Fully nonlinear Froude-Krylov forces for floating offshore wind turbiness

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Background and Aim:

Standard engineering tools employ linear or weakly nonlinear potential flow models for hydrodynamic forcing of floating wind turbines. Computational fluid dynamics models have been applied but remain too expensive for long-duration sea-states.

Fully Nonlinear Potential Flow (FNPF) models, such as REEF3D::FNPF [1], offer a precise representation of wave kinematics, at lower computational cost.

Using a vertical floating cylinder as a simple case-study, this work aims to improve the accuracy of wave-induced forces by embedding Nonlinear Froude-Krylov (NLFK) forces obtained from REEF3D::FNPF and integrating these with a time-domain mooring system model in OrcaFlex.

Methodology:

- ***Treatment of Structure Mesh:***

The structure is created in Sesam GeniE, or any other mesh creation tool, and three parameters are calculated: Centroids of panel element, panel areas and panel normal.

- ***Pressure Interpolation:***

From the output of REEF3D::FNPF[1]; pressures are first calculated via the nonlinear Bernoulli equation and then a *linear interpolation* scheme is applied to get pressures at the mesh centroids.

- ***Time Domain Implementation:***

At each timestep in Orcaflex the external function is called; the position and orientation of the body are passed to the external function and the 1x6 NLFK force (minus linear force) is returned.

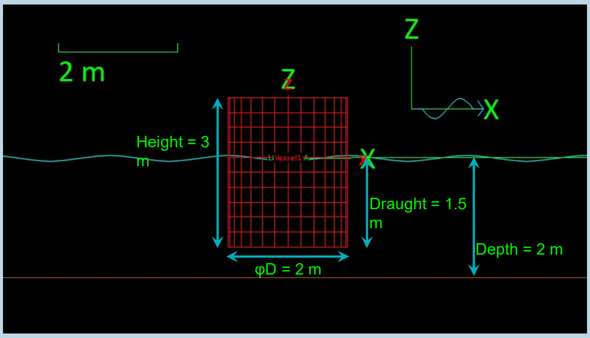

Fig 1: *Numerical setup of cylinder in Orcaflex.*

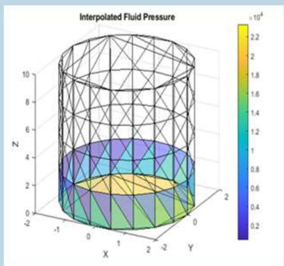

Fig 2: *Pressure Interpolated on the triangular mesh based on fluid velocity input. A simple hydrostatic case in very coarse mesh is shown here.*

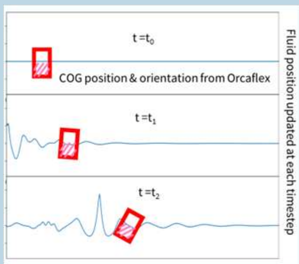

Fig 3: *Time domain implementation of the scheme to estimate nonlinear forcing on the structure; structure position and orientation is updated from Orcaflex*

Numerical Setup – Waves / Structure:

A numerical convergence study is conducted to test sensitivity to wave grid size and structural mesh length.

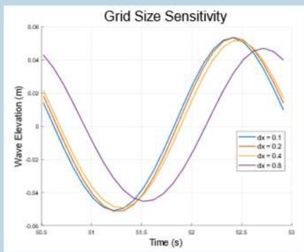

Fig 4: *Grid Sensitivity for a linear regular wave, amplitude of 0.05 m and wavelength of 8 m. Timestep is fixed at 0.1 s*

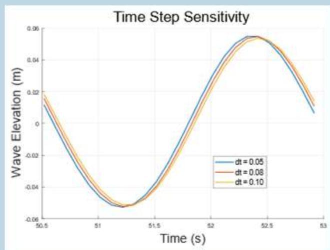

Fig 5: *Timestep sensitivity for a linear regular wave of amplitude 0.05 m and wavelength of 8 m. Wave grid size is fixed at 0.2 m.*

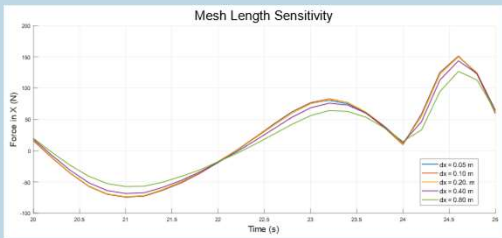

Fig 6: *Mesh length sensitivity of the cylinder structure used. Diameter of 2 m and height of 3 m.*

Herein we choose:
Wave grid size = 0.2 m;
Timestep size = 0.1 s
Structure mesh length = 0.25 m

Results:

➢ *Fixed Structure in Linear Waves*

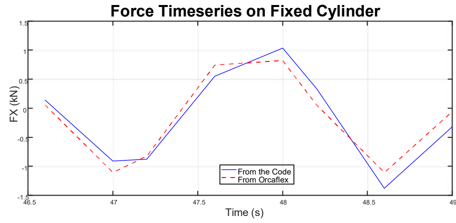

Fig 7 : *Force in x; from Orcaflex and the proposed Methodology.*

	RMSE		
D\λ	2	1	0.5
Fx (kN)	0.0453	0.151	1.7799
Fy (kN)	0.0019	0.0019	0.0019
My (kNm)	0.0538	0.365	1.6646

Tab 1: *RMSE of wave forcing on a fixed circular cylinder for different wavelength. Note that wave amplitude is 0.05 m in all cases*

➢ *Floating Structure in Linear Waves*

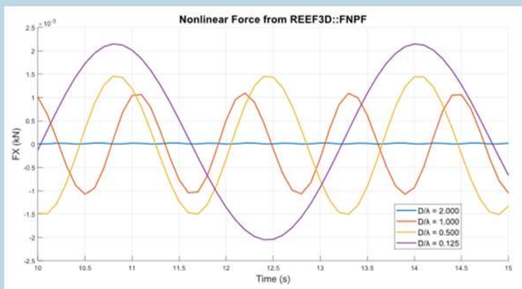

Fig 8 : *Nonlinear wave forces on a floating cylinder in different waves of amplitude 0.05 m. Diameter of 2 m and Height of 3 m.*

The nonlinear forces obtained using REEF3D::FNPF accounts for a maximum of 1% of the first-order wave forces. This seems reasonable given the linear nature of the waves used.

Future Work:

- Use of higher amplitude nonlinear waves for more representative wave loads.
- Apply method to spar-buoy/semi-submersible offshore wind substructures.

References

[1] Hans Bihs, Weizhi Wang, Csaba Pakozdi, Arun Kamath. REEF3D::FNPF—A Flexible Fully Nonlinear Potential Flow Solver. J. Offshore Mech. Arct. Eng. Aug 2020, 142(4): 041902, https://doi.org/10.1115/1.4045915

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