Nonlinear Potential Flow Solver Development in OpenFOAM

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Plymouth University, UK

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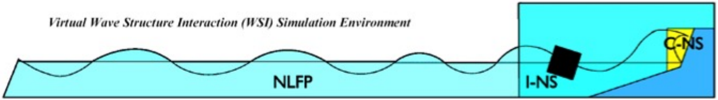
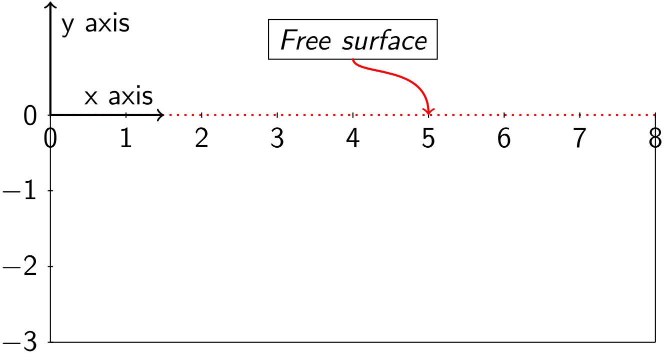
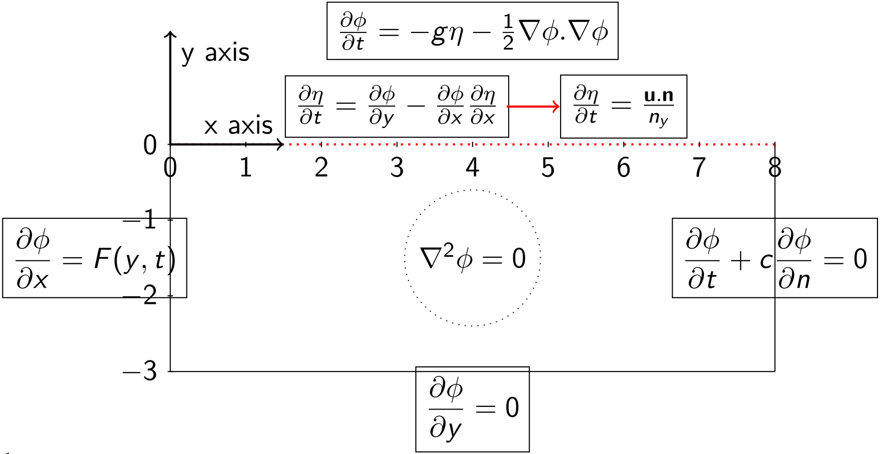
Wave Structure Interaction Simulation Environment



Wave Tank



Mathematical Formulation



$$\frac{\partial \phi}{\partial t} = -g\eta - \frac{1}{2}\nabla\phi.\nabla\phi$$

$$\frac{\partial \eta}{\partial t} = \frac{\partial \phi}{\partial y} - \frac{\partial \phi}{\partial x}\frac{\partial \eta}{\partial x} \longrightarrow \frac{\partial \eta}{\partial t} = \frac{\mathbf{u.n}}{n_y}$$

$$\frac{\partial \phi}{\partial x} = F(y,t)$$

$$\nabla^2\phi = 0$$

$$\frac{\partial \phi}{\partial t} + c\frac{\partial \phi}{\partial n} = 0$$

$$\frac{\partial \phi}{\partial y} = 0$$

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[1] Mayer, S, Garapon, A and Sorensen, LS (1998). “A fractional step method for unsteady free surface flow with applications to non-linear wave dynamics,” *Intl J Numerical Methods in Fluids*, 28(2), 293–315

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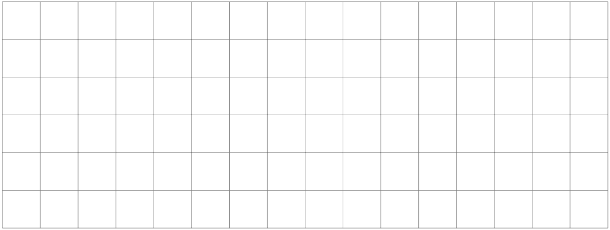
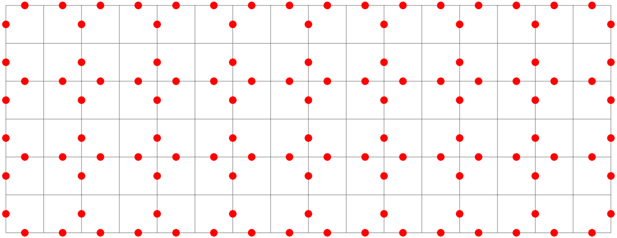
Generate the grid

- Generate the grid



Apply the boundary conditions

- Apply the boundary conditions at the face center



Solve Laplace's equation

- Solve Laplace's equation for the velocity potential.
- Compute the required variables (i.e., velocities $\mathbf{u} = \nabla\phi$, fluxes).

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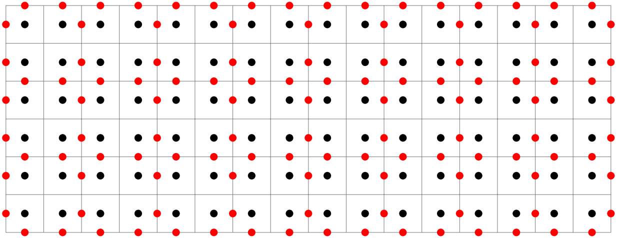
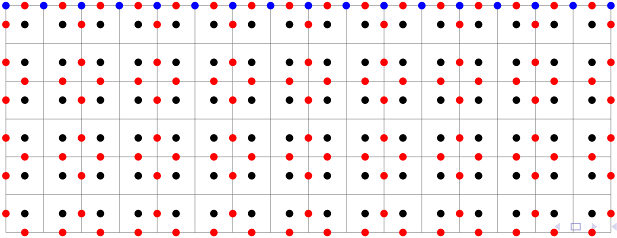


Complications of implementation of the Solver in OpenFOAM

- Simplest idea for **automatic mesh motion** in the FV framework would be to solve an equation to provide **point motion**
- However, as the FVM provides the solution in **cell centres** and motion is required on the points(vertices), this necessarily leads to **interpolation**



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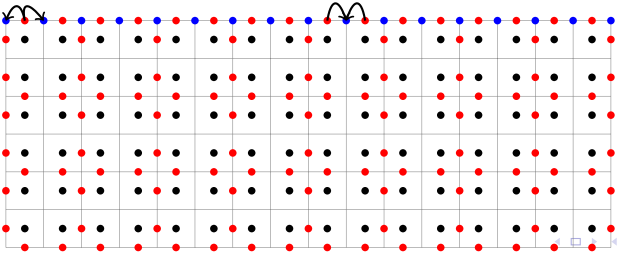

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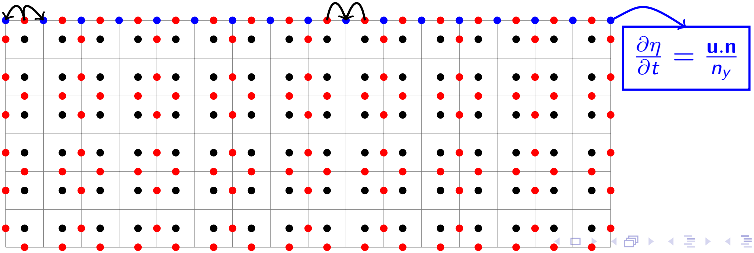

$$\boxed{\frac{\partial \eta}{\partial t} = \frac{\mathbf{u.n}}{n_y}}$$

Automatic Mesh Motion in OpenFOAM

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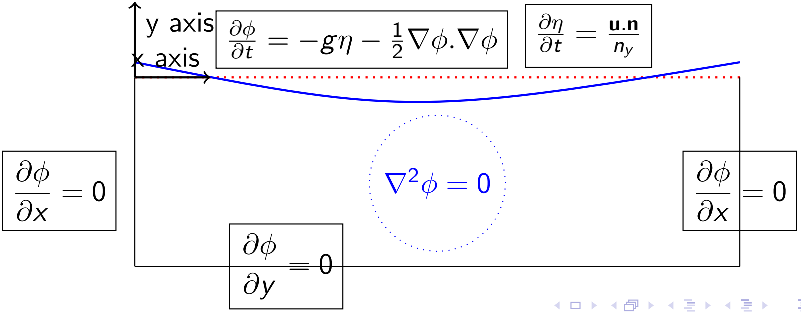
- The role of **internal point motion** is to accommodate changes in the domain shape (boundary motion) and preserve the validity and quality of the mesh
- **Internal point motion** can be specified in a number of ways, without user interaction
- Choices for a simplified mesh motion equation:
  - Laplace equation with constant and variable diffusivity
    - diffusivity $->$ quadratic inverseDistance

Standing Waves set up

$$\eta(x,t) = a\cos(kx)\cos(\omega t) + \frac{\pi a^2}{\lambda}\left[\cos^2(\omega t) - \frac{1}{4\cosh^2(kH)} + \frac{3\cos(2\omega t)}{4\sinh^2(kH)}\right]\cos(2kx) \quad (1)$$



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$$\frac{\partial\eta}{\partial t} = \frac{\mathbf{u.n}}{n_y}$$

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Time Histories of Wave Elevation

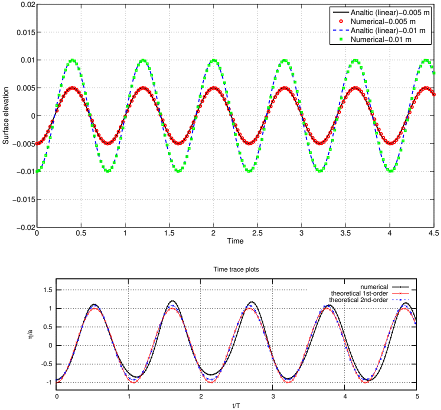


Figure: Time history of free surface elevation at the centre of the domain

Variation of wave period

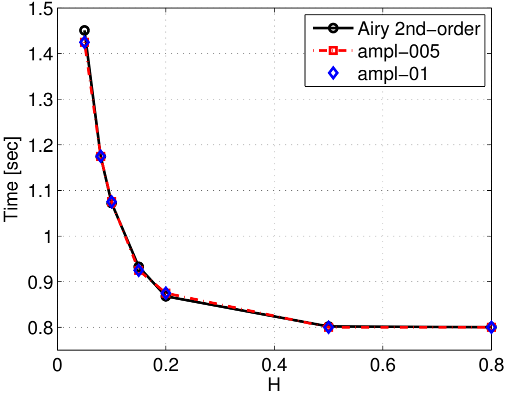
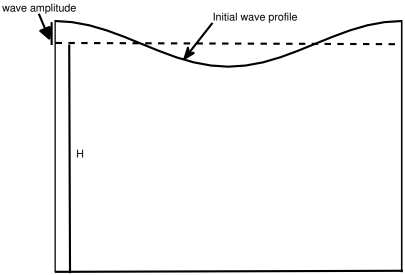
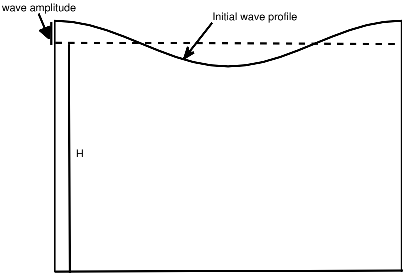


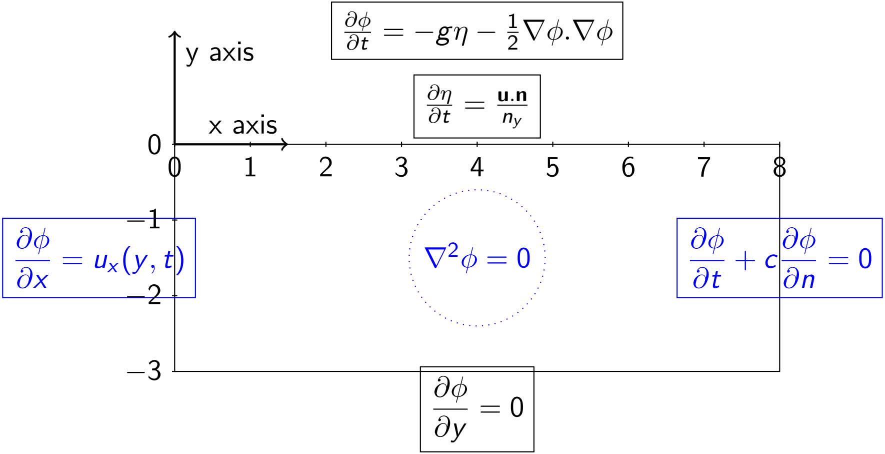
Figure: Variation of wave period against mean water depth normalized by wavelength

Standing Wave Animation





Progressive Waves set up



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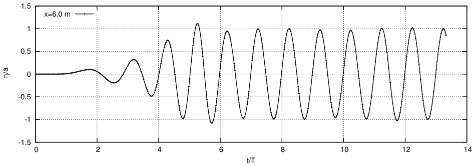
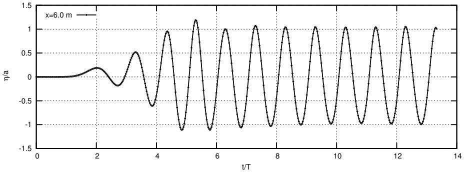


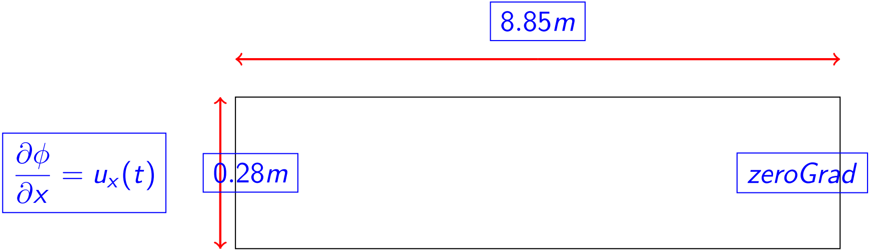
(a) $a = 0.01$ m, $H = 1.5$ m, T=1.5 s



(b) $a = 0.06$ m, $H = 1.0$ m, T=1.5 s.

Figure: Time history of free surface elevation at location $x = 6.0$ m (from inlet boundary)

Comparison with Experiment (F.Gao-2003)



8.85m

$$\frac{\partial\phi}{\partial x} = u_x(t)$$

0.28m

zeroGrad

[1] Gao, F, (2003). “An efficient finite element technique for free surface flow,”Ph.D. thesis, Brighton University, UK.

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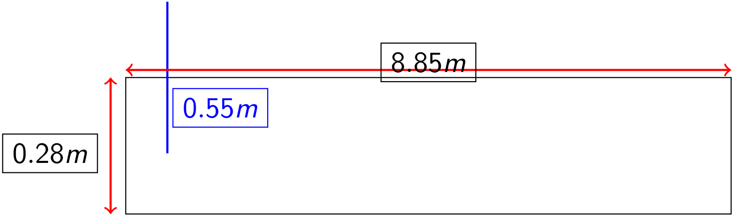


$8.85m$

$0.55m$

$0.28m$

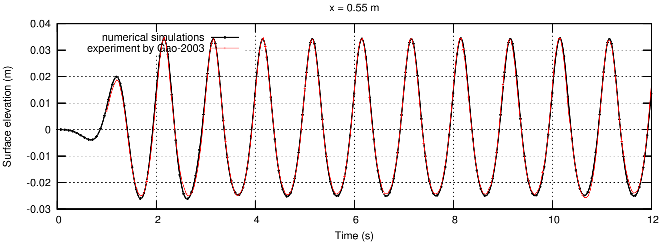
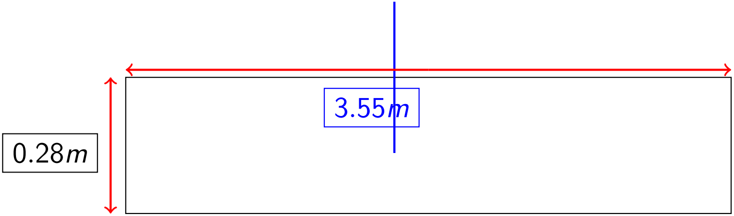


Figure: Time history of wave elevation at location $x = 0.55$ m.

Comparison with Experiment (F.Gao-2003)



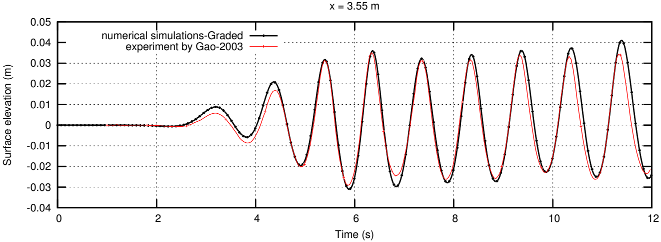
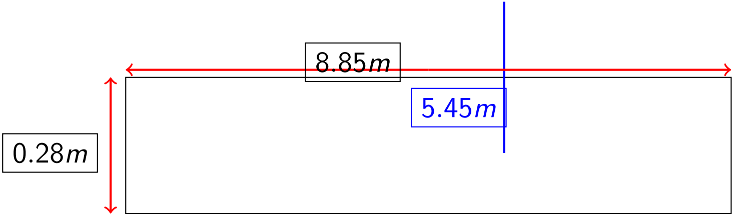


Figure: Time history of wave elevation at location $x = 3.55$ m.

Comparison with Experiment (F.Gao-2003)



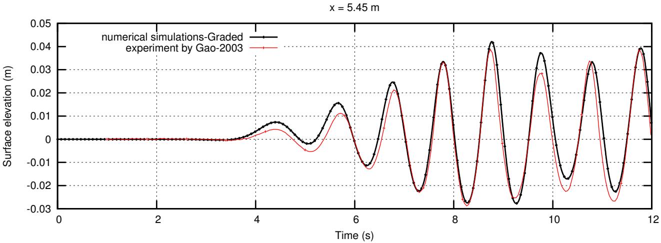
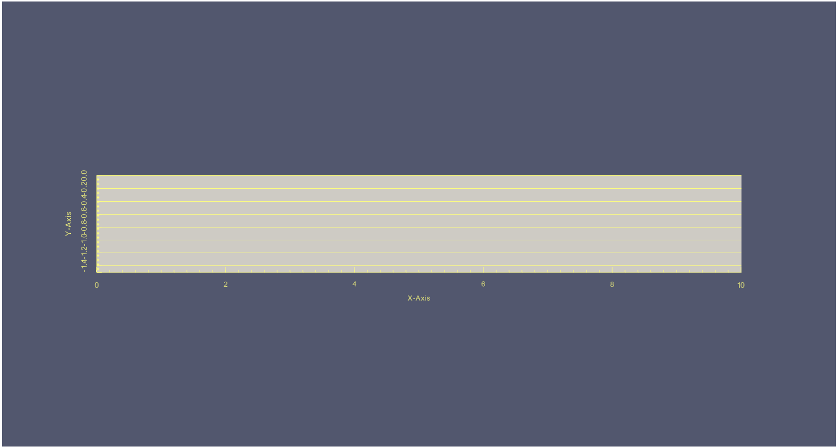


Figure: Time history of wave elevation at location $x = 5.45$ m.

Comparison with experiment



Conclusions and Future Directions

- Developed a free surface tracking solver for numerical simulation of unsteady irrotational fully non-linear water waves

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- **Coupling to available Navier-Stokes solvers in OpenFOAM®**
- **The developed solver and the associated boundary conditions will be released as an open-source for the marine and offshore community**

Thank you