Simulating the interaction between waves and a fixed rectangle with OpenFOAM

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Introduction

The interaction between waves and structures is always a hot topic for researchers. Wave passed through a fixed rectangle, based on VOF method to track the free surface, using the open source computational fluid dynamics solver OpenFOAM had been simulated and validated in both two dimensional and three dimensional in this paper. The nonlinear (NL) k-ε turbulence model was established to solve the incompressible Reynolds-Average Navier-Stokes equation. The results show that OpenFOAM can be used to simulate the interaction between waves and structure.

Governing Equations

Continuity equation

$$\nabla \cdot u = 0$$

Navier-Stokes equation

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot [\rho \boldsymbol{u}\boldsymbol{u}^{\mathrm{T}}] = -\nabla p^{*} - \boldsymbol{g} \cdot \boldsymbol{x} \nabla \rho + \nabla \cdot [\mu \nabla \boldsymbol{u} + \rho \tau_{\mathrm{NL}}] + \sigma_{\mathrm{T}} \kappa_{\alpha} \nabla \alpha$$

k equation

$$\frac{\partial \rho k}{\partial t} + \nabla \cdot (\rho u k) = \nabla \left[\rho \left(\nu + \frac{\mu_t}{\sigma_k} \right) \nabla k \right] + \rho (P_k - \varepsilon)$$

ε equation

$$\frac{\partial \rho \varepsilon}{\partial t} + \nabla \cdot (\rho u \varepsilon) = \nabla \left[\rho \left(\nu + \frac{\mu_{\mathrm{t}}}{\sigma_{\varepsilon}} \right) \nabla \varepsilon \right] + \rho \left(C_1 \frac{\varepsilon}{k} P_{\mathrm{k}} - C_2 \frac{\varepsilon^2}{k} \right)$$

Transport equation for α

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (u\alpha) + \nabla [u_r \alpha (1 - \alpha)] = 0$$

Conclusions

This study focuses on the interaction between wave and a fixed rectangle. In this paper, both two-dimensional and three-dimensional cases are given to study the elevations of wave surface and the distribution of forces. The numerical model solve the incompressible Navier-Stokes equations in combination with VOF method, which is based on an open source CFD toolbox OpenFOAM. And NLk-ε turbulence model is also adopted. Not only the elevations of free surface and forces on rectangle, but also the complex flow field evolution process are given. The results show that the model in OpenFOAM can simulate wave field with a fixed rectangle accuracy.

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Results

Solitary past a fixe rectangle of different depths

η_0=0.1m *Water depth*: 1.0m

Rectangle: 0.5m*0.6m *and its front face is deployed at x=30m*

Submerged case: *still water depth above the obstacle is 0.4m;*

Immersed case: *the still water depth above the obstacle to be 0.25m;*

Floating case: *the obstacle is lifted 0.2m above the still water level.*

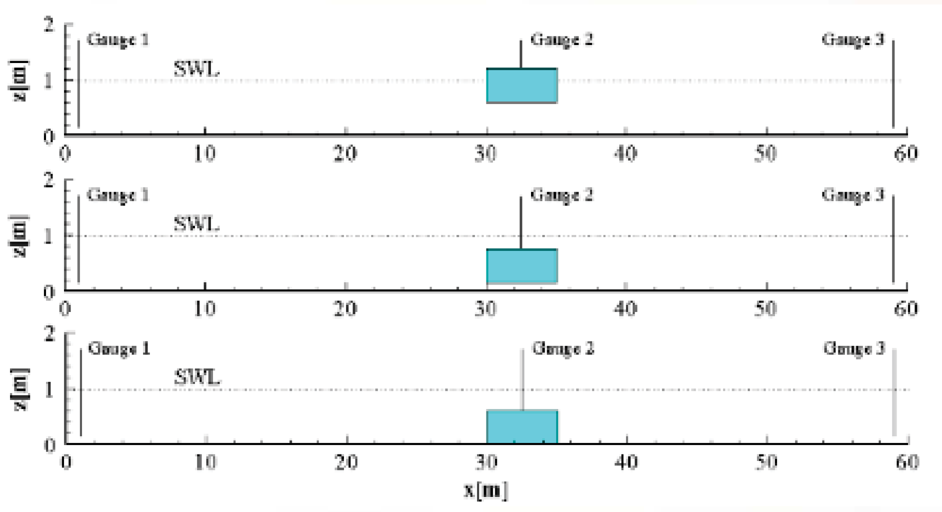

Figure 1 Schematic illustration of a solitary past a submerged, immersed, or floating rectangle

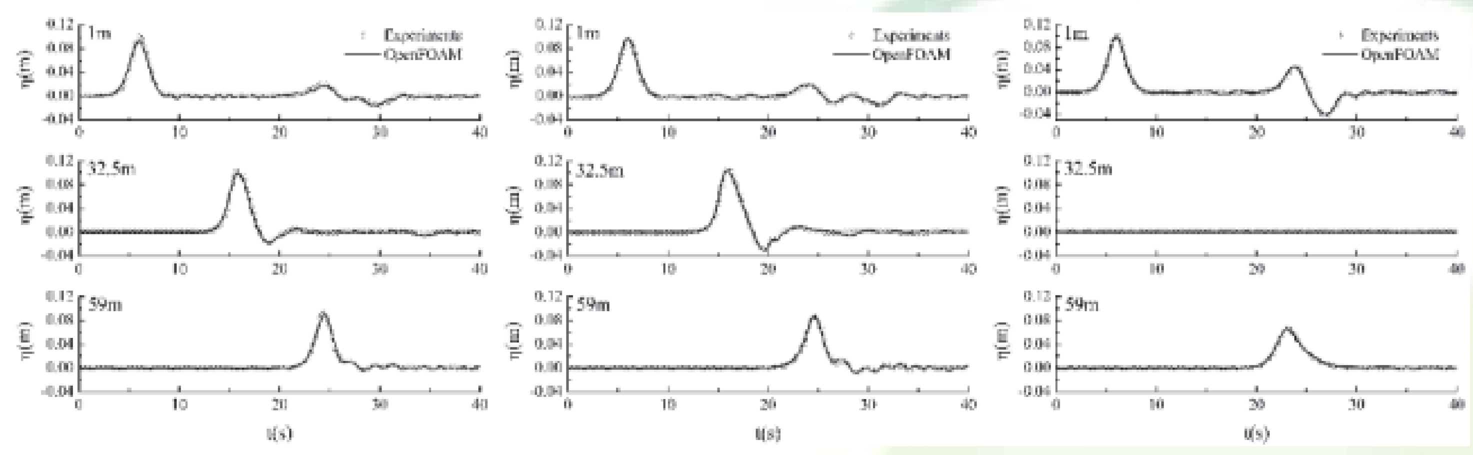

Figure 2 The comparisons of time histories of free surface displacement at x = 1 m, 32.5 m and 59 m between experiments and OpenFOAM (left panel: submerged; middle panel: immersed; right panel: floating)

Figure 3 Temporal and spatial variations for the velocity field calculated using numerical mode (left panel: submerged; middle panel: immersed; right panel: floating)

Regular wave past an immersed rectangle

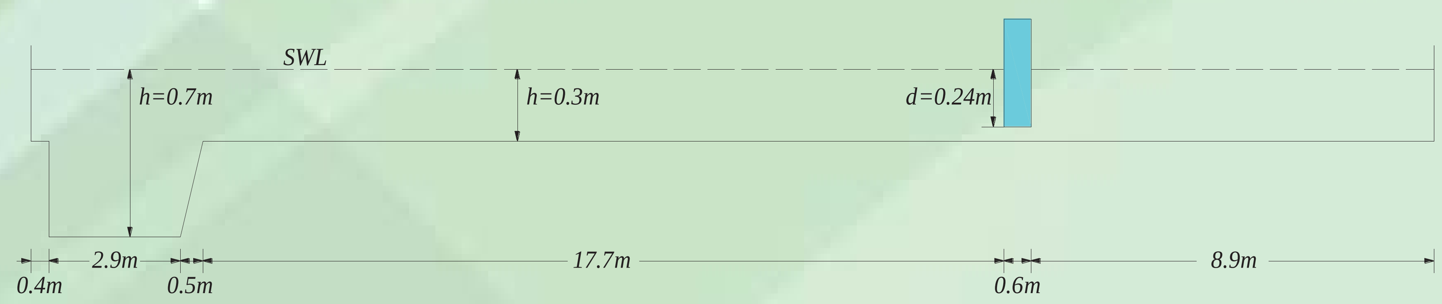

Figure 4 Schematic illustration of a regular wave past an immersed rectangle

Wave tank wide: 14m

Rectangle:

Width B=2m,

Length L=0.6m,

Height H=0.45m

Draft 0.24m

Mid-point coordinates of rectangle was (21.8m, 7m)[9]

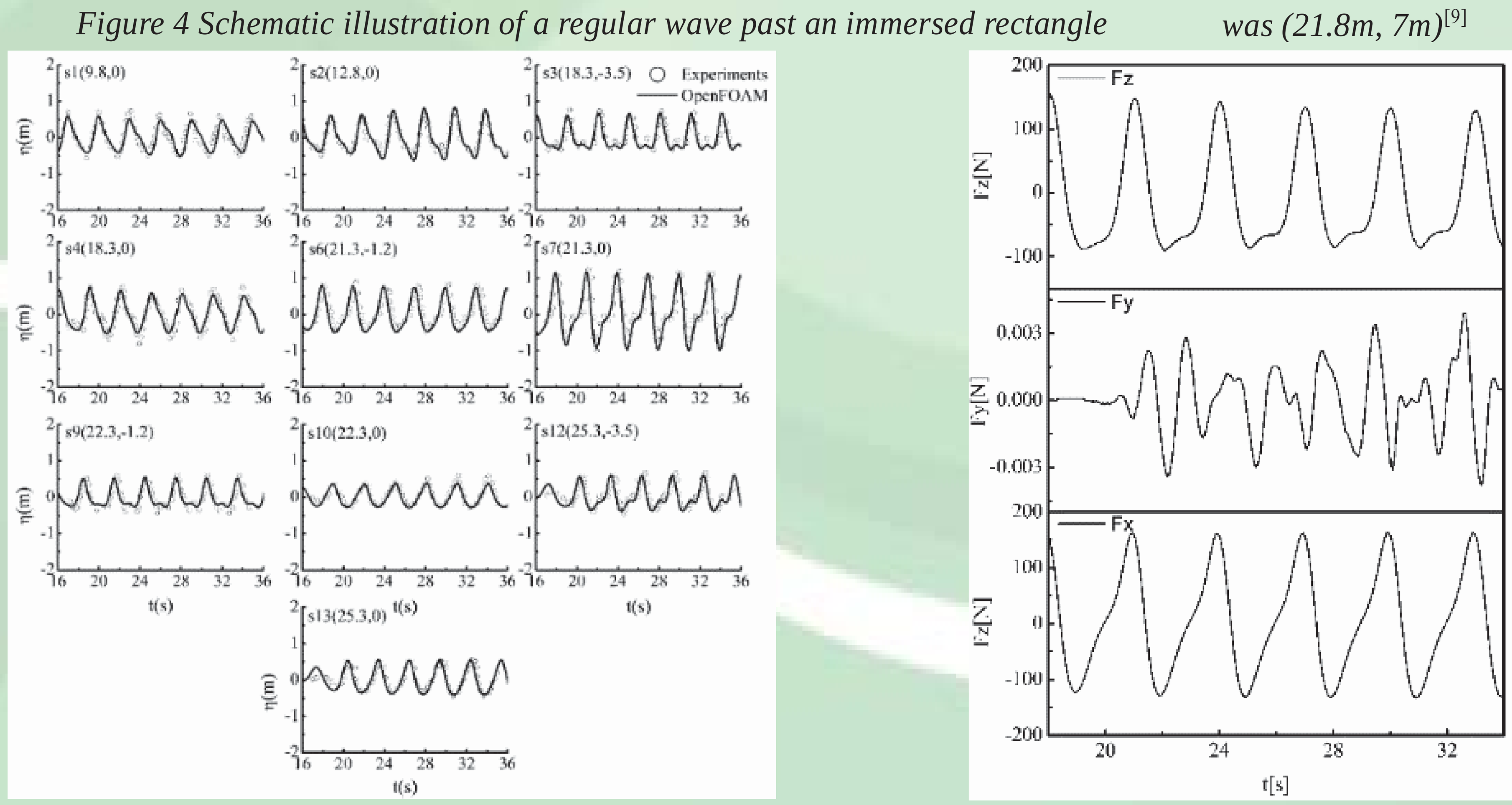

Figure 5 Time series of wave elevations (left panel) and forces on rectangle (right panel)