

DEALING WITH BENTHIC HIGH-CONCENTRATED LAYERS AND FLUID MUD IN COHESIVE SEDIMENT TRANSPORT MODELLING

Erik A. Toorman^{1*} and Qilong Bi¹

¹ Hydraulics Laboratory, Civil Engineering Dept., Katholieke Universiteit Leuven,
Kasteelpark Arenberg 40 – box 2448, B-3001 Heverlee, Belgium

ABSTRACT

INTRODUCTION

Near-bottom high-concentration effects have been identified as a major source of errors in numerical sediment transport models, since the complex particle-turbulence interactions, which lead to drag modulation, are not taken into account [1]. At one hand the physical processes cannot be described exactly and at the other hand the spatial and temporal scales of these processes are too small relative to the mesh sizes and time steps used for large-scale engineering applications.

In many (mainly older) publications, these high-concentrated suspensions are not distinguished from fluid mud. Fluid mud is defined as a “fresh” (i.e. underconsolidated) cohesive sediment deposit, which concentration is above the gelling point, but low enough that the network structure can easily be broken by shear or pore pressures, such that its macroscopic flow behavior can be described as that of a thixotropic fluid. Fluid mud layers are often found in shallow areas subjected to waves or other disturbing mechanisms (e.g. ship movement) which prevent the continuous consolidation and compaction of these layers. The study of fluid mud is of particular importance for the damping of surface waves, the flow resistance of high-concentrated river flows, the definition of navigable depth and various dredging applications.

METHODOLOGY

Since the turbulence in the benthic high-concentration layer in general varies from fully-developed turbulence in the dilute outer layer to laminar at the mud bottom, the vertical mixing is determined from the solution of a low-Reynolds k - ε turbulence model, except for a layer at the bottom where a low-Reynolds mixing-length model is applied. This combination allows a solution on a coarse vertical grid.

However, for very coarse vertical grid spacing, large errors may be generated when the interpolation functions employed by the numerical method cannot be matched with the true profile shape. This happens in particular when the high-concentration layer is of subgrid scale thickness, as usually is the case. In order to minimize errors, it is necessary to apply a novel approach, more related to bed load transport modeling. In the case of the tests with the K.U.Leuven FENST-2D research code [2], which employs 2nd order finite elements, it is found necessary to compute the velocity in the near-bottom node analytically. Likewise it is necessary to compute the values of concentration, turbulence and shear stress analytically for the nodes at the interface between benthic ML model layer and the outer k - ε model layers.

The determination of the necessary analytical closures and interface conditions is far from evident. Different approaches are under investigation: theoretical derivation of equations from two-phase flow theory and semi-empirical closures using inverse modeling of data from laboratory and numerical (LES and DNS) experiments [3]. Unfortunately, by lack of adequate experimental data, it is very difficult to develop, calibrate and validate this methodology. Therefore, the development thus far is based on experimental data for non-cohesive sediments (sand).

FLUID MUD MODELLING

In the case of large scale engineering studies, where waves cannot be resolved due to the coarse horizontal grid resolution, it seems the most efficient to describe a fluid mud layer as part of the bottom model, i.e. by a (pseudo-)

poromechanic model. For this purpose, a new mud bottom model is under development which describes self-weight consolidation following Sanford's method [4], and is extended with a fluidization model to allow the effect of bed strength weakening by surface waves [5].

However, in the case of wave resolving studies, such as detailed mud-wave interaction [6, 7] and nautical bottom research, the large deformations of the fluid mud interface are best modeled by describing the fluid mud as a non-Newtonian thixotropic fluid. As long as the mud and water layers do not mix, it is the easiest to keep the layers separate and track the interface. When erosion of fluid mud is expected, one may choose to track the yield surface. In the case of gravity flow (mud density currents) the liquefied mud should be treated again as a concentrated suspension. These types of simulations have not yet been realized anywhere.

CONCLUSIONS

Progress is being made in the development of an integrative modeling framework to include high-concentration near-bottom effects and fluid mud bed response. The model will furthermore be integrated with the new flocculation model under development [8]. This should allow us to understand the persistent presence of fluid mud in front of the Belgian coast. In order to be able to validate the model in depth, new dedicated high-resolution experiments (including turbulence characteristics in high-concentrated mud suspension flow) need to be carried out.

ACKNOWLEDGEMENTS

This research has been funded in part by the K.U.Leuven Special Research Fund, the BELSPO SSD programme (QUEST4D project) and the EU FP7 programme (THESEUS and FIELD_AC projects).

REFERENCES

- [1] Toorman, E.A. (2002). Modelling of turbulent flow with cohesive sediment. In: *Proceedings in Marine Science, Vol.5: Fine Sediment Dynamics in the Marine Environment* (J.C. Winterwerp & C. Kranenburg, eds.), pp.155-169, Elsevier Science, Amsterdam.
- [2] Thong, M. (2011). Vertical grid requirements for 3D sediment transport modeling. MSc thesis, IUPWARE Programme, K.U.Leuven.
- [3] Swings, M. (2011). Bottom roughness modulation by sediment-turbulence interaction near the bed. MSc thesis, Civil Eng. Dept., K.U.Leuven (in Dutch), 83 pp.
- [4] Sanford, L. (2008). Modeling a dynamically varying mixed sediment bed with erosion, deposition, bioturbation, consolidation and armoring. *Computers and Geosciences* 34, 1263-1283.
- [5] Roels, A. (2010). Development of a dynamic morphological mud bottom model. MSc thesis, Civil Eng. Dept., K.U.Leuven (in Dutch), 100 pp.
- [6] Toorman, E.A. (2008). An investigation into the thixotropic wave dissipation potential of fluid mud. *AGU Chapman Conference on Physics of Wave-Mud Interaction* (Amelia Island, Florida, November 2008). Book of Abstracts, p.24.
- [7] Villaroel, A. (2009). Flow modeling of fluid mud. MSc thesis, Civil Eng. Dept., K.U.Leuven (in Dutch), 82 pp.
- [8] Lee, B.J, E. Toorman, E. Toorman, M. Fettweis, J. Wang and Qilong Bi (2011). 1-Dimensional vertical simulation of bimodal flocculation dynamics in a turbulent flow field of a coastal zone. Abstract ACOMEN'11 (Liège, November 2011).