O1043 - A MODIFIED K ε TURBULENCE MODEL FOR COHESIVE SEDIMENT TRANSPORT WITH A FLUID MUD LAYER

Mud Rheology and Fluid Mud

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Abstract

When a hyperconcentrated fluid mud layer (defined as having a bulk density above the gelling point) is present on the seabed or the bottom of a channel, the generation of turbulence by shear flow cannot properly be modelled with a standard turbulence model (like *k-epsilon*) because the growth of turbulent eddies in inhibited by the multitude of sediments in hyperconcentrated conditions just above the bed and the large amount of energy required to transport the particles is no longer available to turbulence production. This mechanism of turbulence damping is most clearly observed in the data from the flume experiments with sand by Cellino (1998).

In the present study the k-epsilon turbulence model is chosen, being the most commonly used turbulence model for vertical mixing in coastal engineering. The proposed method is designed for sediment transport models based on mixture theory. Two major modifications are needed:

1) the fluid viscosity should be replaced by the effective viscosity of the mud suspension or fluid mud, and
2) low-Reynolds damping functions to generate proper values of turbulent kinetic energy (TKE = k) and turbulent dissipation rate (TDR = ε) in the inner boundary layer, where the standard model fails since turbulence is no-longer fully developed here.

The analysis of data from new dedicated experiments in a rotational rheometer with vane spindle strongly supports the hypothesis that the equilibrium flow curve for fluid mud is well described by a perfect Bingham model in the laminar flow regime. The parameters of the rheological model are empirically related to the sediment concentration. The experimental data from Celino (1998) for sand give further insight how a non-Newtonian suspension generates additional granular stresses in the transient regime. These concepts are combined to develop a closure for the effective viscosity of the sediment-water mixture, additionally making use of the insights from a newly developed hybrid mixture/two-phase flow model in OpenFOAM, which is used as a numerical laboratory (Ouda & Toorman, 2019).

Low-Reynolds damping functions have been derived from DNS data for smooth-wall turbulence as a function of non-dimensional wall-distance. By rescaling the non-dimensional wall coordinate ($z_+ = zu_*/\nu$) and the model constants with the effective (non-Newtonian) mixture viscosity, similar damping functions can be used for fluid mud as for clear water. Based on these modifications, the law of the wall is also corrected to define proper near-bottom boundary conditions in the case of coarse vertical meshes.

Both types of closures are implemented in a 1DV model for steady uniform open-channel flow, where the turbulence model is implemented in a similar way as in the well-known GOTM model (Umlauf et al., 2007). Equilibrium concentration profiles are computed for various steady shear velocities. By lack of data for experiments with cohesive sediments, the methodology is validated with Cellino's (1998) flume data for high-concentrated sand transport.

In addition, attention has been payed to improving the accuracy of the numerical implementation of the turbulence equations. The high non-linearity of the two turbulence variables, approximated (most commonly) by linear interpolation functions between neighbouring grid points, can induce large deviations and errors, in particular in the last grid cell near the bottom. This has large consequences regarding the accuracy of both hydrodynamics and sediment transport. Moreover, this problem has been found to be mesh dependent. Therefore, the near-wall boundary conditions are redefined to minimize the errors. The alternative conditions are based on three criteria: conservation of flux and correct values of wall shear stress and near-wall TKE (i.e. correct force and energy balance). Moreover, the TKE production term is also discretized in an alternative, more accurate way.

The method is tested on different vertical mesh resolutions: a high-resolution mesh to resolve not only the fully-developed outer layer, but also the inner layer all the way down to the immobile bed, and coarse resolution meshes to define minimal requirements for large-scale 3D simulations which are expensive because of their large horizontal domain scale.

The modified numerical formulation has been tested in the 1DV model, before being implemented and tested into the TELEMAC3D code.

The methodology is then further extended for the case where the fluid mud layer thickness is smaller than the vertical mesh size. In this case the fluid mud flow is a subgrid scale phenomenon. A method is being designed to describe fluid mud flow as a bed load transport formula, which provides also the near-bed reference concentration for the resolved suspension flow in the outer layer.

References

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