

DECIDING OPTIMAL PARAMETER FOR INTERNAL WAVEMAKER USING COUPLING OF DAKOTA AND OPENFOAM

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In order to generate a water wave adequately in numerical simulation, several specialized techniques have been developed: internal wavemaker, static boundary method and moving boundary method. For internal wavemaker, especially, geometry of mass source region needs to be decided minimizing numerical error. Chen and Hsiao [1] suggested the method to set the dimension of wavemaker, deriving height from linear wave theory and constructing empirical formula about wavenumber and width of wavemaker, with FLOW-3D code. The procedure, however, required hundreds of trial calculations, followed by excessive computational cost. In this paper, automated process to find optimal geometry for given relative water depth is proposed, introducing coupling of DAKOTA and OpenFOAM. The waves2Foam utility had been modified to simulate the generation of second-order stokes wave and linked with DAKOTA to control the input file and observe the output file.

The continuity equation and the Navier-stokes equation were adopted as governing equation to describe incompressible viscous flow. The continuity equation which includes wavemaker as following:

$$\nabla \cdot \vec{\mathbf{U}} = \begin{cases} s(t) & \text{for } \vec{x} \in \Omega \\ 0 & \text{for } \vec{x} \notin \Omega \end{cases} \quad (1)$$

$$s(t) = \frac{2C\eta W}{l_x l_y l_z} \quad (2)$$

where $\vec{\mathbf{U}}$ is velocity vector of flow, $s(t)$ represents mass source function for corresponding target wave and Ω is mass source region. The mass source function is defined in the form of (2), where C is phase velocity, η is surface elevation, W is width along span and l represents the dimension of mass source region in each direction.

The momentum equation for incompressible viscous flow can be written as following:

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla \cdot (\rho \mathbf{U} \mathbf{U}^T) = -\nabla p + \nabla \cdot \mathbf{T} + \rho \mathbf{f}_b \quad (3)$$

where p is pressure, \mathbf{T} is viscous stress tensor and \mathbf{f}_b is body force vector. In the momentum equation, velocity and pressure are calculated using PIMPLE algorithm of OpenFOAM. The water surface elevation was tracked using volume of fluid scheme, represented as following:

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha \mathbf{U}) = 0 \quad (4)$$

$$\rho = \rho_l \alpha + \rho_g (1 - \alpha) \quad (5)$$

$$\mu = \mu_l \alpha + \mu_g (1 - \alpha) \quad (6)$$

Where α represents specific volume of fluid and subscript l and g indicates liquid and gas respectively.

The regular 3D wave was generated with following mass source function.

$$s_x(x, t) = \frac{2C \sin H}{l_y l_z} \frac{1}{2} \sin((k \cos \theta) |x - x_c| - wt) \quad (7)$$

$$s_y(y, t) = \frac{2C \cos H}{l_x l_z} \frac{1}{2} \sin((k \sin \theta) |y - y_c| - wt) \quad (8)$$

In order to exclude effect of unwanted reflection wave from boundary, numerical sponge layer is allocated to the edge of computational domain. In the sponge layer, the following additive term is implemented to momentum equation, dissipating kinetic energy of fluid.

$$D_x = \theta_{xy} \sqrt{\frac{g}{h}} (N + 1) \left(\frac{\max(|x-x_0|, |y-y_0|)}{l} \right)^N \quad (9)$$

$$D_y = \theta_{xy} \sqrt{\frac{g}{h}} (N + 1) \left(\frac{\max(|x-x_0|, |y-y_0|)}{l} \right)^N \quad (10)$$

$$D_z = \theta_z \sqrt{\frac{g}{h}} (N + 1) \left(\frac{\max(|x-x_0|, |y-y_0|)}{l} \right)^N \quad (11)$$

The parameter x_0, y_0 indicate the starting position of sponge layer, while N and θ are adjusted for intensity of dissipation.

The schematic design of numerical setup and an example of calculated surface elevation are shown in figure 1 and 2 respectively.

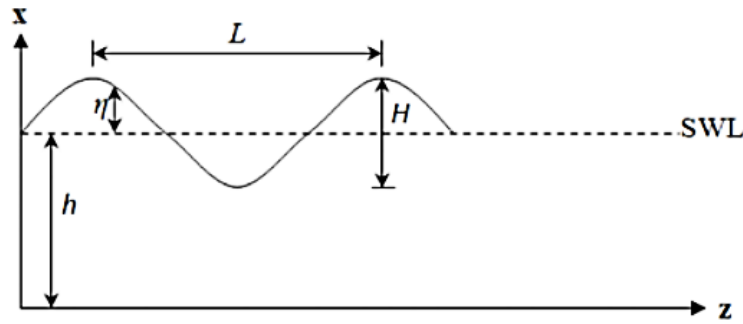


Figure 1: Schematic drawing of computational domain

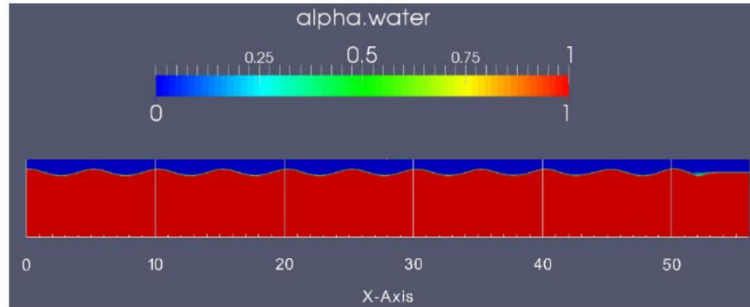


Figure 2: Example of visualized surface elevation by numerically generated wave

The numerical model is validated comparing generated wave and expected target wave, computing root-mean-square error between them with following formula, where N is the number of observation point.

$$\text{RMS} = \frac{1}{\eta_{ref,max} - \eta_{ref,min}} \sqrt{\frac{\sum_{i=1}^N (\eta_{ref,i} - \eta_{m,i})^2}{N}} \quad (12)$$

For coupling of DAKOTA and OpenFOAM, the input and output files of OpenFOAM solver was directly connected to DAKOTA, regarding OpenFOAM as block-box. DAKOTA directly control the file 'waveProperties.input', which define the parameters for wave generation in mass source region. The result of calculation is evaluated with the output file, 'surfaceElevation.dat', which contains surface elevation by numerically generated wave according to time. The calculation is started with trial parameters and automatically repeated until optimal parameters were found by DAKOTA, using its own optimization algorithm. The overall routine is described in Figure 3.

The modified OpenFOAM solver with mass source function, numerical sponge layer, and DAKOTA optimization successfully generated target waves, finding optimal geometry of mass source region with fewer trial calculation and computational cost.

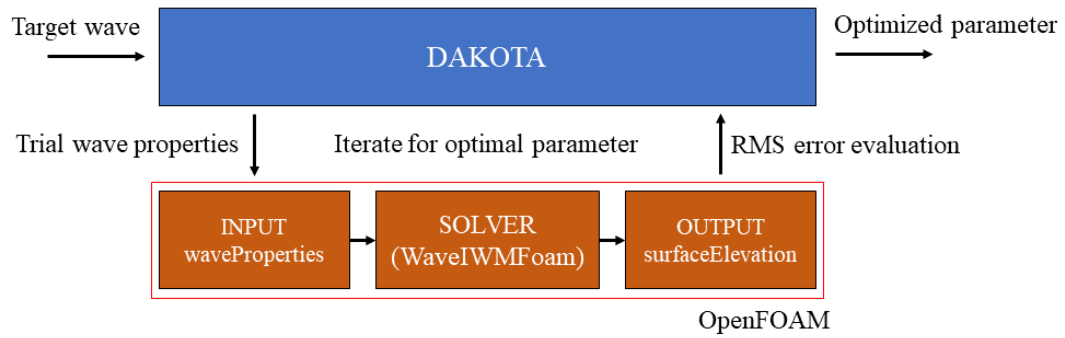


Figure 3: Parameter optimization routine for coupling DAKOTA and OpenFOAM

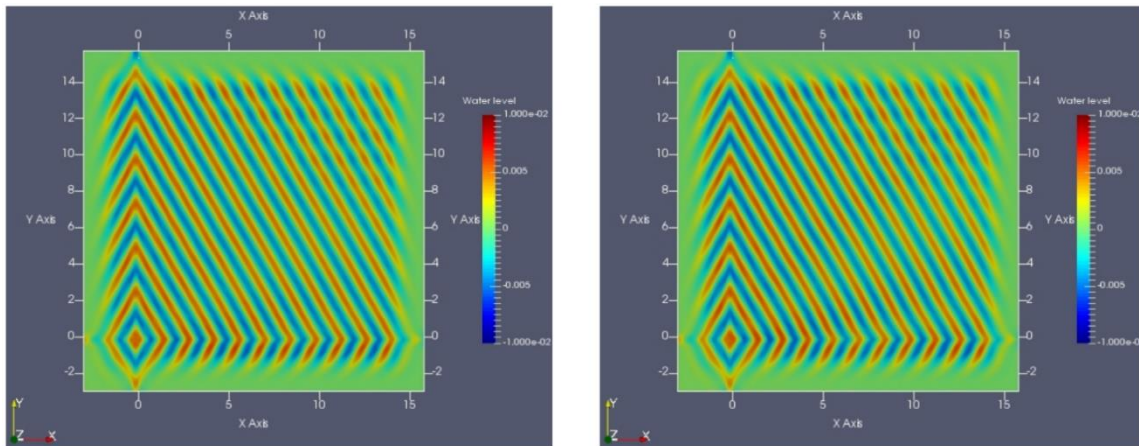


Figure 4: Surface elevation by directional Stokes 2nd wave at 30T(left) and 60T(right)

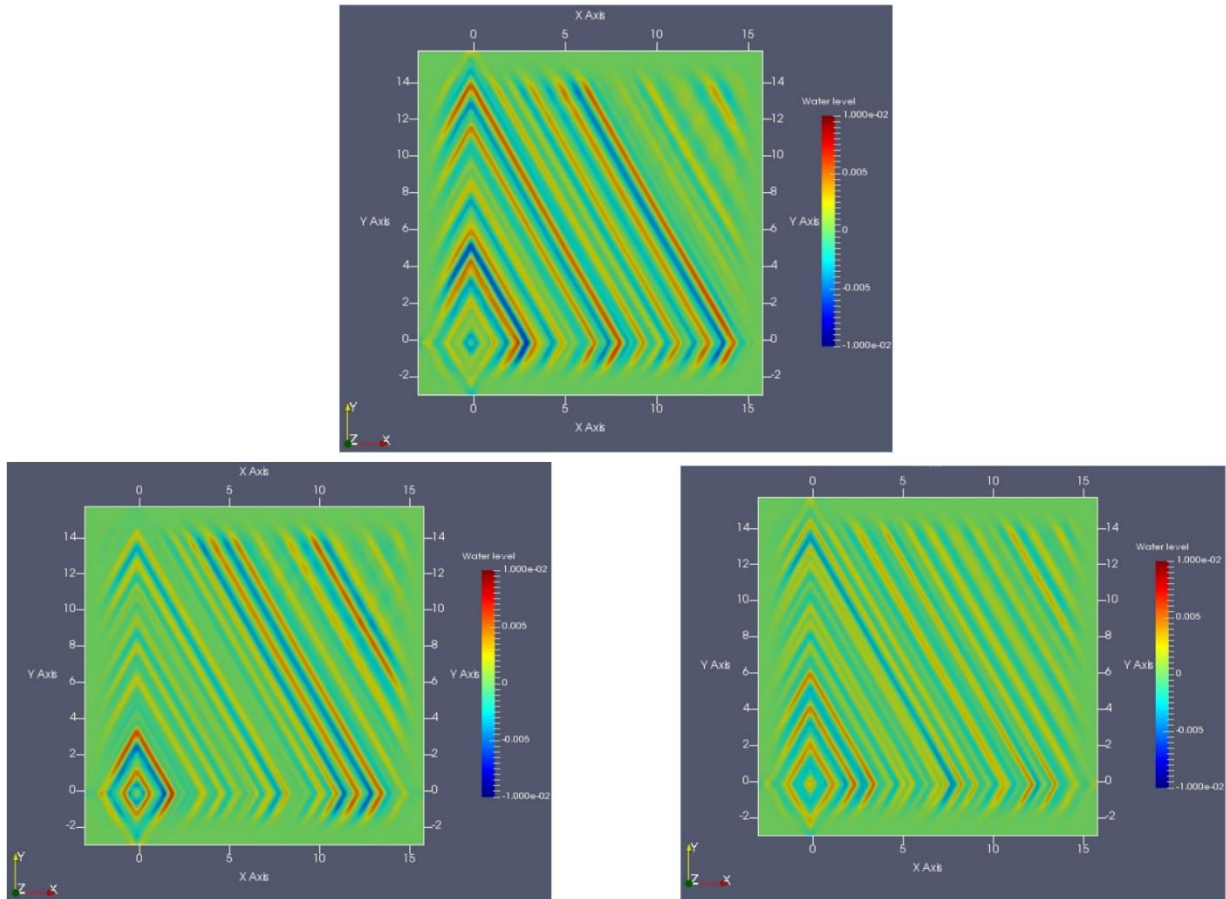


Figure 5: Surface elevation by TMA spectrum at t=30T(up), 40T(left) and 60T(right)

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