CAN BETTER TURBULENT MIXING REDUCE DENSITY INDUCED SHIP FORCES DURING LOCKAGE?

by

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EXTENDED ABSTRACT

For navigation locks, the forces on moored ships during the lockage are a most relevant design criterion, as they are a measure for the safety of the ships during the locking process. In most cases, these forces are controlled by the choice of the filling system and by the valve schedules. For locks at the boundary between fresh and saltwater regions, the situation differs significantly from locks with the constant water density. While more complex filling systems (longitudinal culverts, pressure chamber under the lock chamber etc.) are rather robust in terms of the impact of density differences, through-the-head systems show a significant impact of the density induced currents on the vessel. In order to evaluate the impact of the turbulent mixing at the lock head on the density induced forces, a numerical model was set up. The model and first results are presented here.

For the new lock of Brunsbüttel at the Kiel-Canal, a major sea lock with a chamber length of 360 m and a design ship size of ~40000 t, physical mode tests were performed. The lock model was built with a scale of 1:47 and was operated with fresh water in order to test the lock performance. Later these tests complemented by further numerical tests, which additionally included the impact of salinity. The numerical tests were performed on the basis of the software package OpenFOAM®. The solver “interDymFoam” was used. It is suitable for moving objects in a two-fluid environment and is based on the Volume of Fluid method (VOF). The solver was enhanced by a transport equation for the “increase of density by salt” *c* in (1). The diffusion coefficient *D* was assumed to be a function of the turbulent viscosity. A density coupling was incorporated in the computation of the mixture density ρ_m from the water content α in (2).

$$\frac{\partial c}{\partial t} + \vec{\nabla}(c\vec{u}) - \vec{\nabla}\left(D\,\vec{\nabla}c\right) = 0 \tag{1}$$

$$\rho_m = \alpha \cdot \rho_{freshwater} + (1-\alpha)\cdot \rho_{air} + c \tag{2}$$

With this enhanced numerical model, the lock of Brunsbüttel was investigated. The models included moving valves and a moving vessel with six degrees of freedom, held in position by a set of three springs which resembled the mooring line system. The turbulence was computed on the basis of a Large Eddy Simulation (LES), using a k-equation subgrid-scale turbulence model. After this model was set up, the freshwater investigations of the physical model were repeated and later additional tests with the brackish water conditions at the river Elbe were performed. It was shown that for the brackish water of the Elbe the density impact on the vessel is rather small. Later, in a more general test series, the impact of higher salt contents and different geometries was tested.

In total, three different geometry variants (straight culverts with sills for the valves; culverts with horizontal breaker bars; culverts with vertical breaker bars, see also Figure 1) were tested for three hydraulic set ups (fresh water inside the lock chamber and fresh water outside; salt water inside and fresh water outside; fresh water inside and salt water outside). Additionally to those nine base cases the impact of different valve schedules and of variations in the spring system were tested, too. The computations have proven to be quite cumbersome, as the computation times are rather long (several days on a cluster system for each case) and the computations required substantial effort to achieve stability.

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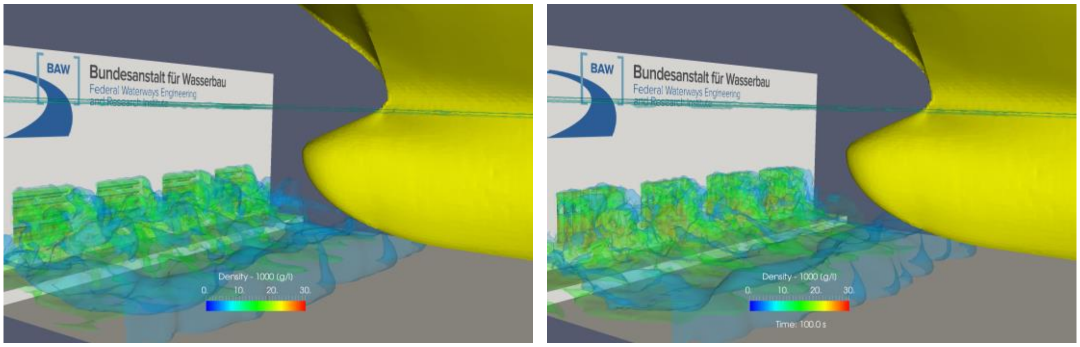

Figure 1: Salt water entering the model with horizontal breaker bars (left) and vertical breaker bars (right). The bow of the vessel is visible in yellow.

A special focus was put on the density induced currents and finally the forces on the vessel. Figure 1 shows the spreading of salt in the chamber for the breaker bar configurations. The momentum of the flow is not sufficient to mix the density layer. Figure 2 shows the recorded forces for the scenarios with horizontal breaker bars. It is obvious, that the filling system operates nicely for the situation with fresh water inside and outside the lock. But with saline water outside the lock, the ship forces increase significantly.

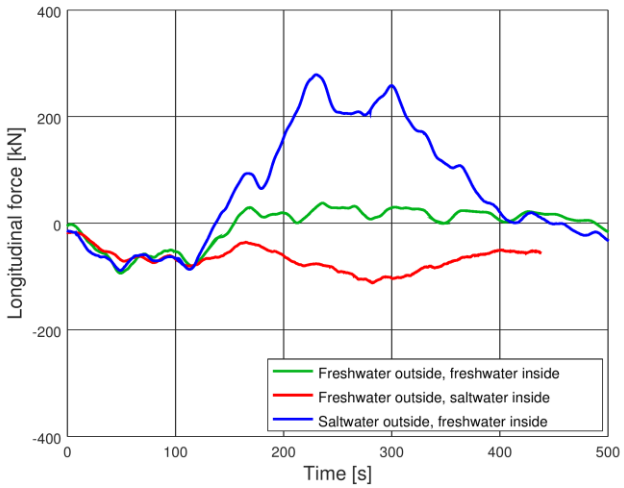

Figure 2: Impact of density driven flow on the longitudinal ship forces for the “horizontal breaker bars”configuration

The goal was to test whether the mixing process induced by the energy dissipation of the filling system significantly decreases the density induced ship forces. This proved to be difficult to analyze, because the hydraulic performance of the different geometries resulted in differing flow rates for the same valve schedules. This made further adjustments necessary. It was decided to operate the test cases without breaker bars with slower valve schedules, in order to achieve global filling dynamics similar to the cases with breaker bars. At the time of writing, these additional computations were not finished yet. But already the prior computations lead to the conclusion, that the breaker bar systems work well for the situation with similar water densities inside and outside the lock. The forces acting on the vessel from the decrease of momentum are small and the forces are governed by the surge wave from the valve opening. But for the situations with significant density differences, the forces in these configurations increase significantly. Thus, the breaker bars help only a little to decrease the ship forces in comparison to the simple straight culverts with properly adapted valve schedules. As conclusion it can be derived, that more complex filling systems are necessary to significantly decrease the forces induced by fluid density differences.