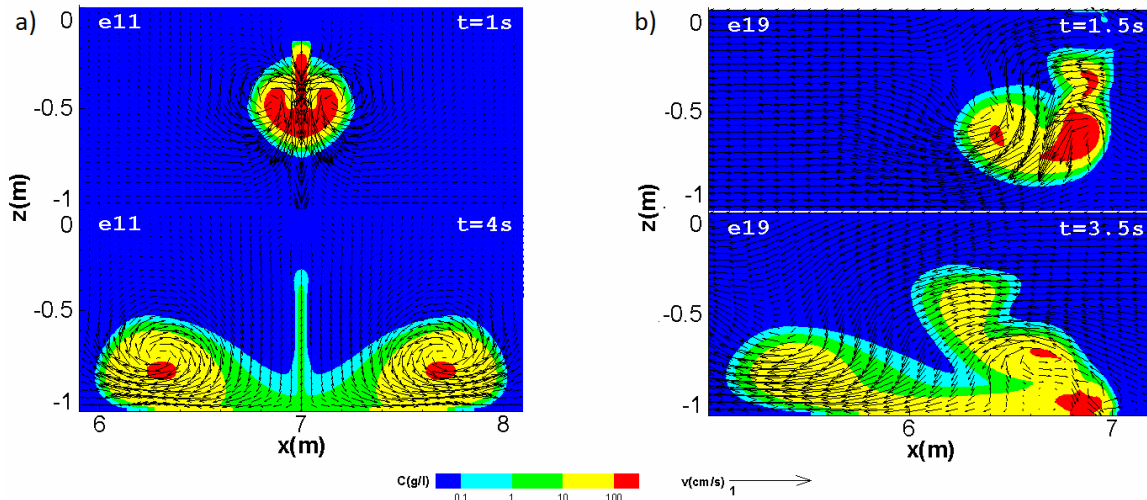


Figure 4: Development of two counter-rotating vortices: a) test e11; b) test e19: solid phase velocity.

Figure 2a presents the time evolution of the maximum radius R of the sediment cloud obtained by the two-phase model and the single-phase one, compared with the experiment [6] and the analytical solution proposed by Krishnappan [8]. Clearly, the two-phase model results are fairly in agreement with the experiment and the analytical solution, whereas the single-phase model results more and more differ the experimental values during the second half period of convective descent phase. Indeed Figure 2a shows that over this period, the single-phase model gives a radius, which is nearly constant

(≈ 18 cm). This can explain by the fact that the development of the sediment cloud in a single-phase model is only engendered by the density gradient, and no solid-fluid interaction is taken in consideration. Yet this interaction that express by the drag force is dominant in such a flow. The longitudinal profiles of vertical velocity plotted in Figure 2b show that the vertical velocity of the solid phase is always larger than the fluid phase one. Figure 3 presents the iso-value contours of sediment concentration as well as streamlines at $t=1.5$ s obtained from the two-phase model (Figure 3a) and the single-phase one (Figure 3b) for test *e11*. Obviously the two-phase model reproduces two counter-rotating vortices, which allow a full development of the sediment cloud. As the cloud grows, the surrounding water is entering inside the cloud while the iso-value contour is expanding. This illustrates that the horizontal velocity component of fluid- and solid- phase are unequal in the direction and magnitude. No counter-rotating vortices are observed in the single-phase model results. This is why the sediment cloud obtained by the single-phase model is not developed as physically expected. The experimental observations are therefore qualitatively well captured by the two-phase model.

Figure 4 presents the evolution of the sediment cloud as well as solid velocity fields in still water (Figure 4a) and in a water flow of velocity, $U_c=25$ cm/s (Figure 4b). Note that the conservation of mass in the computation domain is good enough as far as the relative error is around 0.05%.

V CONCLUSIONS

This study presents numerical simulations of dredged sediment disposal with and without ambient currents by using a two-phase flow model. This modelling well suit to such cases with fluid and solid phase velocities (all the components) differ each other in amplitude and in direction. The numerical results obtained by the model are fairly in agreement with experimental data during the convective descent phase. The formation and propagation of density current are also realistic with experiments. For the parameters remaining inaccessible from the experiment such as the concentration field, the formation of counter-rotating vortices, the influence of ambient current or particle diameter, the numerical model provides an estimate or a representation that is in qualitative accordance with other published data. The actual study deals with non-cohesive sediments. For such a case, no consolidation effect is encountered. To deal with cohesive sediment, the consolidation routine should be activated but more important is the need to account for the flocculation/deflocculation processes that should play a fundamental role in the dynamic of the system.

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