Resilient Integrated-Coupled FOW platform design methodology (ResIn)

Using porous-media for CFD modelling of wave interaction with thin perforated structures

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Introduction

- In marine engineering various structures exist that consist of thin perforated elements, e.g. breakwaters or aquaculture containers.
- Detailed CFD modelling where the microstructural geometry is resolved explicitly is possible, but the computational demand for this can make it prohibitive.
- This work presents CFD modelling of wave interaction with thin perforated cylinders where the impact of the structure on the flow is represented by using a volume-averaged macro-scale model by means of a homogeneous pressure drop.

Aquaculture container

Vertical-wall breakwater

Macro-scale porous-media approach

Governing equations:

- Incompressible two-phase (immiscible) Volume-Averaged Navier-Stokes equations, [1,2]

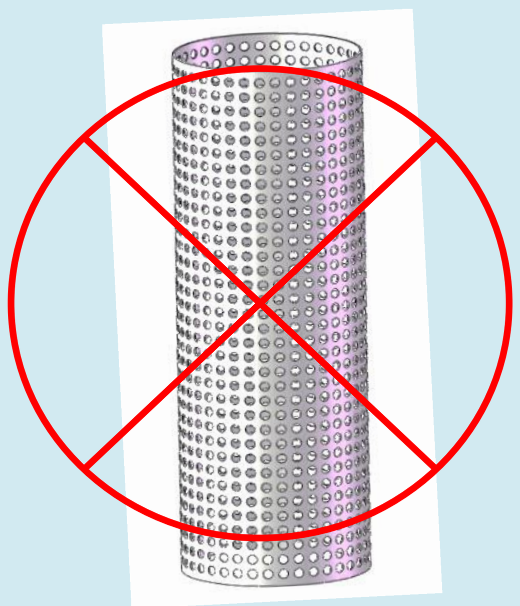
$$\nabla \rho \boldsymbol{U} = 0,$$

$$\frac{\partial}{\partial t}\rho\frac{\boldsymbol{U}}{n} + \nabla\left(\rho\frac{\boldsymbol{U}}{n}\frac{\boldsymbol{U}}{n}\right) = -\nabla p - \mathrm{g}\rho + \nabla\cdot\left(\mu_{\mathrm{eff}}\nabla\frac{\boldsymbol{U}}{n}\right) + \sigma\kappa\nabla\alpha + \Delta P$$

n [-] ...porosity (void area/total area)

- Volume-Of-Fluid (VOF) interface-capturing

$$\rho = \alpha\rho_{water} + (1-\alpha)\rho_{air}$$
$$\mu = \alpha\mu_{water} + (1-\alpha)\mu_{air}$$



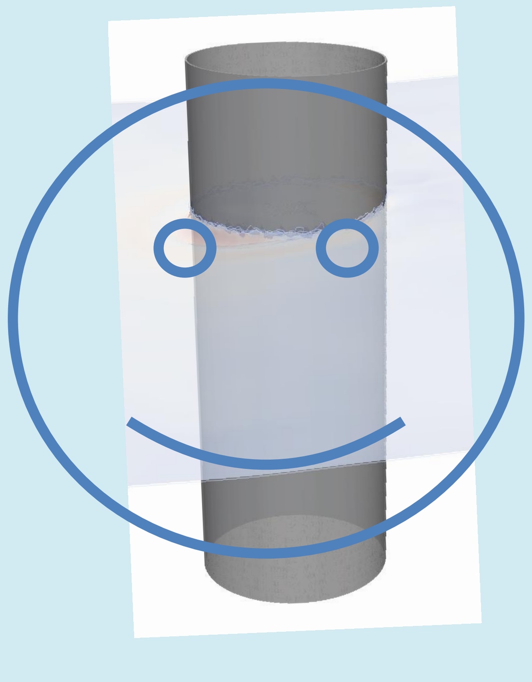
Microstructural resolution

Theoretical **pressure-drop** model:

- The flow across a thin perforated sheet is dominated by turbulent dissipation (high Reynolds-numbers) → drag term

$$\Delta P = \frac{C_f}{2}\frac{\boldsymbol{U}}{n}\left|\frac{\boldsymbol{U}}{n}\right|\rho\Delta x$$

- $C_f = \frac{1-n}{\delta n^2}$ [-] ... drag coefficient, Molin [3]
- $\delta = 0.5$ [-] ...discharge coefficient; in oscillatory flow dependent on Keulegan-Carpenter number, Tait [4], Hamelin [5]



Macro-scale porous-media approach

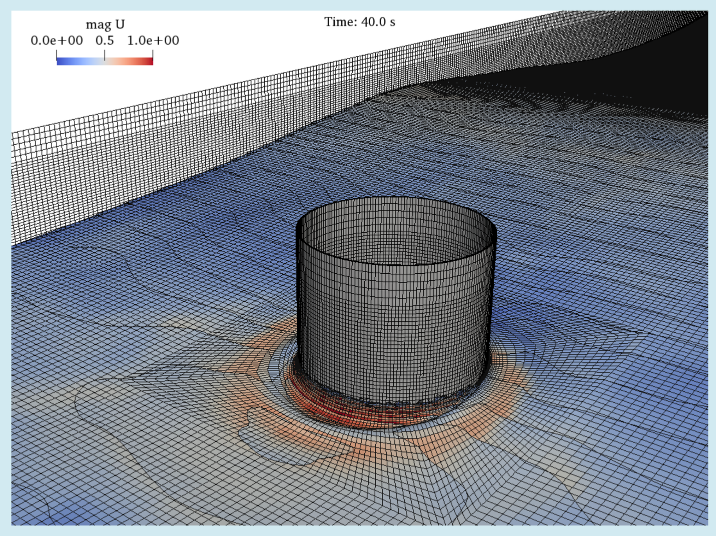
Model setup

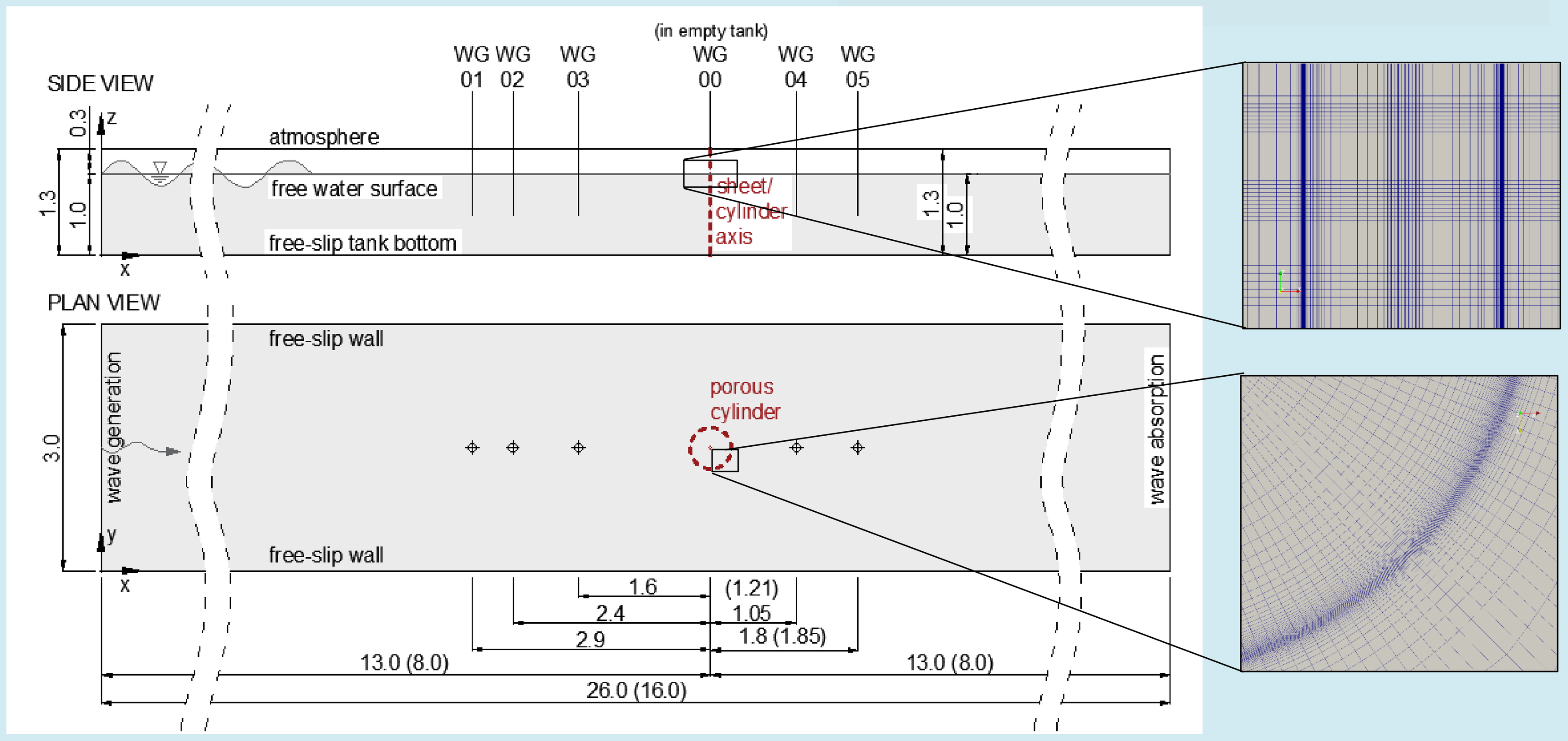
Porous cylinder in wave flume:

- Porosities n = 0.2, 0.3
- Thickness d = 5mm
- Diameter D = 0.50m

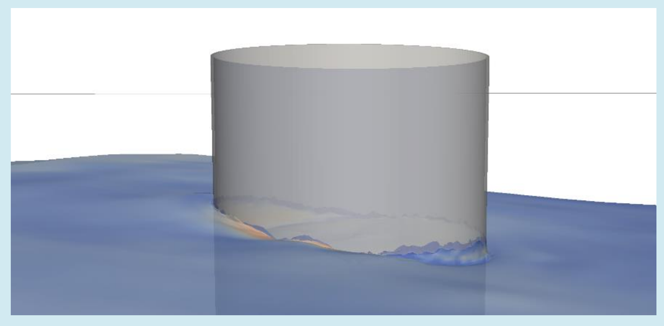
Wave modelling:

- Static boundaries with an active wave absorption method, [6]
- Input: a range of regular 2[nd] – order Stokes waves



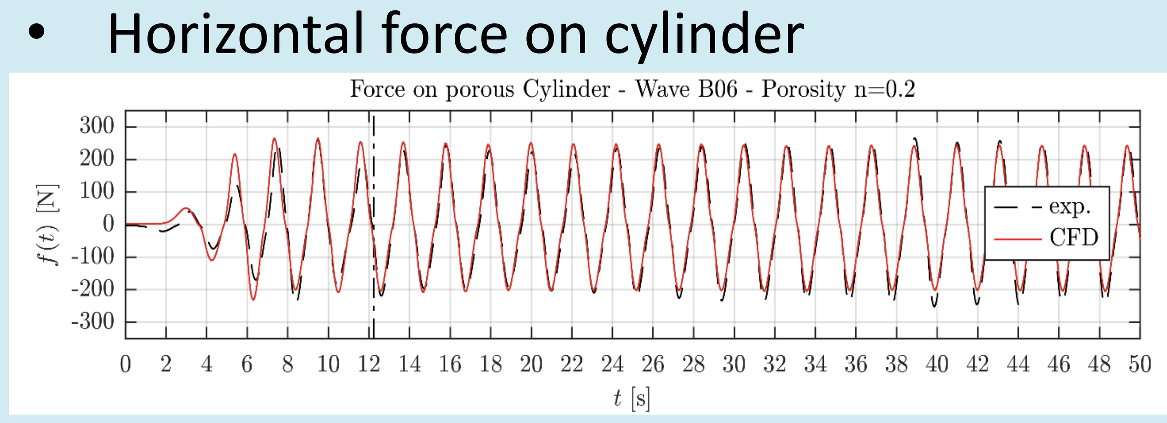


Validation against experimental results

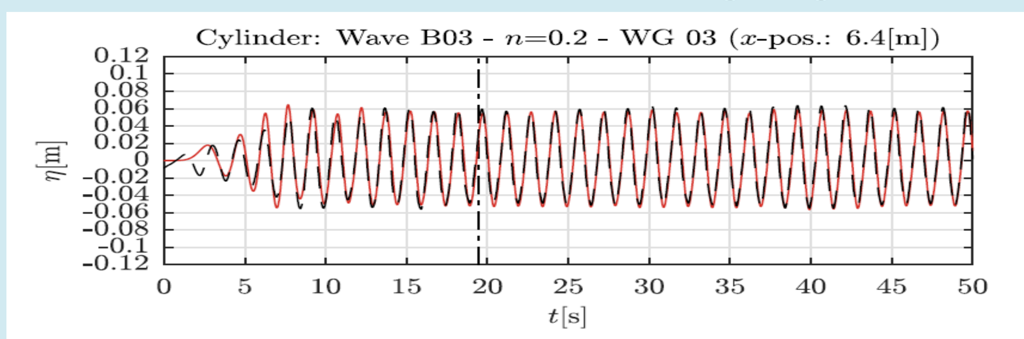


watch the animation

- Horizontal force on cylinder



- Wave elevation at wave gauges



[7,8]

Conclusions and future work

- The results indicate that a porous-media approach is capable of reproducing the large-scale interactions between waves and fixed thin perforated structures.
- It is shown that the applied theoretical pressure-drop model as volume-averaging closure term is capable of replicating the characteristic quadratic pressure-drop of the flow across thin perforated barriers for the range of regular wave frequencies, wave steepnesses as well as sheet porosities considered.
- The application of the present method to fixed structures will be extended to moving and floating thin perforated structures.

References

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