
Theoretical and numerical aspects of the open source BEM solver NEMOH

Aurelien.babarit@ec-nantes.fr

Gerard.delhommeau@ec-nantes.fr

Ecole Centrale de Nantes - CNRS

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 :
$$\begin{cases} \vec{\nabla} \cdot \vec{V} = 0 \\ \vec{\nabla} \times \vec{V} = \vec{0} \end{cases}$$

→ Velocity derives from a velocity potential:

$$\vec{V} = \vec{\nabla}\Phi$$

→ Pressure is obtained from Bernoulli formula:

$$p + \rho g z + \frac{1}{2}(\vec{\nabla}\Phi)^2 + \rho \frac{\partial \Phi}{\partial t} = \text{Cste}$$

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

$$\Delta\Phi = 0 \quad M \in \Omega$$

On body surface

$$\frac{\partial\Phi}{\partial n} = \vec{V} \cdot \vec{n} \quad M \in S_B$$

On body

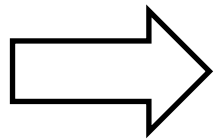
$$\frac{\partial\Phi}{\partial n} = 0 \quad M \in S_{bottom}$$

FSC

$$\left. \begin{aligned} \frac{\partial\eta}{\partial t} + \vec{V}\eta \cdot \vec{V}\Phi &= 0 \quad M \in SFS \\ \frac{\partial\Phi}{\partial t} + g\eta + \frac{1}{2}(\vec{V}\Phi)^2 &= 0 \quad M \in SFS \end{aligned} \right\}$$

Radiation condition

$$\sqrt{R} \left(\frac{\partial\Phi}{\partial n} - ik \right) (\Phi - \Phi_0) \rightarrow 0 \quad R \rightarrow \infty$$



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

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

- Froude-Krylov force 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 perturbation 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

- > Linear BEM code (solves linear BVP)
- > Use of the generalized mode approach
- > Use of source distribution
- > Wave part of the Green function 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.

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

Code structure

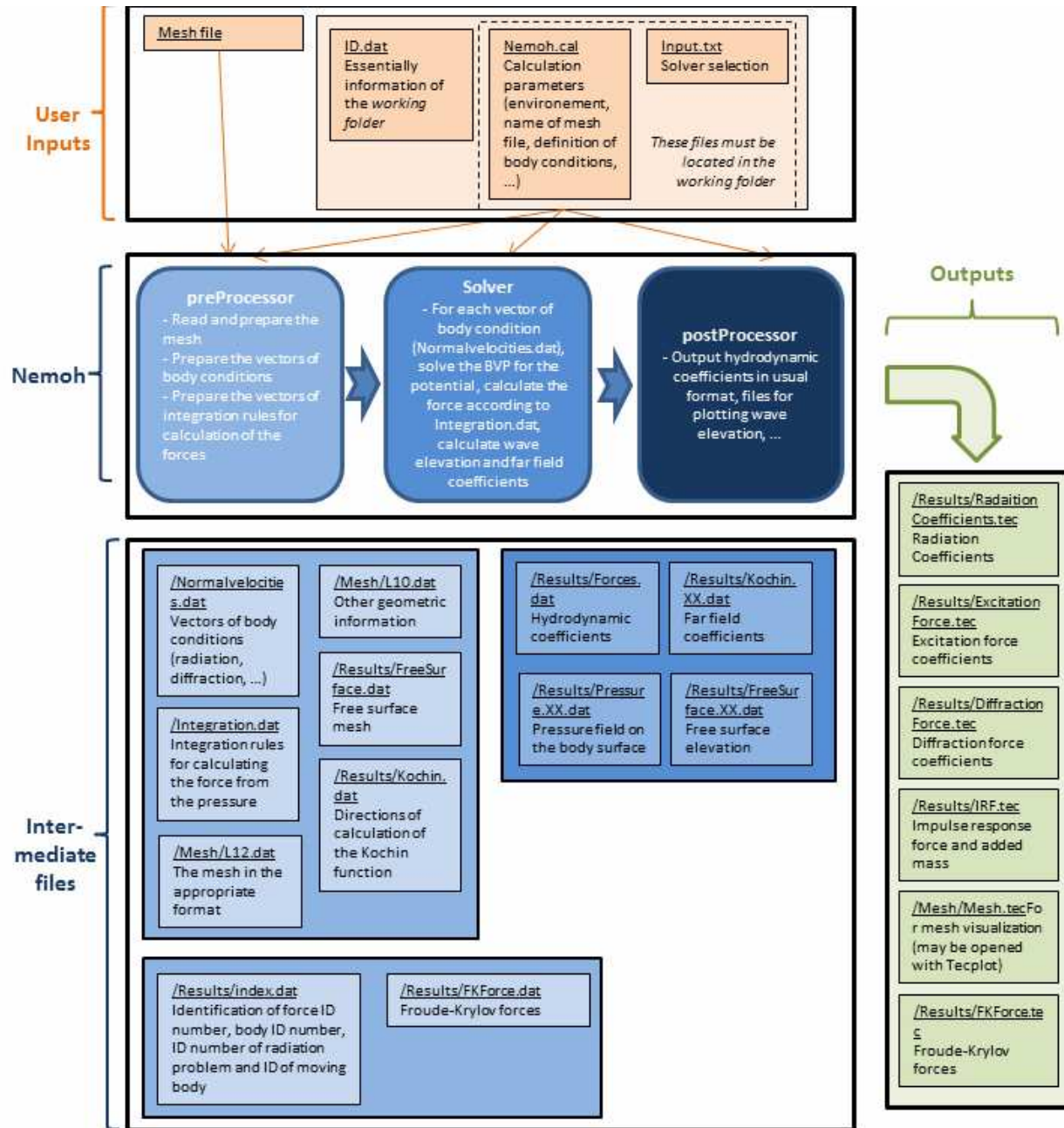
Nemoh is:

>PreProcessor

>Solver

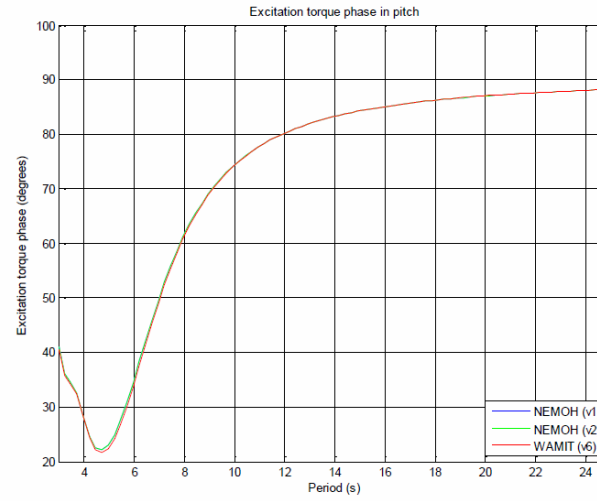
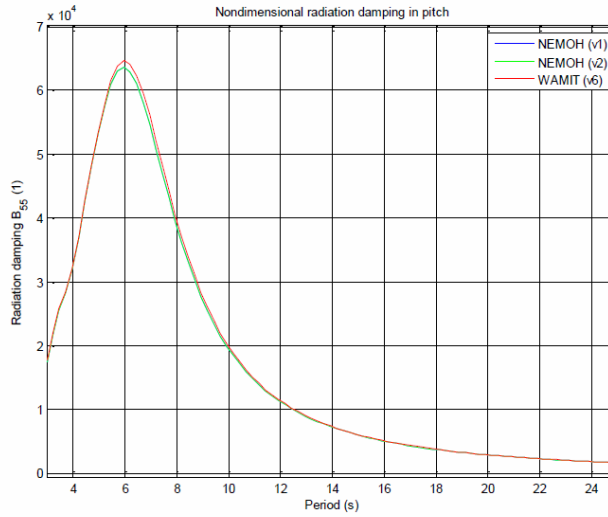
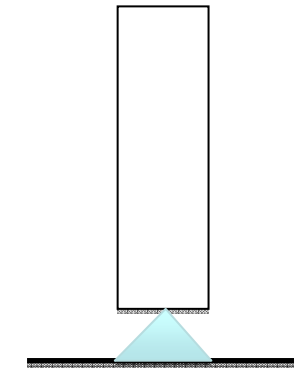
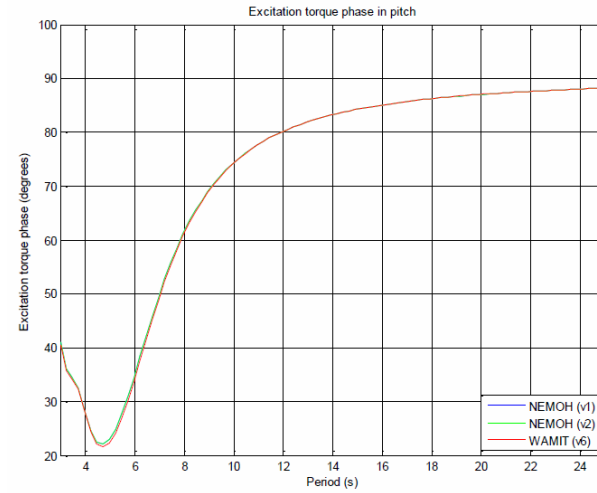
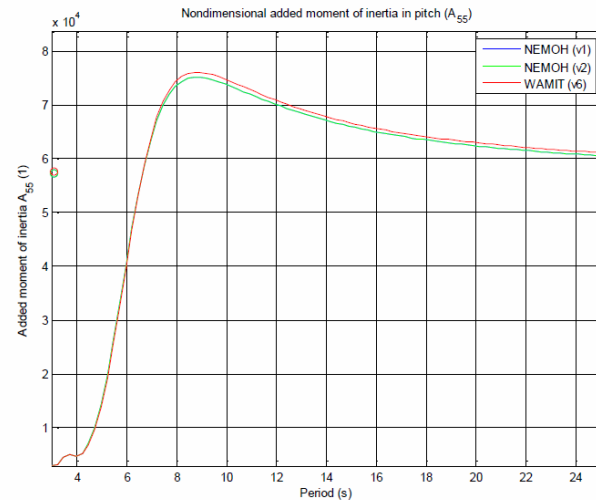
>postProcessor

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



Verification & Validation

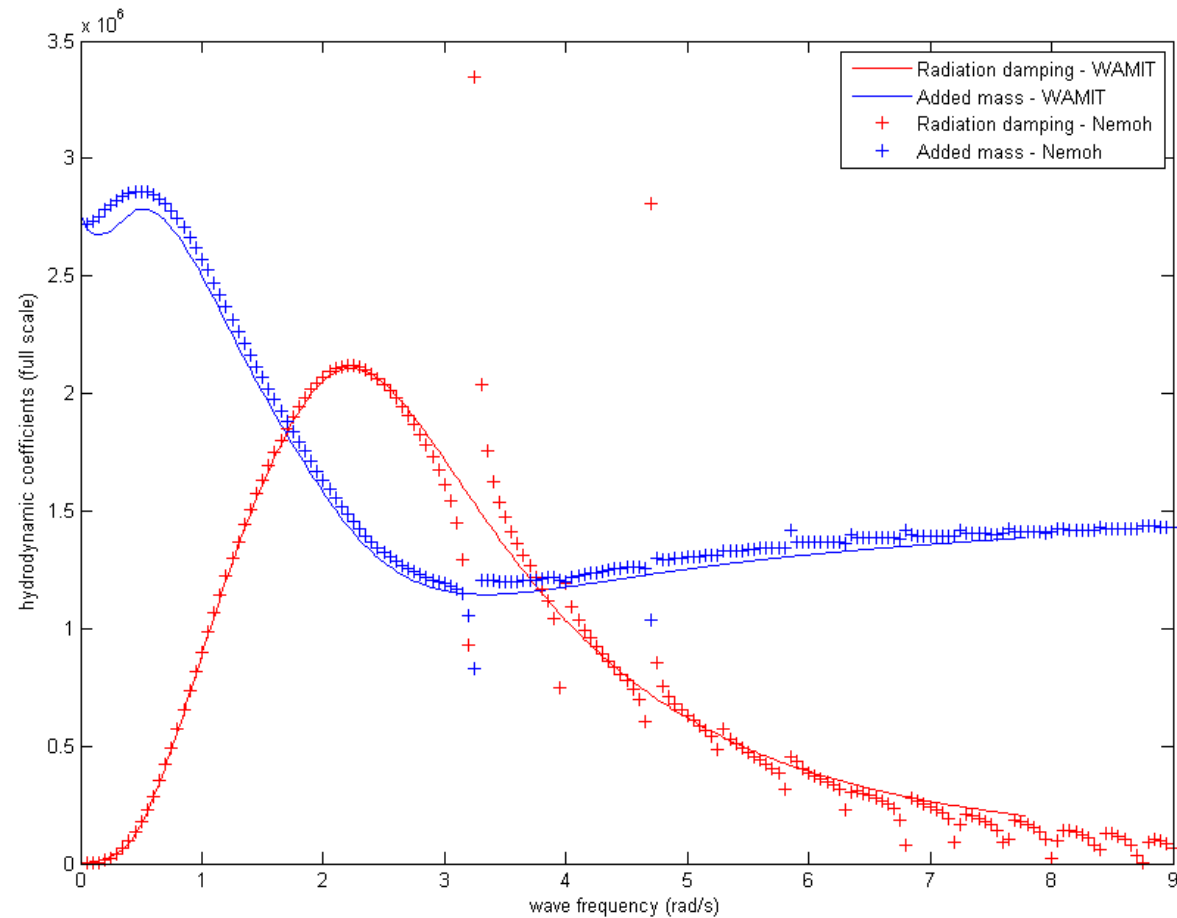
> Pitch-pitch coefficients for an upright box hinged at sea bottom



Calculations by
Cathal
Cummins

Verification & Validation

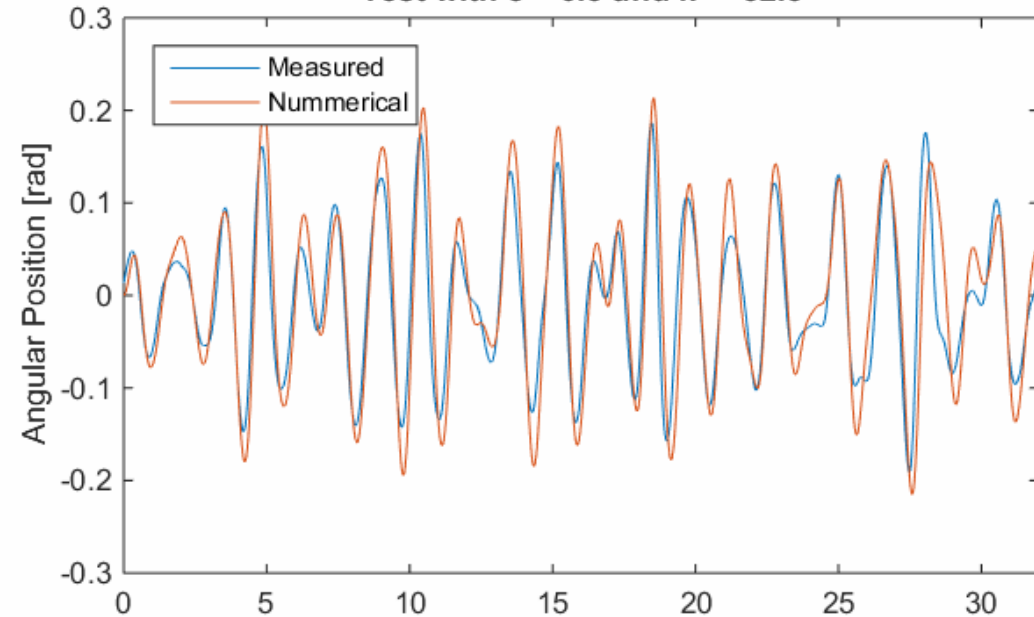
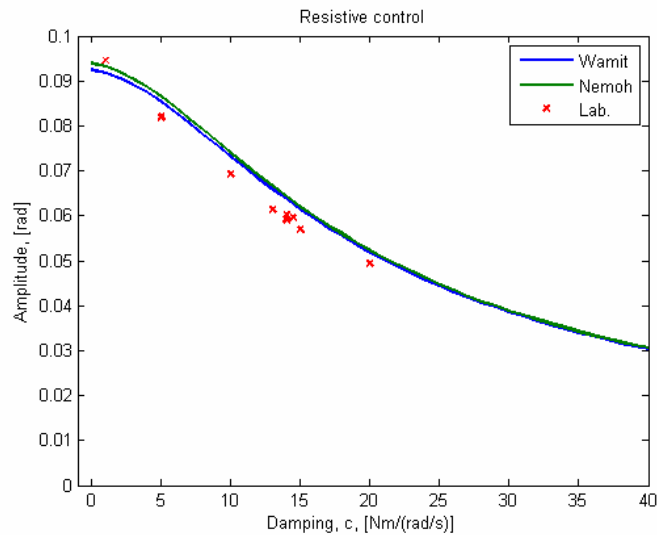
> Pitch coefficient for the Wavestar absorber



WAMIT
calculations by
Morten Kramer

Verification & Validation

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

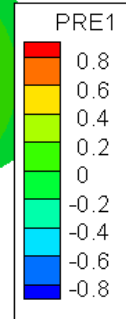
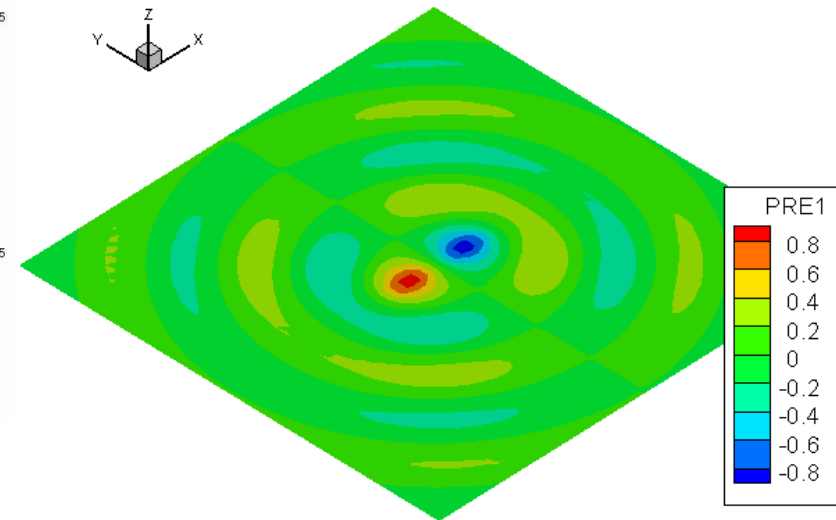
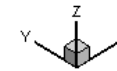
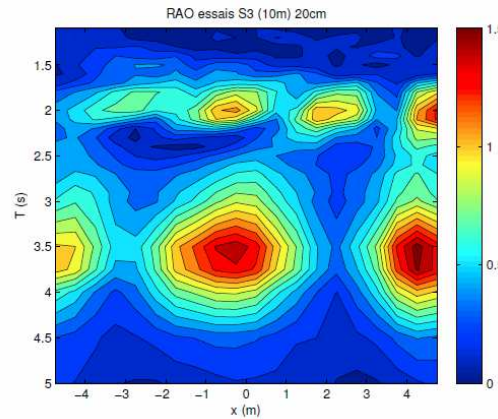
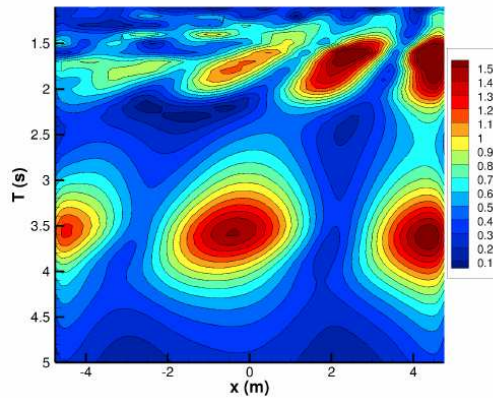
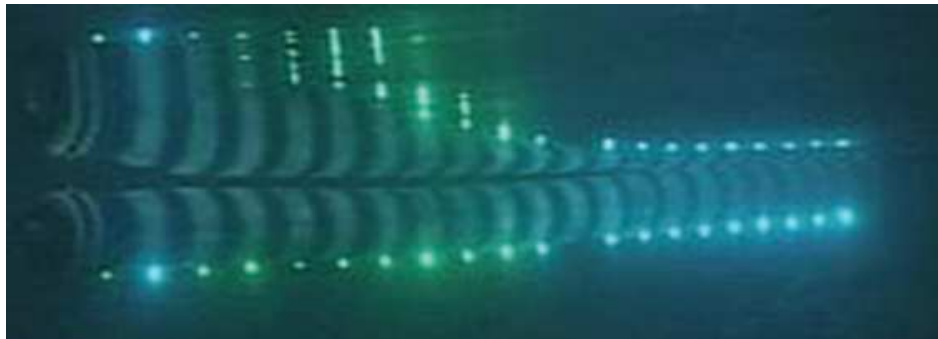
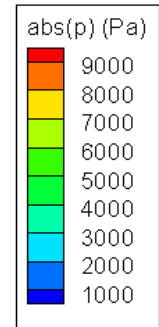
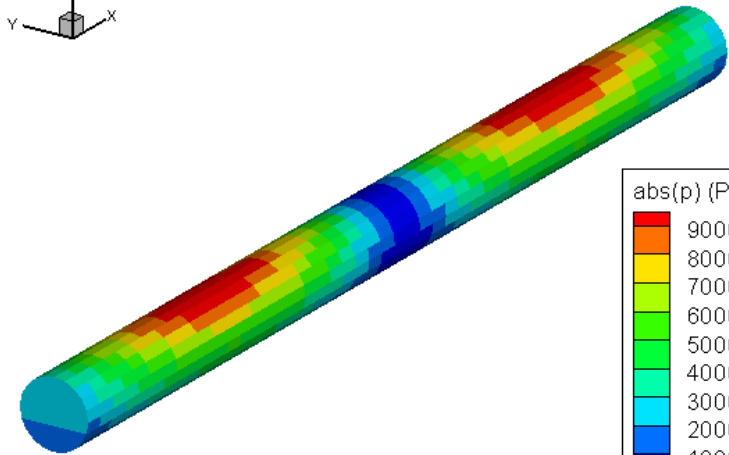
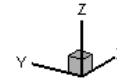


Calculations and experiments by Jarrah Orphin, Mats Sonderstup Rohe, Jonas Bjerg Thomsen

Applications

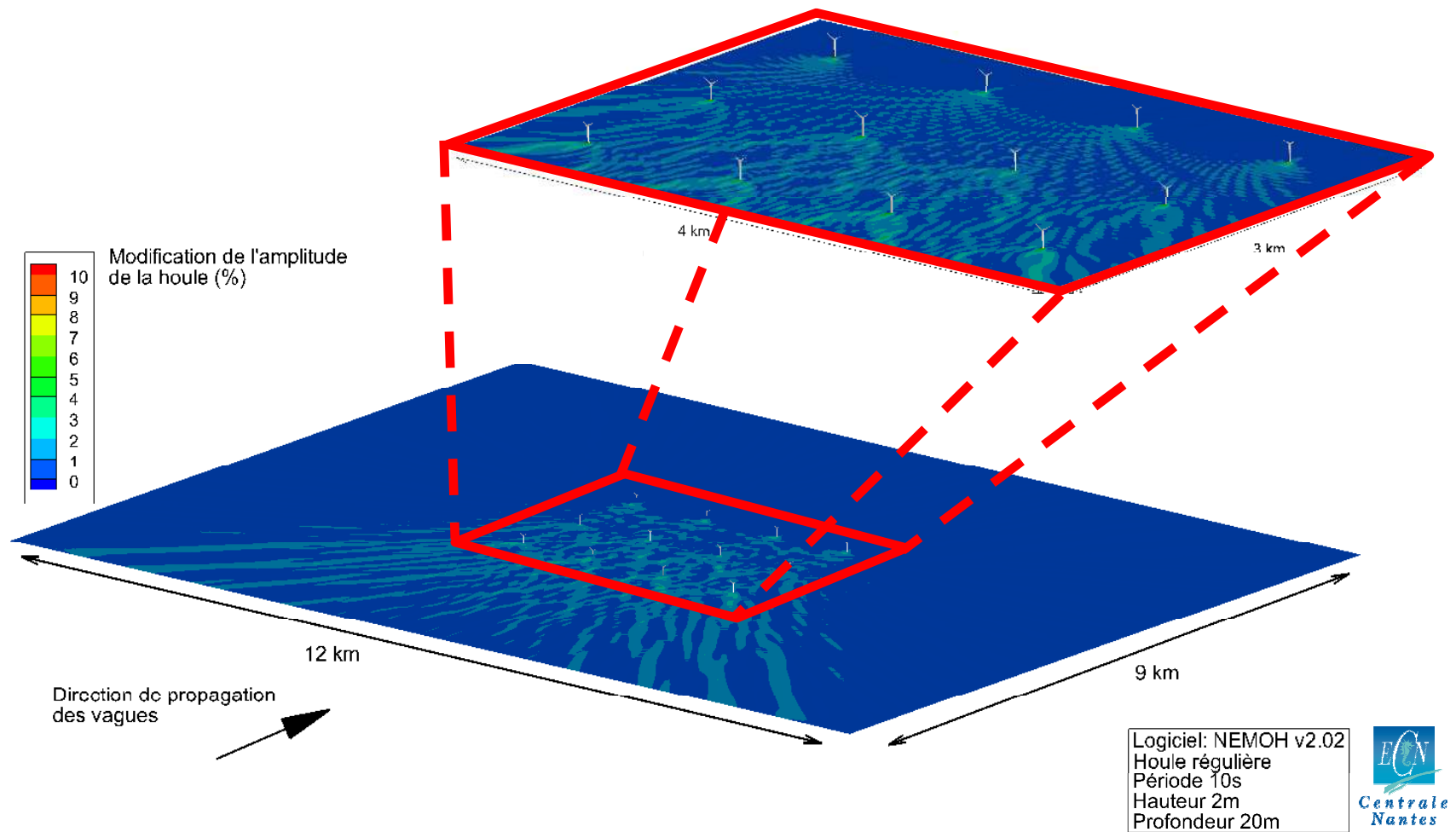
> Bulge motion of a flexible tube

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



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 !
- > Acknowledgements: financial support of French National Research Agency (ANR, projects MONACOREV ANR-11-MONU-018-01 and LabexMER ANR-10-LABX-19-01)