Numerical modelling of sediment transport with OpenFOAM for very shallow foreshores

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BACKGROUND AND OBJECTIVES

At the Belgian coast, a very typical cross-section can be found: a mildly sloped beach in front of a dike with a promenade and an almost continuous line of high rise buildings.

Coastal safety against flooding is provided by a hard dike structure, fronted by a nourished beach and a storm wall on the crest of the dike.

These coastal defense measures are designed according to the Master Plan Coastal Safety [2], which prescribes the use of the traditional EurOtop [3] prediction formulae to quantify wave overtopping volumes. However, these formulae are too conservative for the typical Belgian cross-section. Assumptions have to be made regarding for example the wave boundary conditions and the geometry. Furthermore, the effect of long waves, directional spreading, oblique waves and dynamic beach profiles are not taken into account.

Within CREST, less conservative and more accurate modelling tools are being developed for calculating wave loading forces and wave overtopping. This research focusses on the influence of sediment transport and the related changing beach morphodynamics on overtopping and wave loading.

NUMERICAL MODEL

A numerical (2DV) model employing OpenFOAM [4] code is being developed, wherein:

- The Reynolds-averaged Navier-Stokes equations are solved: flow is resolved over the complete water depth and modelling of complex overtopped flow is allowed.
- A sediment transport module is incorporated to capture bed load, suspended load transport and changing beach morphodynamics.

Suspended load transport is modelled by a traditional convection-diffusion equation:

$$\frac{\partial c}{\partial t} + \nabla.(\mathbf{U} - \mathbf{w_s})c = \nabla.(\nu_t \nabla c)$$

with c the sediment concentration, $\boldsymbol{w_s}$ the sediment fall velocity vector and ν_t the sediment diffusivity.

The bed load transport rate in different directions is given by:

$$\boldsymbol{q}_B = q_0 \frac{\boldsymbol{\tau_B}}{|\boldsymbol{\tau_B}|} - C|q_0|\nabla\eta$$

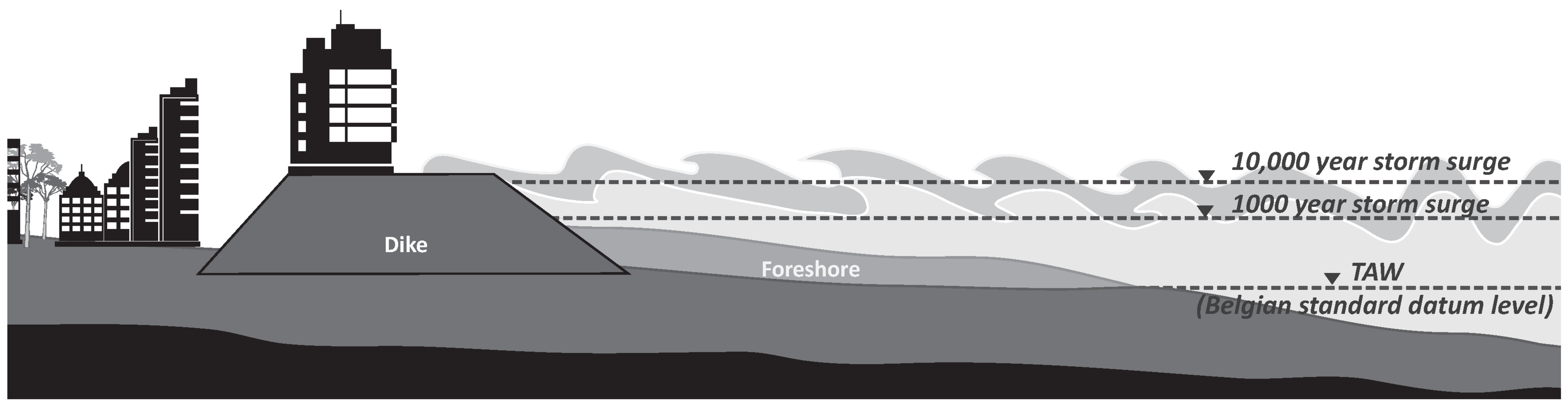
where η is the bed elevation, C a constant to reflect the slope effect on the sediment flux (value between 1.5 and 2.3), q_0 the total bed load calculated with an empirical formula and $\boldsymbol{\tau}_B$ the bed shear stress.

The bed elevation is determined with the Exner equation:

$$\frac{\partial \eta}{\partial t} = \frac{1}{1-n}(\nabla.\boldsymbol{q}_B + D - E)$$

Where D represents the deposition flux, E the entrainment flux and n the porosity.

The bed elevation is taken into account by a moving mesh approach.

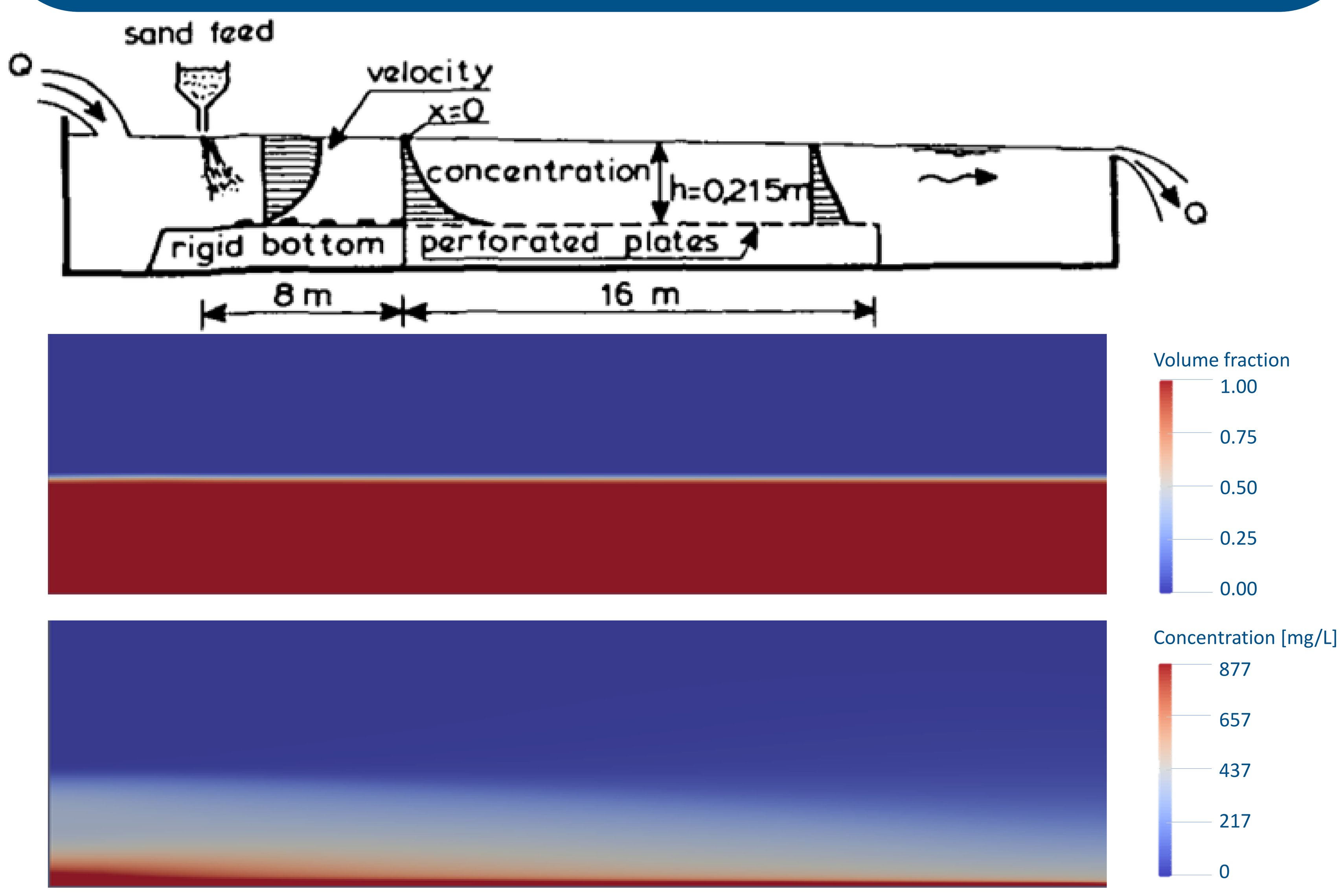


Typical cross – section at the Belgian coast [1].

Snapshot of an OpenFOAM result of wave propagation on a sloping beach with a dike and a wall (air: blue, water: red, beach + dike + wall: grey).

VALIDATION BY EXPERIMENTS

The experiment of Ribberink and Wang [5] has been simulated to validate the suspended load module. In this experiment, deposition in a straight channel is simulated. Entrainment of the sediment is not possible due to the perforated plates. In the numerical simulation, a concentration profile is imposed at the inlet boundary based on the experimental data. Concentration profiles at several locations are compared with experimental data (work in progress).



Experiment of Ribberink and Wang [5]. The upper figure shows a definition sketch. The middle figure shows the volume fraction (air: blue, water: red). The lower figure shows the suspended sediment concentration.

ACKNOWLEDGEMENTS & REFERENCES

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