Study of turbulent structures across surge waves

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Abstract

Methods

InterFoam solver is utilized to simulate effectively the turbulent nature of surge waves. This solver uses volume of fluid method to capture the nature of two-phase flow. Two different turbulent models are implemented: 2-equation Reynolds Averaged Navier-Stokes (RANS), $k-\varepsilon$, and Large Eddy Simulation (LES) using Smagorinsky sub-grid scale viscosity. In order to incorporate the impact of turbulent fluctuations in air-entrainment at the interface of two fluid for the $k-\varepsilon$, a source term is added to the phase equation based on Hirt (2003):

$$\frac{\partial \alpha_l}{\partial t} + \nabla \cdot (\alpha_l \boldsymbol{u}) + \nabla \cdot [\boldsymbol{u_c} \alpha_l (1-\alpha_l)] = \frac{\delta V}{\delta t} * \left(\frac{1}{V_{cell}}\right).$$

Where α_l is the water phase, $\boldsymbol{u}$ is the velocity vector, $\boldsymbol{u_c}$ is the relative velocity, V is air volume , and V_{cell} is cell volume.

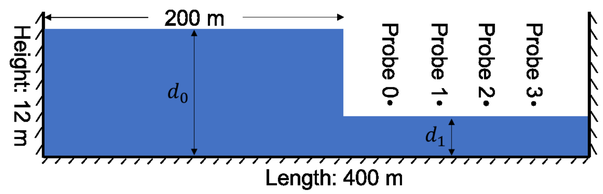

Figure 1: The schematic of the computational domain. Points 0 to 3 are evenly distributed downstream of the gate at every 30 meters.

Results

The simulation presented here is conducted for reservoir depth, $d_0 = 10\ m$, downstream depth, $d_1 = 2\ m$, where gate is located at $x = 200\ m$.

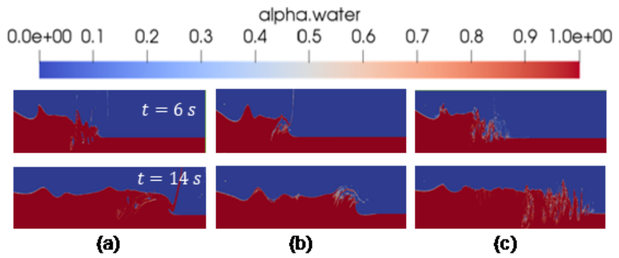

Figure 2: Phase distribution at $t = 6$ and $14\ s$ for surge wave Froude number, $Fr_s = c/\sqrt{gd_1} = 2.12$, where c is surge wave's celerity. (a) $k-\varepsilon$ without source, (b) $k-\varepsilon$ with source, (c) LES.

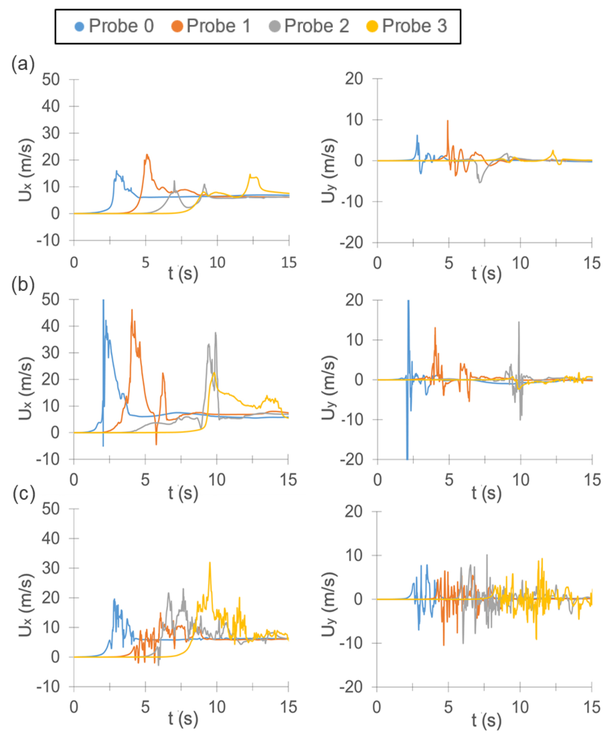

Figure 3: Time series of longitudinal velocity, U_x and vertical velocity, U_y from $t = 0$ to $15\ s$, $Fr_s = 2.12$, (a) $k-\varepsilon$ without source, (b) $k-\varepsilon$ with source, (c) LES.

Conclusions

As demonstrated in Figure 2(b), adding the air source term to the $k-\varepsilon$ model, created the entrapment of finer air pockets at the interface. Furthermore, large scale air pockets are observed in Figure 2(a) which are no longer visible with implementation of source term in Figure 2(b). LES model, as it captures larger than grid-scale fluctuations, generates the most air entrainment behind the surge front. U_x and U_y plots across points 0 to 3 identify the arrival of surge waves. For point 0 one peak only exists for U_x in all three models, however, for points 1, 2 and 3 a secondary peak appears except for point 1 in model (a). LES model compared to $k-\varepsilon$ generates detailed fluctuations, but follows peak trends observed in $k-\varepsilon$. Adding the air source term, however, significantly impacts the results. Since three models generate different flow patterns, it is essential to validate them with available experimental data and select the most suitable model for the research.

Bibliography

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