Drag on an object towed through a fluid mud layer: CFD versus experiment

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Introduction

The managing authorities of harbours and navigation ways are under increasing pressure to reduce the costs for maintenance dredging. Therefore, the Flemish Government has been investing in a unique and ambitious research programme to study the so-called *nautical bottom* problem, i.e. the search for a universal definition and a practical *in-situ* measurement technique for a (set of) parameter(s) which allows decision makers to accurately know when the passage of a ship over a mud bottom is without danger.

The traditional criterion for the nautical bottom is based on bulk density of the mud layer, because density is a characteristic which can be determined in a relatively easy way *in situ*. The typical critical value in many harbours is 1.2T/m^3, but may vary in other places. However, this criterion implicitly assumes a unique and monotonous relationship between bulk density and bulk viscosity. Rheological measurements on fluid mud have indicated that it can be characterized as a yield stress fluid, with typical visco-elastic behaviour below yield and visco-plastic behaviour above yield. However, the parameters that describe this behaviour are found to change with time. To be more precise, due to the fact that fluid mud is a gel-forming water-cohesive sediment mixture (a weak, continuous 3D network of aggregated flocs), the bonds of the floc structures may break or reform depending on the deformation history. This is called thixotropy. Consequently, there is no unique relationship between nautical resistance and bulk density.

Research

Since the actual resistance experienced by a ship manoeuvring closely above or even in contact with a fluid mud layer depends on the kinematic history the ship and deformation history of the fluid mud layer, Flanders Hydraulics Research (FHR) has decided to start a research project to investigate the ability of CFD to simulate such manoeuvres. In the present first phase, the aim is to investigate whether it is possible to simulate with a numerical model a simple experiment where an object is towed through a fluid mud layer. The water layer is omitted at this stage in order to avoid the added complexity of the problem generated by the occurrence of multi-scale turbulence phenomena in this layer, which then need to be simulated as well.

The rheological model implemented in the CFD code is a corrected version of the structural kinetics model proposed by Toorman (1997) (Toorman *et al.*, 2014; Toorman, in prep.).

For this reason a towing test facility has been designed and built at FHR, where the drag force is continuously measured on an object towed at a controlled speed (Fig. 1). These data are used to validate a numerical simulation of the experiment, fed with rheological parameters determined by a specially designed protocol, partially based on Toorman (1994), applied to samples of the fluid mud tested in a Paar-Fysica 300C rheometer (Claeys *et al.*, 2015).
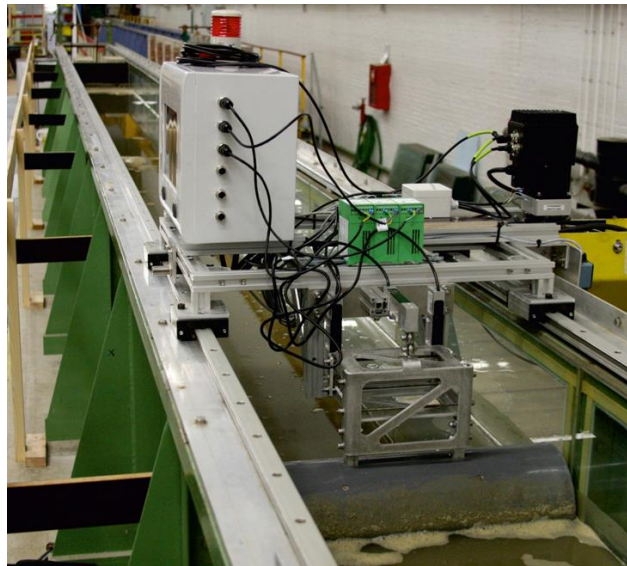
Fig. 1. Test section at Flanders Hydraulics Research showing a 0.2m diameter cylinder at rest in the test section. The cylinder can be towed at controlled speed, and horizontal and vertical forces are recorded.
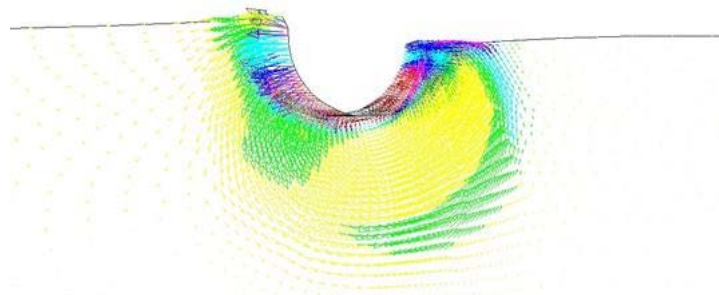

Fig. 2. Predicted flow field and free surface deformation around a 0.2m diameter cylinder, towed at a speed of 0.05m/s (to the left) through a fluid mud layer with a bulk density of 1.17T/m3 (colours represent variation in degree of structural break-down).

Results and discussion

The first towed object is a 0.2m diameter cylinder, submerged for 50%, spanning the full width of the channel (Fig. 1). This object allows a reduced 2DV model. The problem has been simulated first with the finite element FENST-2D research code from KU Leuven (Fig. 2). Since the flow field cannot be measured in the experiment, validation of the model is carried out by comparison of the drag force evolution and the deformation of the mud surface.

Subsequently, the open source OpenFOAM software will be adapted to allow full 3D simulation of the experiments. This 3D model will be used to test more complex object shapes.

Comparison of model results with experimental data will be presented at the conference.

References

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