Theoretical and numerical aspects of the open source BEM solver NEMOH

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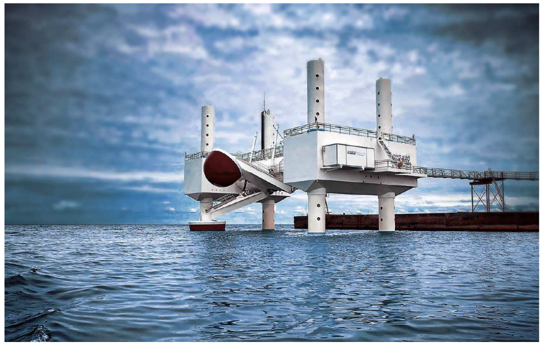
Context

> BEM codes based on linear potential flow theory are still widely used for wave-structure interactions in numerical W2W models for WECs
  - Performance estimates, Design optimization, Development of control algorithms, Array effects

  > Why: because they are extremely fast in comparison with other approaches

  > BEM codes (WAMIT, Diodore, DIFFRACT, Hydrostar, Aquaplus, …) used for computation of hydrodynamic coefficients are expensive (despite they were developed long time ago)

> In Jan. 2014, ECN decided to release its BEM code in open source.



Motivation

> To date, ~900 users registered on Nemoh's forum. Nemoh user community is growing quickly

> Nemoh has been found very useful for many of its user but its full potential has not yet been realised because :

- Documentation is poor
- No verification and validation test cases

> This paper → summary of the theoretical and numerical aspects of the open source BEM solver NEMOH

Free surface potential flow theory : assumptions

> Inviscid fluid : $\nu = 0$

> Incompressible and irrotational flow : $\begin{cases} \vec{\nabla}.\vec{V} = 0 \\ \vec{\nabla} \times \vec{V} = \vec{0} \end{cases}$

→ Velocity derives from a velocity potential: $\vec{V} = \vec{\nabla}\Phi$

→ Pressure is obtained from Bernoulli formula: $p + \rho g z + \frac{1}{2}\left(\vec{\nabla}\Phi\right)^2 + \rho \frac{\partial \Phi}{\partial t} = \text{Cste}$

Interest: flow is completely described the velocity potential (scalar) Φ :

→ 1 unknown Φ vs 4 unknowns (V_x, V_y, V_z and p)

The non linear boundary value problem

In fluid volume

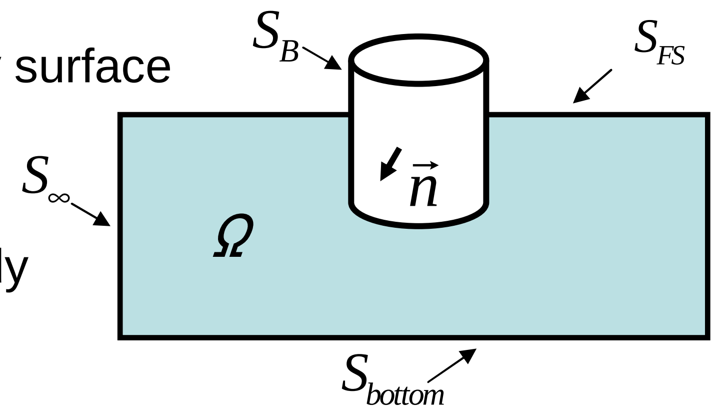
On body surface

On body

FSC

Radiation condition

$$
\begin{cases}
\Delta\Phi = 0 & M \in \Omega \\
\dfrac{\partial\Phi}{\partial n} = \vec{V}.\vec{n} & M \in S_B \\
\dfrac{\partial\Phi}{\partial n} = 0 & M \in S_{bottom} \\
\dfrac{\partial\eta}{\partial t} + \vec{\nabla}\eta.\vec{\nabla}\Phi = 0 & M \in SFS \\
\dfrac{\partial\Phi}{\partial t} + g\eta + \dfrac{1}{2}\left(\vec{\nabla}\Phi\right)^2 = 0 & M \in SFS \\
\sqrt{R}\left(\dfrac{\partial\Phi}{\partial n} - ik\right)(\Phi - \Phi_0) \to 0 & R \to \infty
\end{cases}
$$



$$
\alpha(M)\Phi(M) = \iint_{\cup S}\left(\Phi(M')\frac{\partial G(M,M')}{\partial n'} - G(M,M')\frac{\partial\Phi(M')}{\partial n'}\right)dS'
$$

After some maths

(Green's 3rd ident Interest ?

From a 3D problem to a 2D problem→ Much less unknowns

Approximations of the non linear BVP

> 1st order (fully linear)

- Small motion around mean position, small steepness
- Linearized free surface equations, body conditions on mean position of body surface
- BVP usually solved in frequency domain, robustness ++, CPU time , accuracy +- (but usually surprisingly good)

⇨ WAMIT, Diodore, Hydrostar, Diffract, Aquaplus, Nemoh, …

> Fully non linear

- No wave breaking
- Time domain, robustness +-, CPU time +-, accuracy ++ (high order loads, springing, ringing)

⇨ XWAVE, LAMP4, NWT_LHSV

> Non linear Froude Krylov

- Fourde-Krylov foce calculated on the instantaneous body surface (hydrostatic + dynamic), diffraction/radiation with linear BVP
- Time domain, robustness +-, CPU time +, accuracy +-
- Approach is not consistent: stretching

⇨ MANAV, LAMP2, …

> Weak-scatterer

- Small pertubartion w.r.t to incident wave field → linearisation of FSC on instantaneous position of the incident wave
- Time domain, robustness +, CPU time +, accuracy + (Consistent non linear Froude-Krylov)

⇨ WS_ECN, LAMP3, AEGIR

Nemoh

$$
\begin{cases}
\Delta\Phi = 0 & M \in \Omega \\
\dfrac{\partial\Phi}{\partial n} = f(M) & M \in \overline{S_B} \\
\dfrac{\partial\Phi}{\partial n} = 0 & M \in S_{bottom} \\
\dfrac{\partial^2\Phi}{\partial t^2} + g\dfrac{\partial\Phi}{\partial n} = 0 & z = 0 \\
\sqrt{R}\left(\dfrac{\partial\Phi}{\partial n} - ik\right)(\Phi - \Phi_0) \to 0 & R \to \infty
\end{cases}
$$

> Linear BEM code (solves linear BVP)

> Use of the generalized mode approach

> Use of source distribution

> Wave part of the Green funtion is calculated using interpolation in a look-up table

> Outputs:

- 1st order hydrodynamic coefficients (added mass, radiation damping, excitation force)
- Far field coefficients (Kochin function)
- Free surface elevation, pressure field
- Removal of irregular frequencies (to be released soon)
- 2nd order coefficients (QTF) → see paper by Philippe et al.

> http://lheea.ec-nantes.fr/doku.php/emo/nemoh/start

Code structure

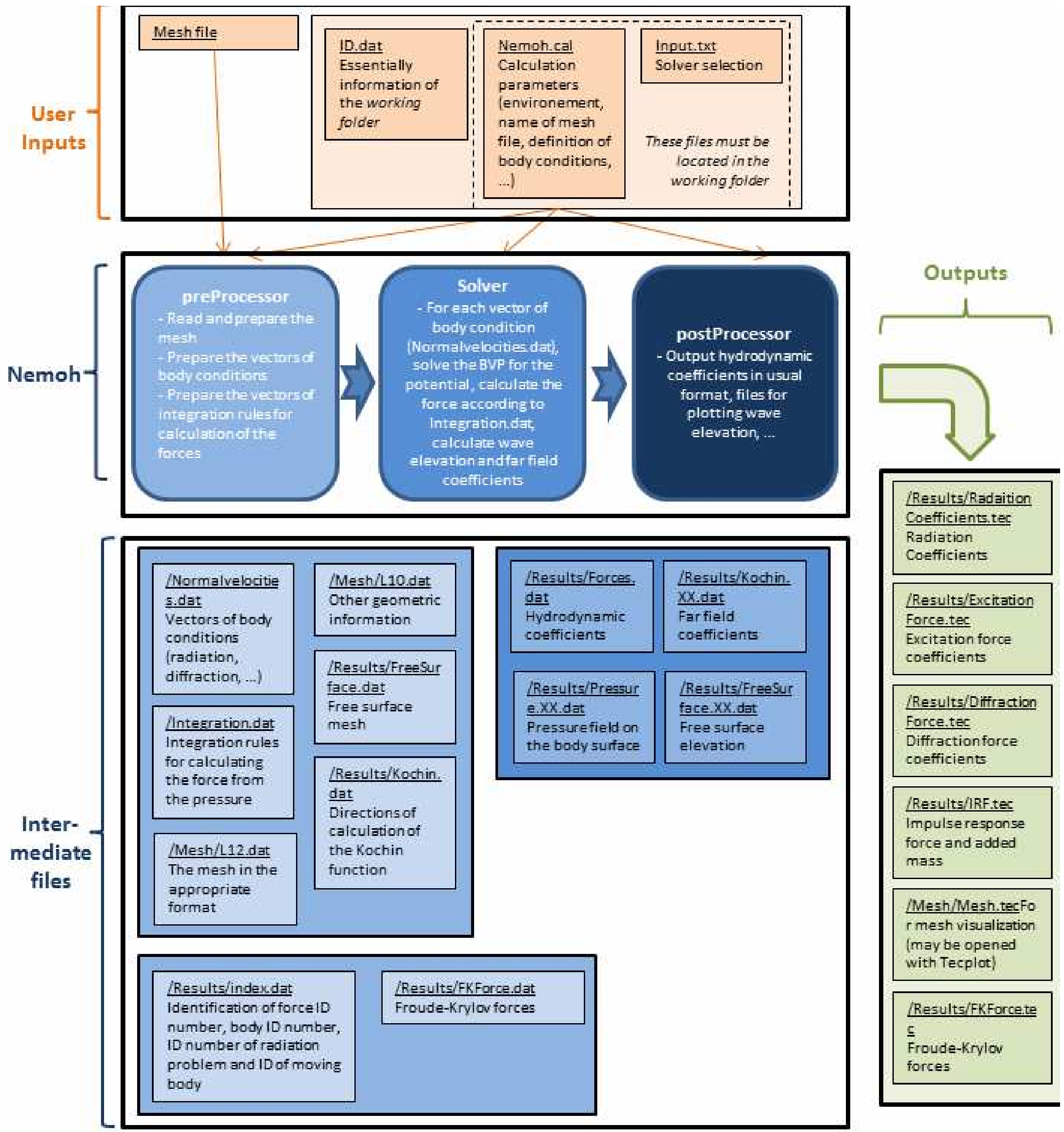
Nemoh is:

>PreProcessor

>Solver

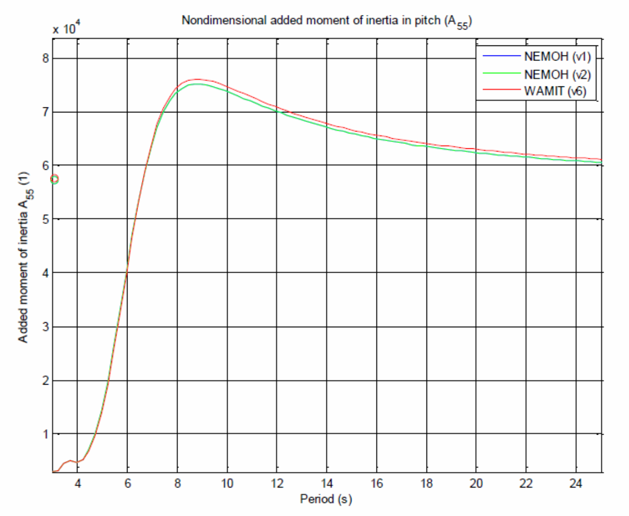
>postProcessor

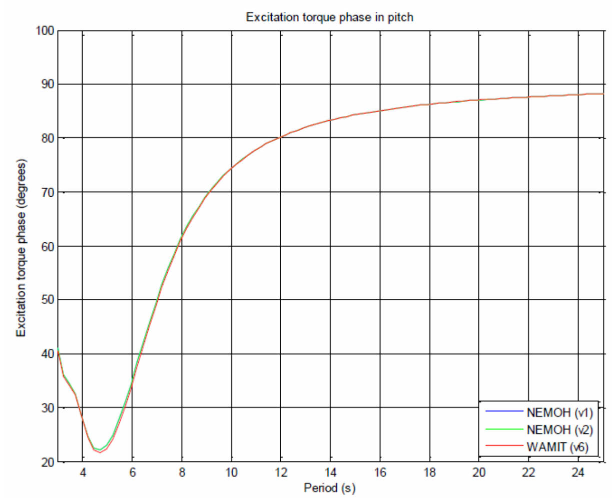
Matlab wrappers and mesh generation in Matlab provided for convenience (not Nemoh)

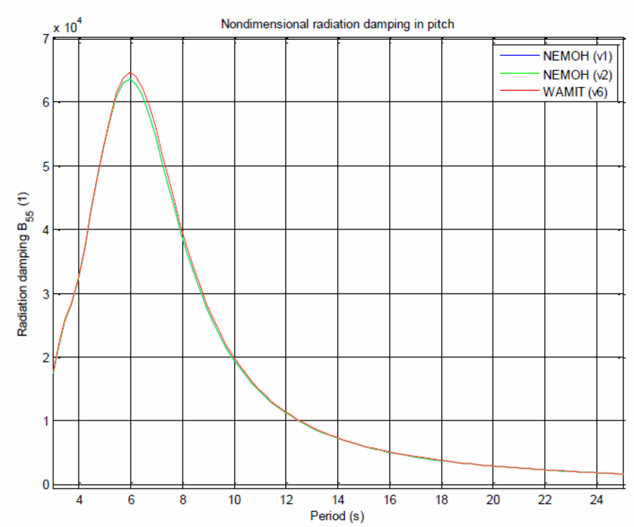


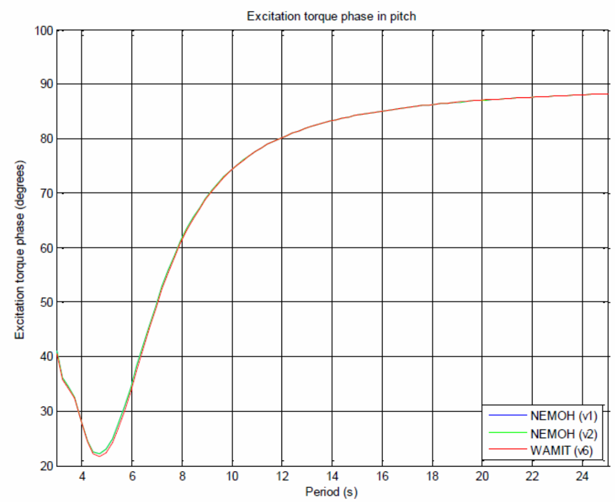
Verification & Validation

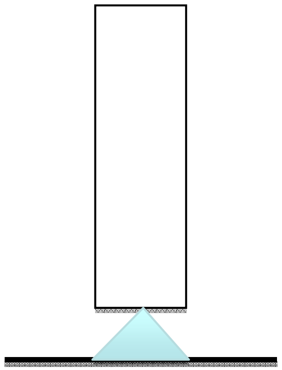
> Pitch-pitch coefficients for an upright box hinged at sea bottom







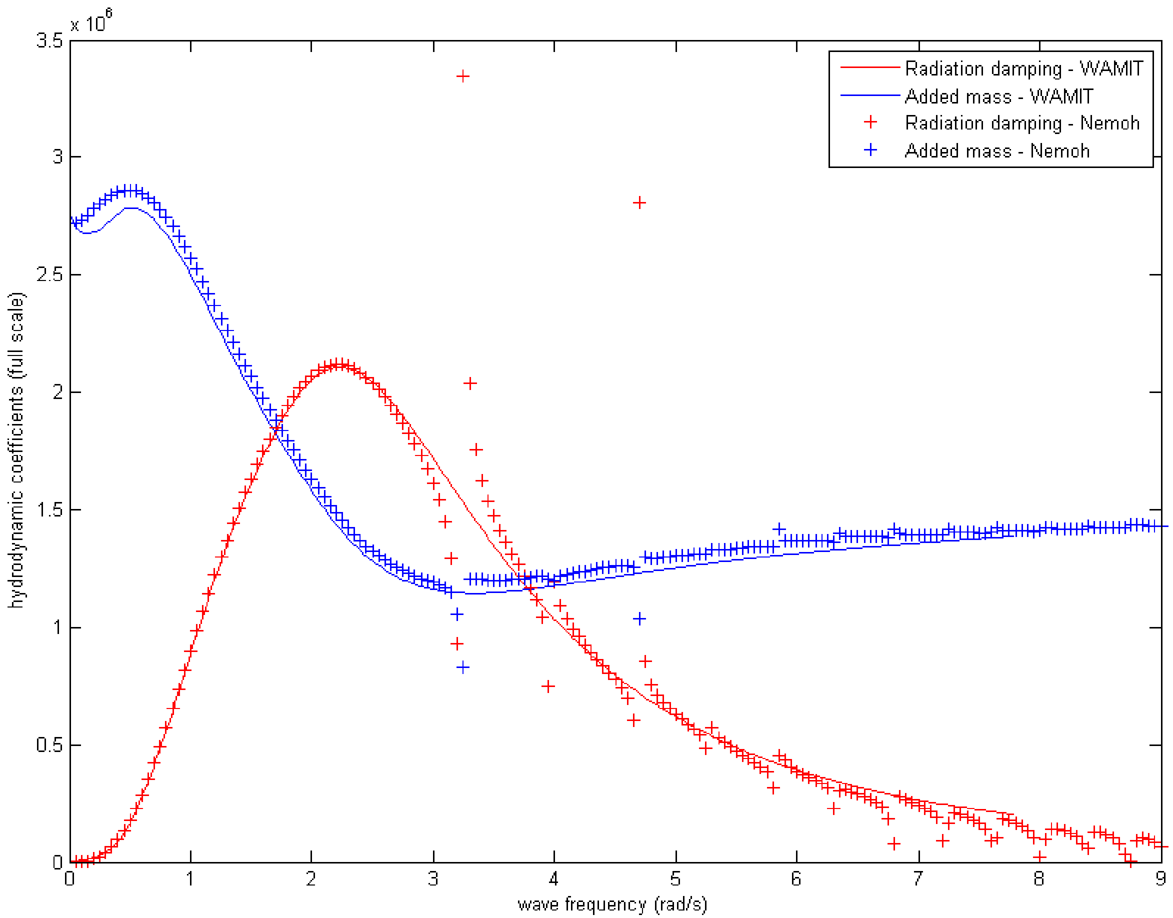


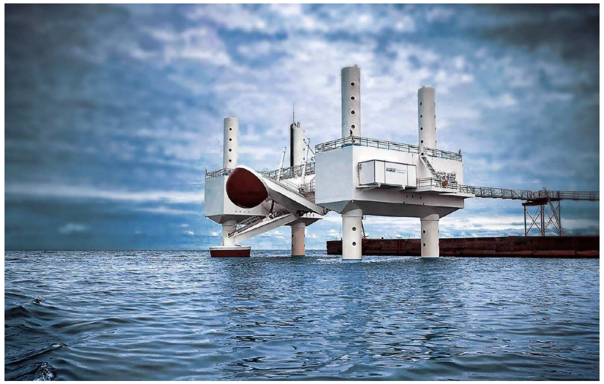


Calculations by Cathal Cummins

Verification & Validation

> Pitch coefficient for the Wavestar absorber

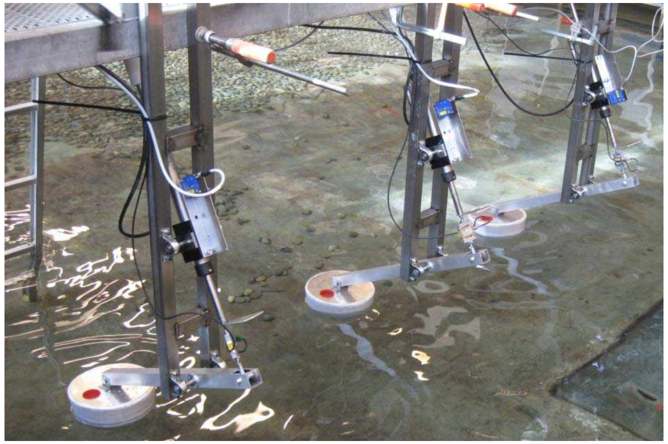


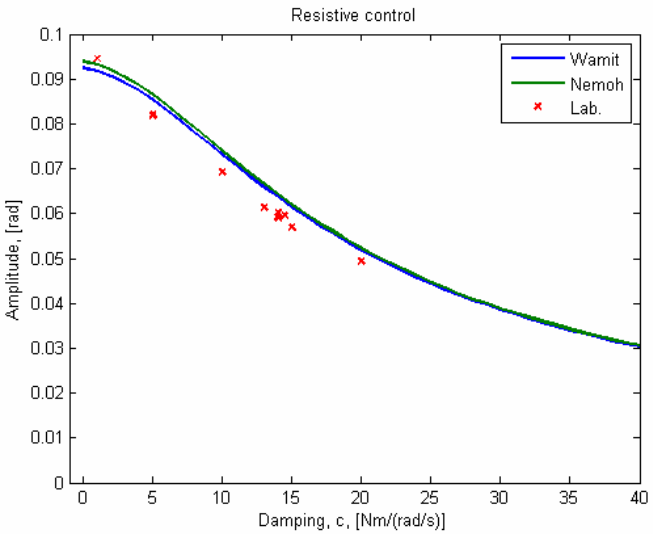


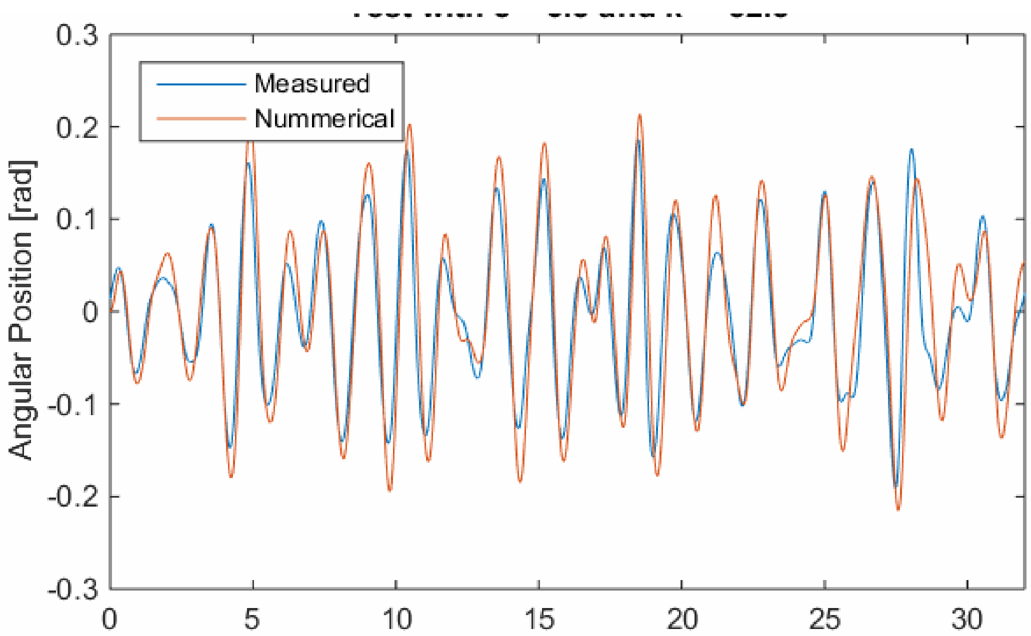
WAMIT calculations by Morten Kramer

Verification & Validation

> Comparison of motion response for model scale of Wavestar absorber. Hydrodynamic coefficients calculated with Nemoh.





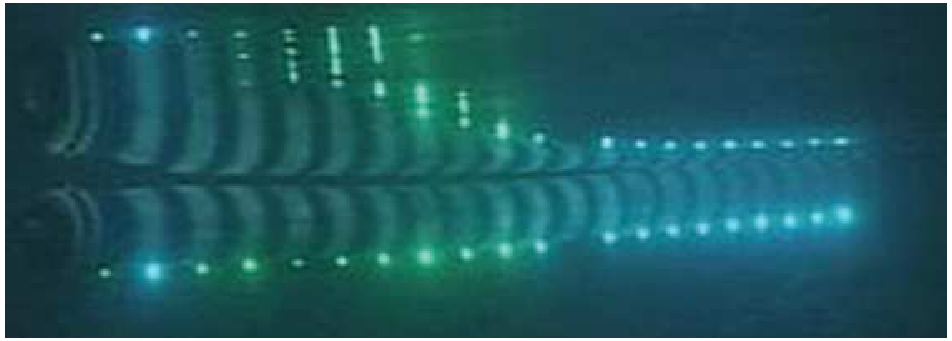


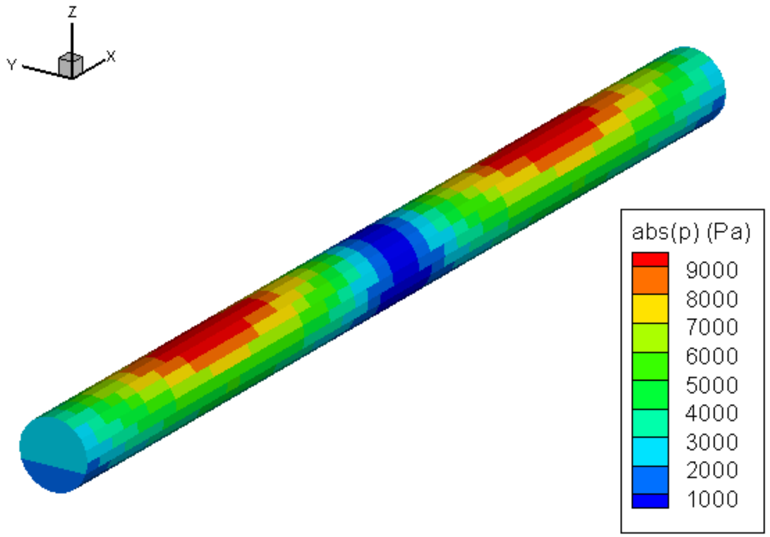
Calculations and experiments by Jarrah Orphin, Mats Sonderstup Rohe, Jonas Bjerg Thomsen

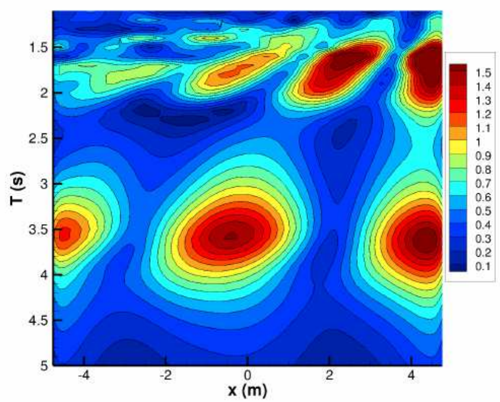
Applications

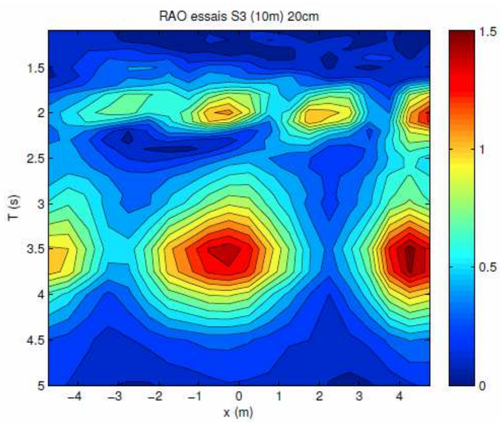
> Bulge motion of a flexible tube

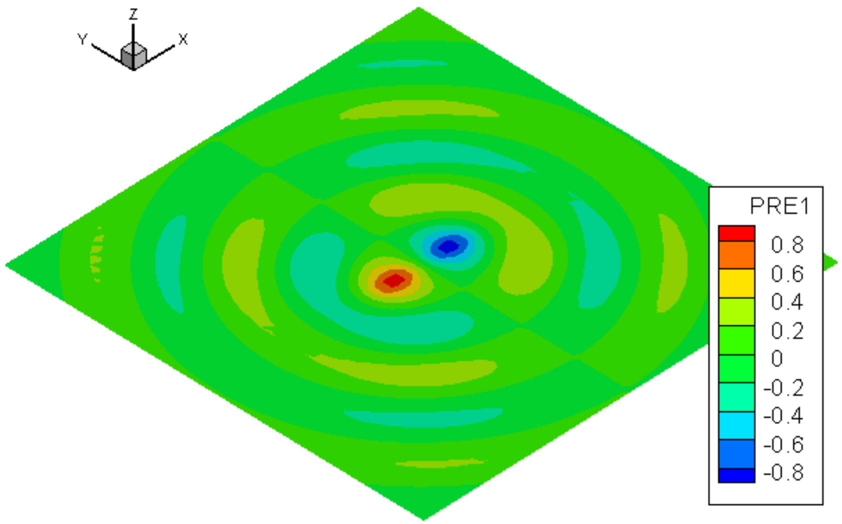
$$\vec{V}.\vec{n} = \sin\left(\frac{x}{L}\right)$$





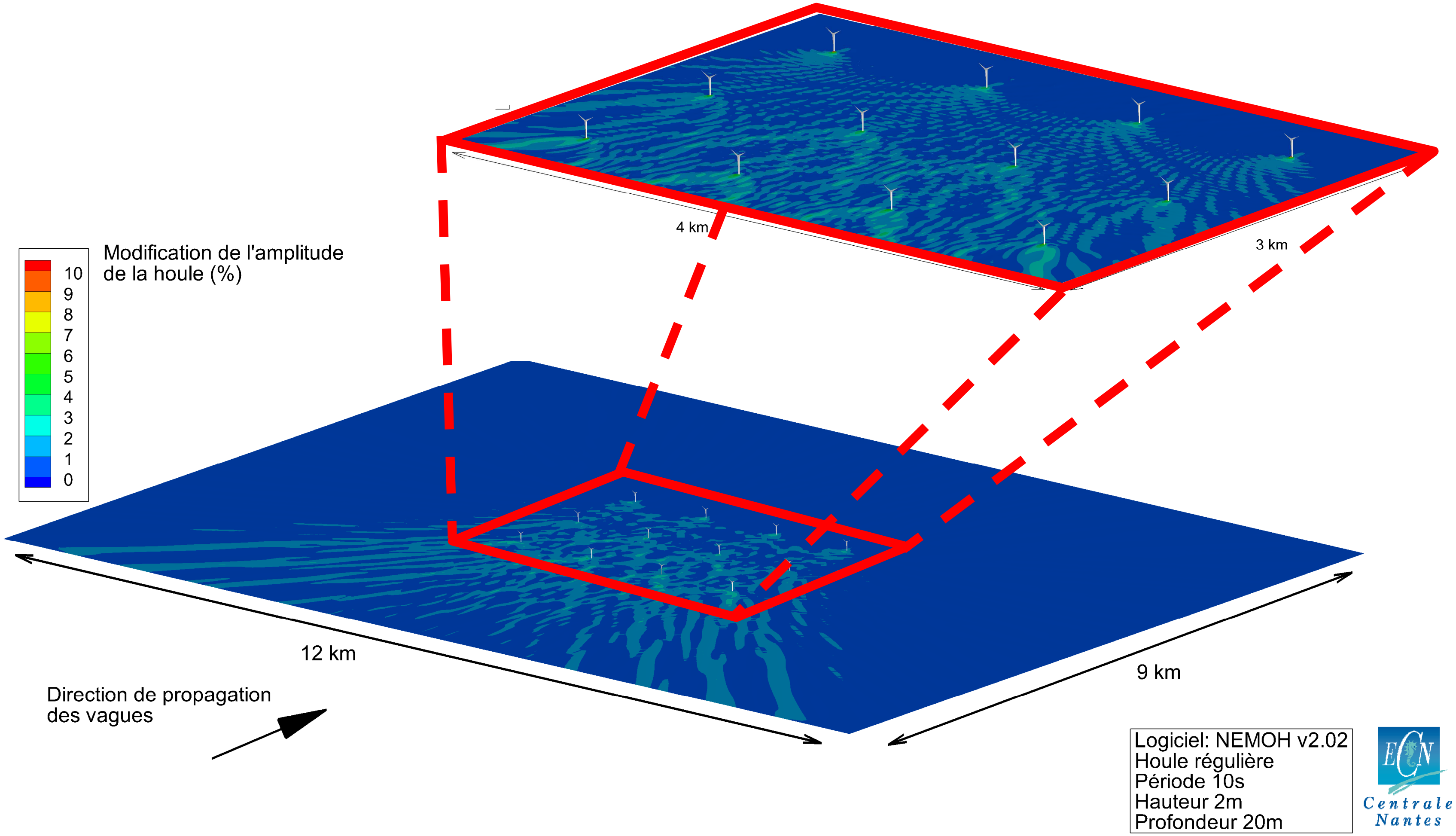






Applications

> Wave diffraction by a fixed offshore wind farm



Conclusions and perspectives

> Nemoh: open source BEM code for calculation of hydrodynamic coefficients

> Perspectives
- More documentation
- Verification & validation test cases
- Removal of irregular frequencies
- Second order coefficients (QTFs)
- Dipoles
- Code acceleration (multiple scattering and/or use of diff equation for Green function)
- Link to time domain

> Interested ? Join the developer group !

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