CFD Simulations of a Passively Controlled Point Absorber

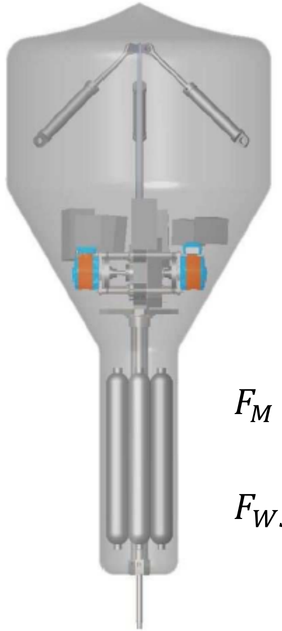
Minghao Wu, Weizhi Wang, Johannes Palm and Claes Eskilsson
Department of Shipping and Marine Technology
Chalmers University of Technology

Research Objectives

- Point absorber WEC – designed by CorPower
- CFD simulation – motion in regular waves
- PTO
- Passive control system

CORPOWER OCEAN

Passive control system – WaveSpring



$$F_{WS,z} = N_c p(z) A_c \cdot \frac{z}{\sqrt{l_0^2 + z^2}}$$

$$F_M + F_{PTO} = (-k \cdot \Delta l - F_{Pre} - C_{PTO} \cdot u_1) \cdot \boldsymbol{n}_1$$

$$F_{WS} = F_{WS,z} \cdot \boldsymbol{n}_1$$

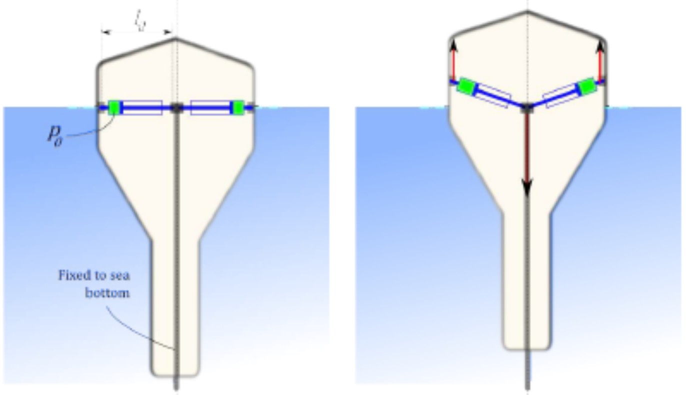


Fig. 5. Illustration of how the buoy displacement induces a vertical spring force with negative stiffness. Buoy in mean vertical position (left) and displaced upwards (right).

Hals et al (EWTEC 2015)

Hydrodynamics Modellings

BEM

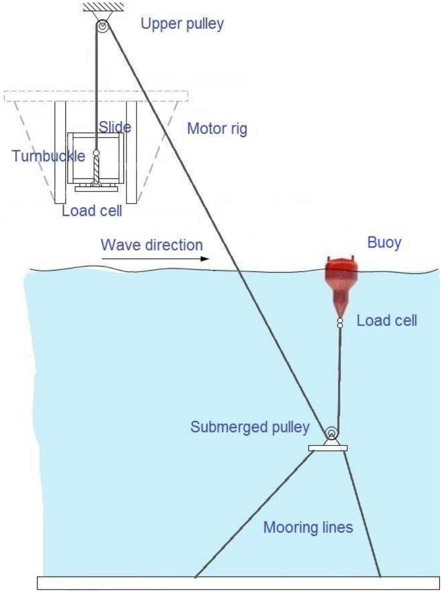
- **Small** amplitude assumption
- **Small** motion assumption
- Viscous term simplified
- Overtopping not captured
- Some 2nd order effects included (eg. drift, QTF etc)
- Nonlinear source term included in time-domain simulation
- **FAST** computation

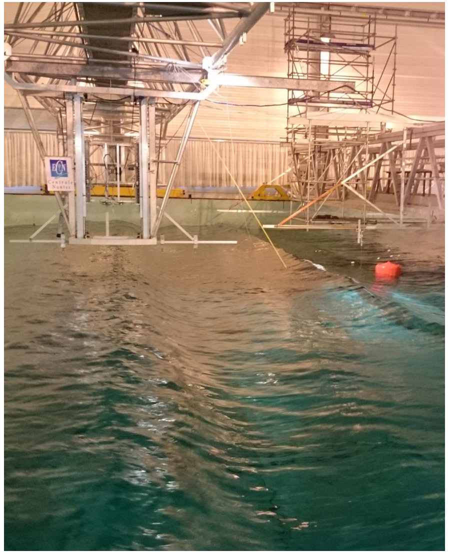
CFD

- Nonlinear effects **'All-inclusive'**
- Single fluid approximation
- Multiphase through (often) VOF
- Turbulence models
- **SLOW** COMPUTATIONS

Physical Experiments

- Hals et al (EWTEC 2015)
- Wave basin in Nantes
- 1:16 scale buoy
- PTO Linear damper
- No mooring – linear spring
- WaveSpring





Hals et al (EWTEC 2015)

Numerical modellings

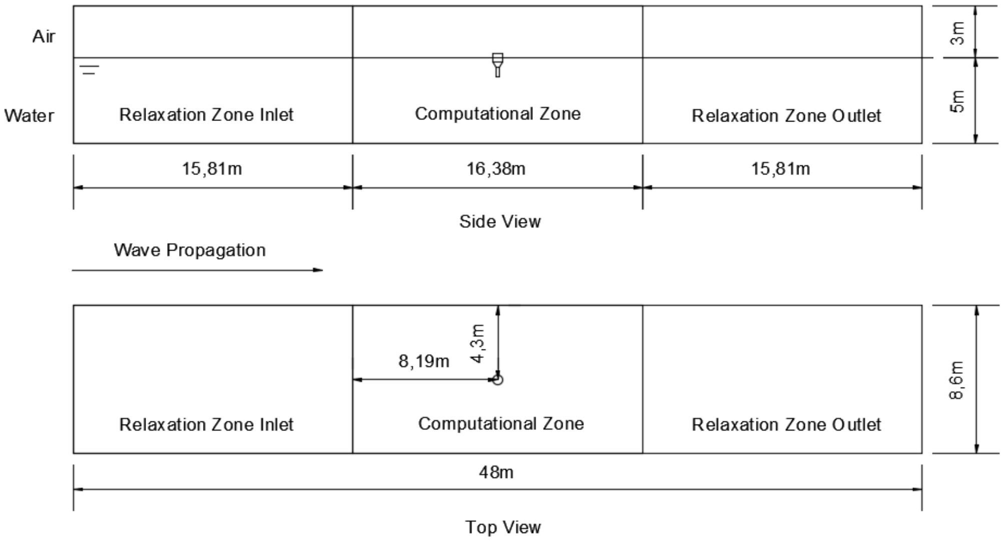
Method

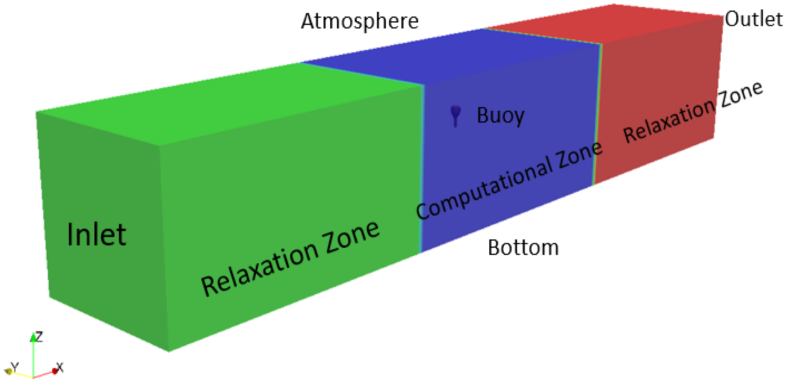
- URANS
- VOF
- NWT
- Fluid to floating-body interaction

Solver

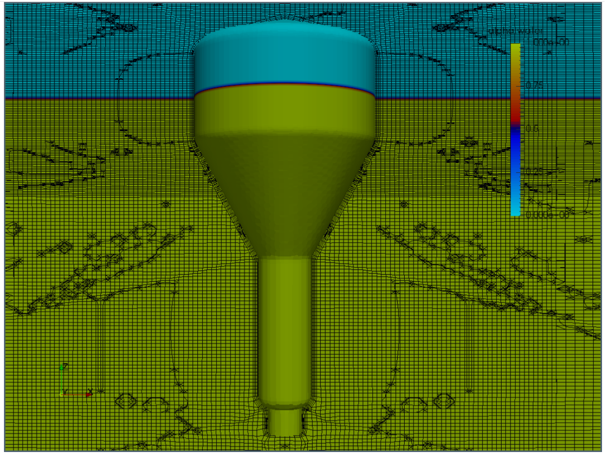
- OpenFOAM package
- Fluid domain – ***interDyMFoam***
- 6DOF - ***sixDoFRigidBodyMotion***
- Pre-tension mooring , PTO, WaveSpring – **in-house coding**
- Wave generation – ***waves2Foam***

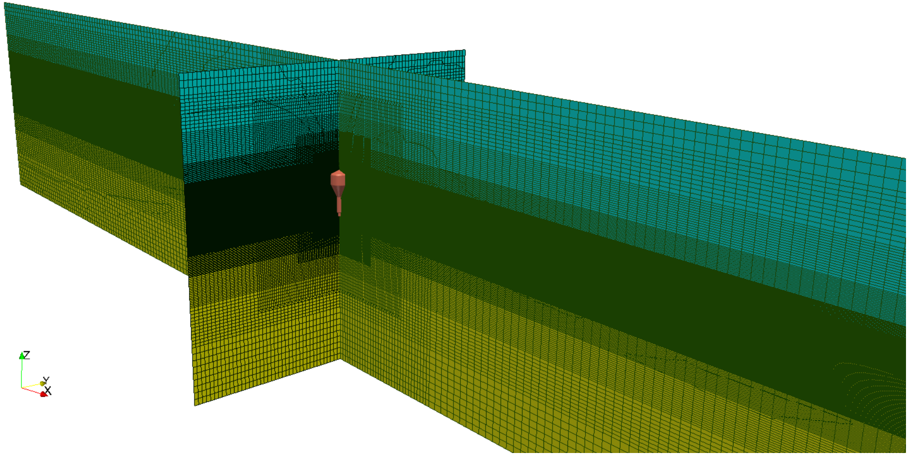
Numerical settings - domain





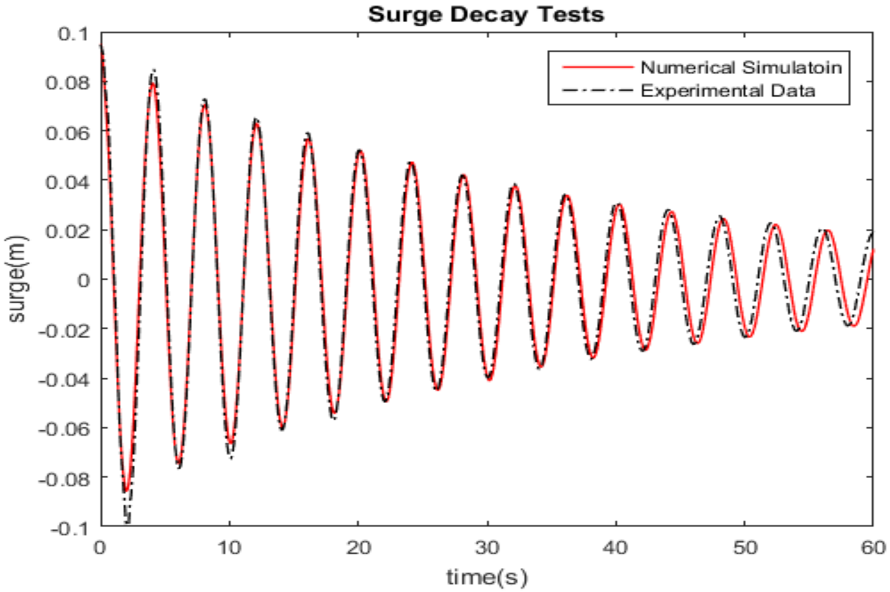
Numerical settings - grids





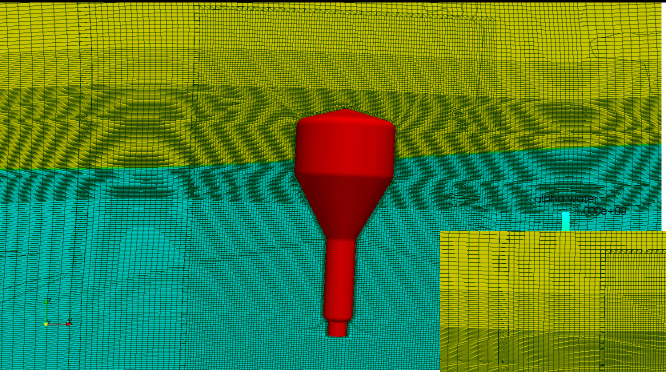
Surge Decay

- 10M cells
- Initial horizontal offset 0.1m
- Linearized damping ratio
- Average periods

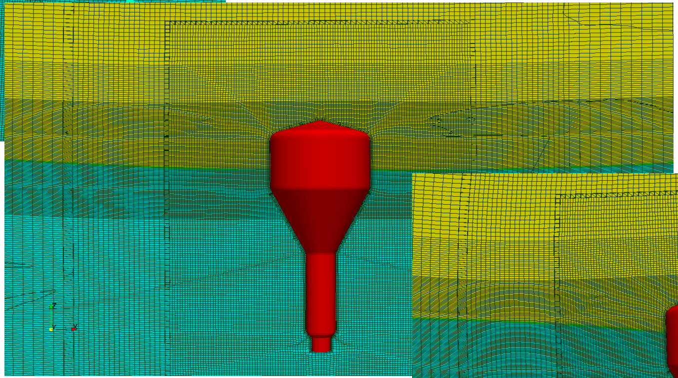


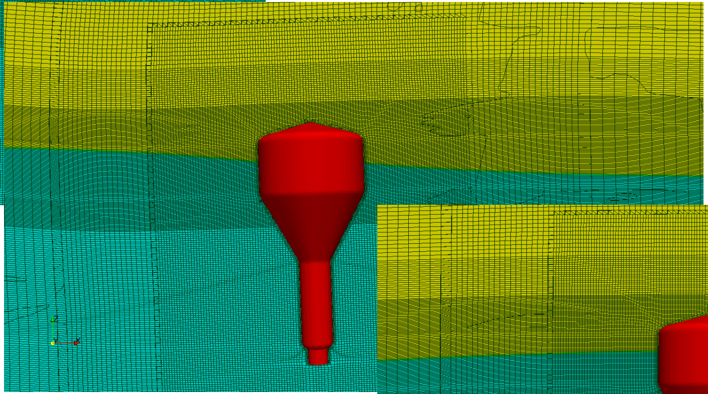
Results	Exp	CFD	Rel. error
Average period, T (s)	3.98	4.03	1.26%
Damping ratio	0.00955	0.0875	-8.32%

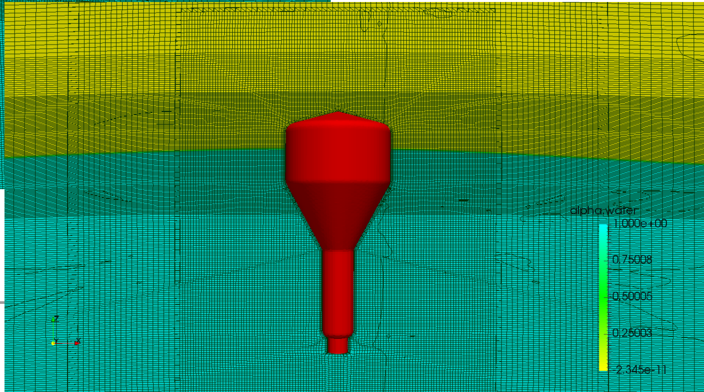
$$\delta = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{t_{Trough,i} - t_{Peak,i}}\ln\frac{a_{Trough,i}}{a_{Peak,i}}$$



With linear damper PTO

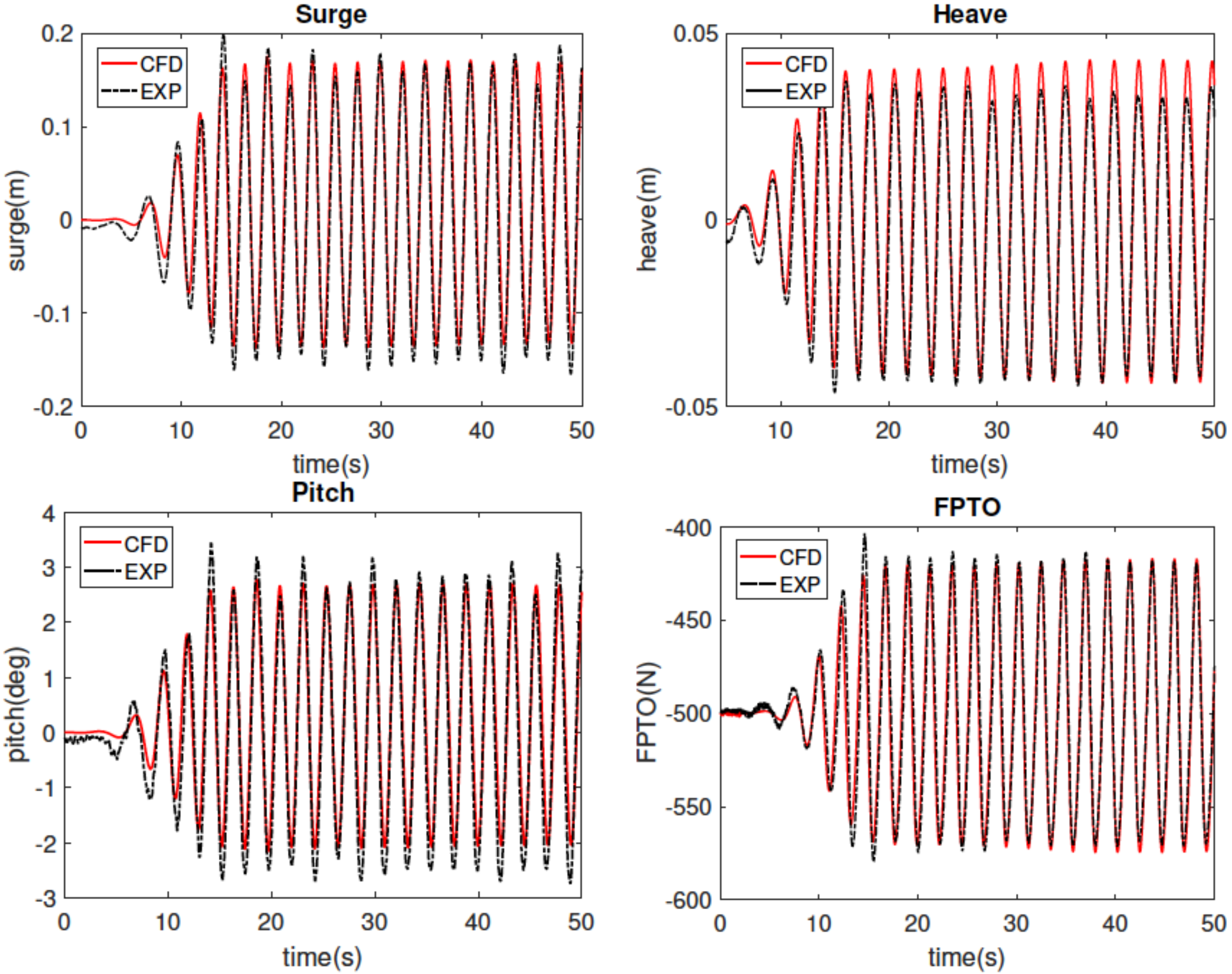






- 10M cells
- Regular waves
  T=2.25s
  H=15.6cm
  H/L=0.02
- Sensitive to pre-tension (3%)

PTO only

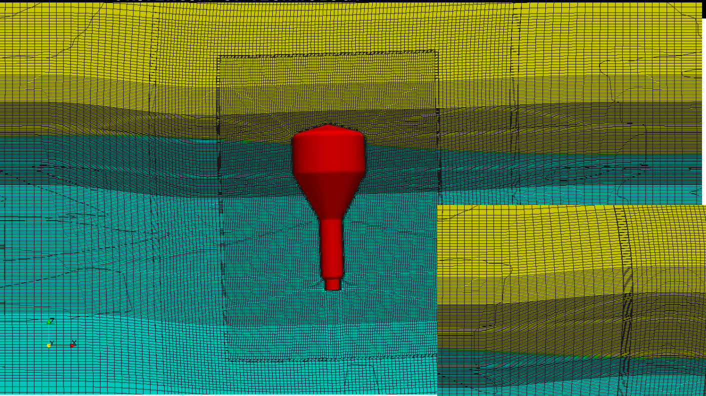


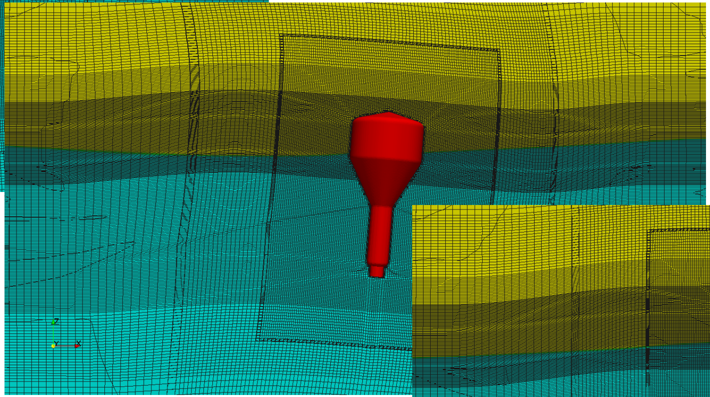
- 10M cells
- Regular waves
  T=2.25s
  H=15.6cm
  H/L=0.02
- Sensitive to pre-tension (3%)

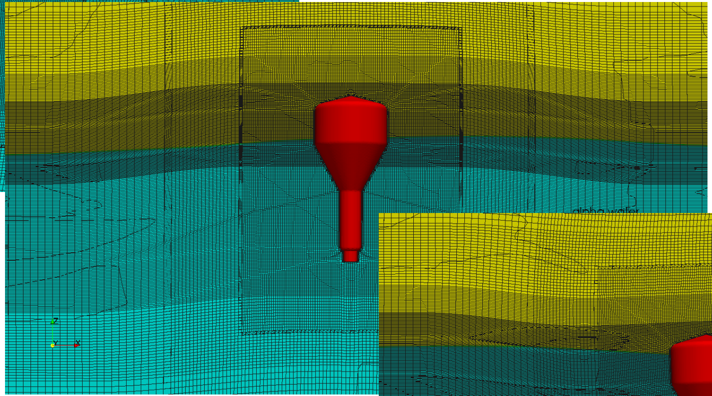
PTO only

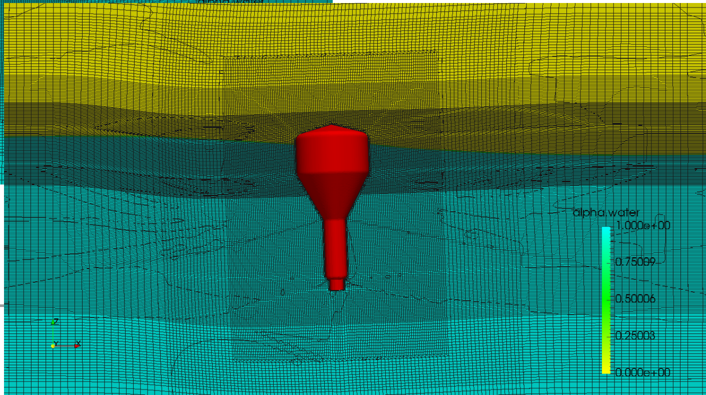
Results (Average double amplitude)	Exp	CFD	Rel. error
Surge (m)	0.3206	0.3037	-5.271%
Heave (m)	0.0771	0.0850	10.246%
Pitch (deg)	5.4426	4.7536	-12.659%
PTO-mooring system force (N)	153.64	154.41	**0.503%**

Hals et al (EWTEC 2015)







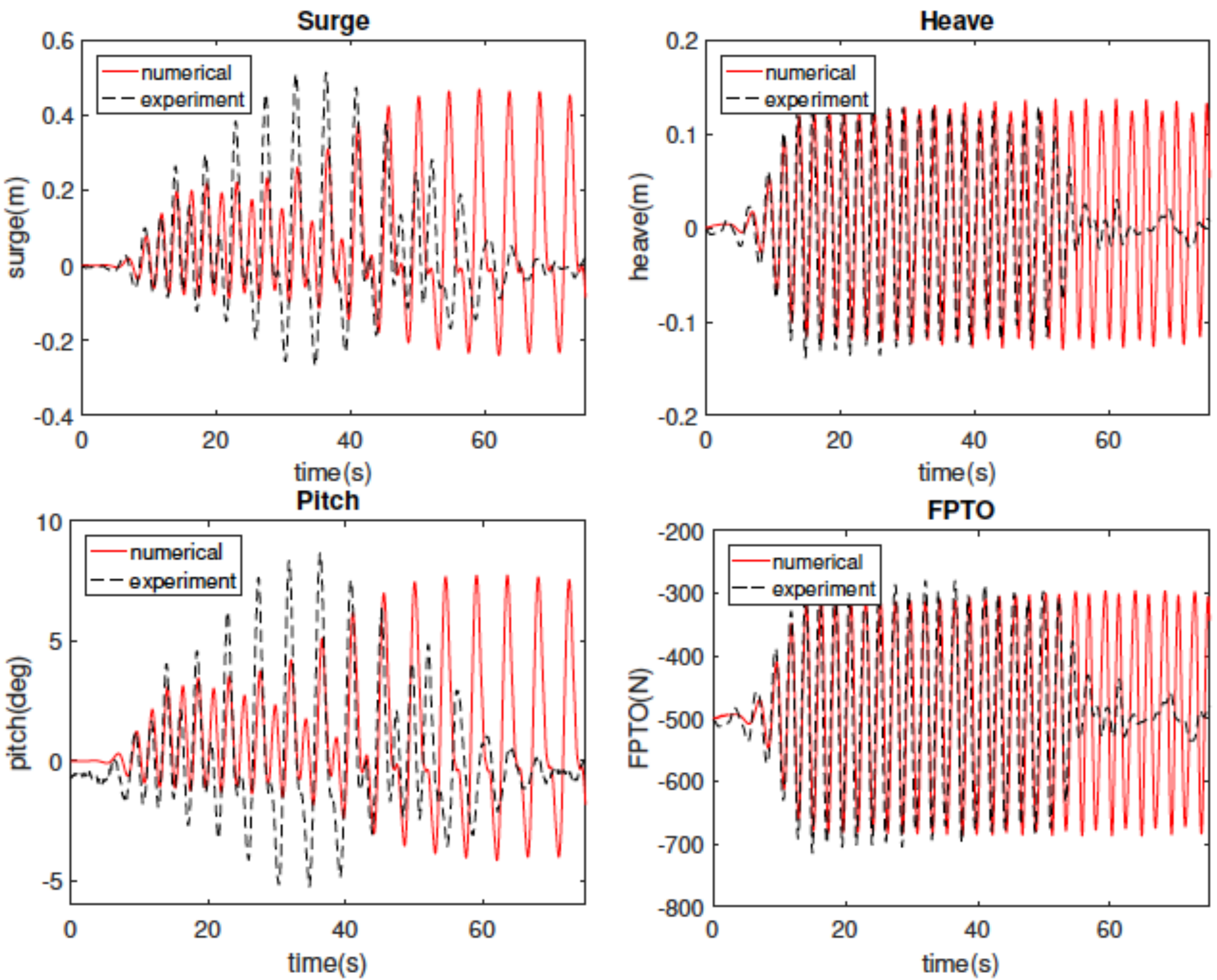


With WaveSpring and linear damper PTO

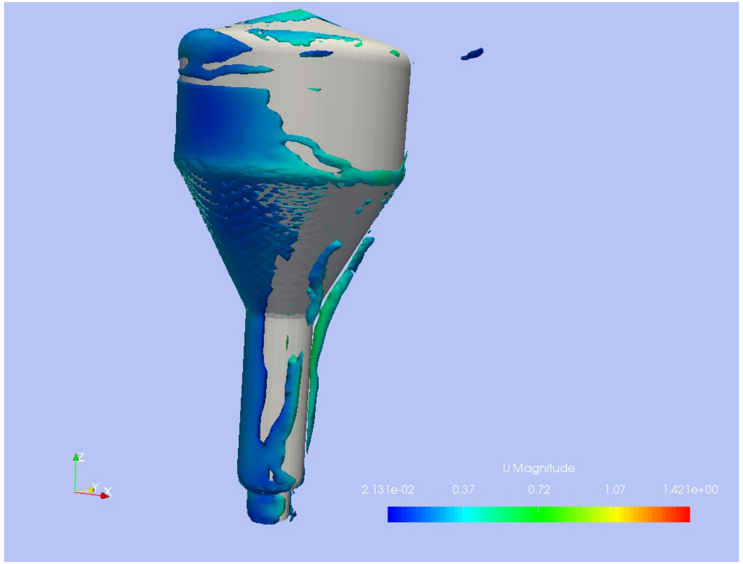
- 10M cells
- Regular waves
  T=2.25s
  H=15.6cm
  H/L=0.02
- Sensitive to pre-tension (3%)

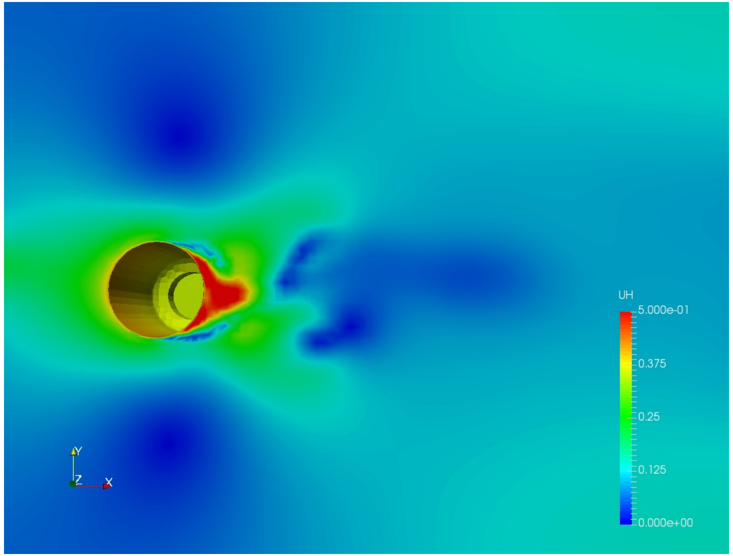
PTO+ WaveSpring

- 10M cells
- Regular waves
  T=2.25s
  H=15.6cm
  H/L=0.02
- Sensitive to pre-tension (3%)



PTO+WaveSpring





PTO + WaveSpring

Results	Experimental	Numerical	Rel. error
Maximum amplitude			
Surge (m)	0.7800	0.7068	-9.385%
Pitch (deg)	13.88	11.88	-14.45%
Averaged double amplitude			
Heave (m)	0.2541	0.2486	**-2.165%**
PTO-mooring system force (N)	399.96	370.77	**-7.298%**
WaveSpring force, F_{WS} (N)	383.19	365.14	**-4.710%**

Hals et al (EWTEC 2015)

Verification & Validation

- Numerical uncertainty (Eça & Hoekstra, JCP 2014)
  - **Discretization error**
  - **Iteration error**
- Modelling error (turbulence - ongoing)
- Geometry error (not performed)
- Domain error (done - no influence of width)

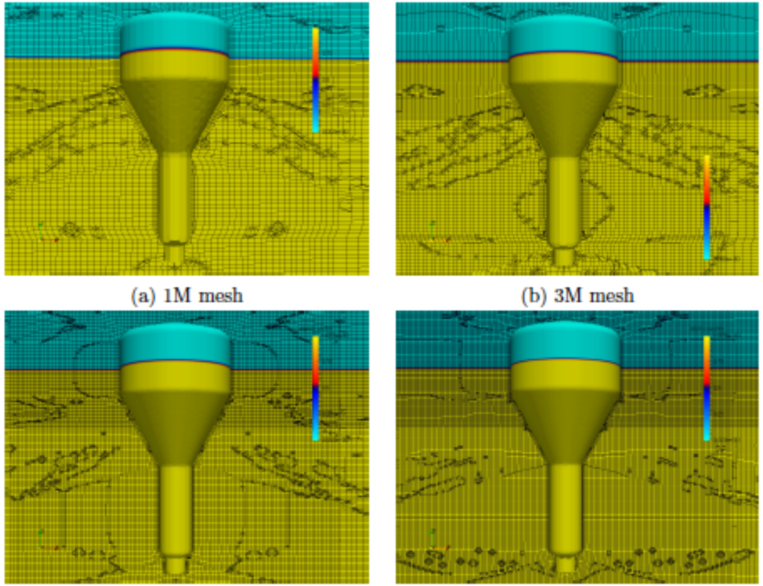
Verification & Validation procedure

Case name	1M	3M	10M	20M
Level 0 cell size x, y (m)	0.48	0.33	0.215	0.175
Level 0 cell size z (m)	0.33	0.25	0.167	0.136
Grid number	1075404	3082530	10886096	19934406
Grid within wave height	15	20	30	37
Max. y+ from simulation	208	131	49.2	99.7

$$\varepsilon = \delta_{RE} = \phi_i - \phi_0 = a h^p$$

$$U_\phi = F_S |\varepsilon|$$

$$x_{b\,ND} = x_b / H_0$$
$$z_{b\,ND} = z_b / H_0$$
$$\theta_{ND} = \theta / kH_0$$
$$RF_{ND} = RF / \rho g H_0 S_w$$

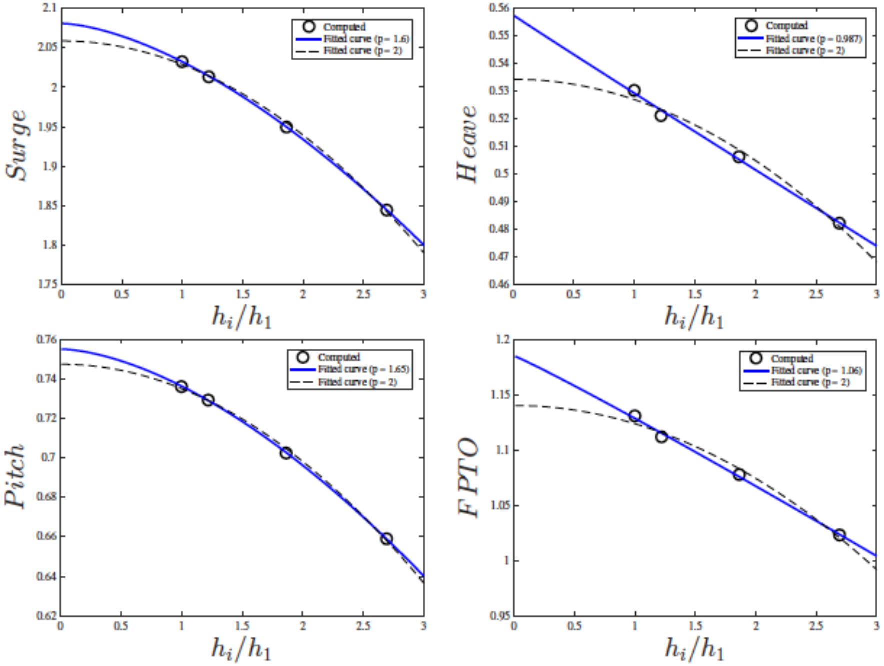


(a) 1M mesh (b) 3M mesh (c) 10M mesh (d) 20M mesh

Figure 6: Different mesh configuration near the buoy

Discretization error

Uncertainty	Surge	Heave	Pitch	Res.Force
20M	6.14%	3.77%	2.37%	7.53%
10M	8.45%	4.54%	3.29%	9.21%
3M	16.49%	6.76%	6.56%	14.31%
1M	29.61%	9.61%	12.02%	20.65%



Iterative error

Uncertainty	Surge	Heave	Pitch	Res.Force
5 iterations	0.907%	0.425%	1.354%	0.661%
10 iterations	0.095%	0.023%	0.090%	0.043%

- Should use 10 in order to keep iteration error two orders of magnitude lower than disc. error

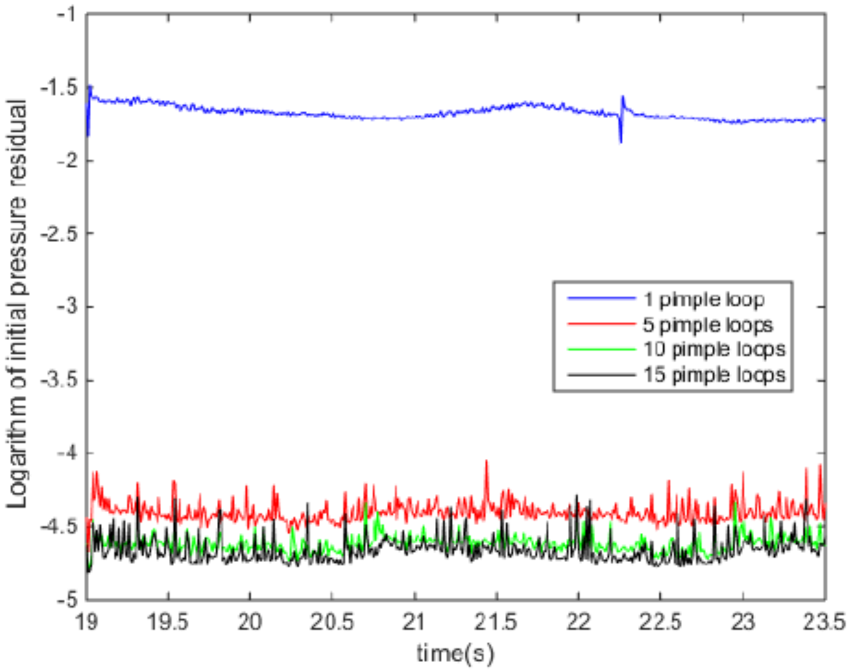


Figure 20: Initial pressure residual in the two periods

Concluding remarks

- 1 The innovative design of CorPower is validated with CFD
- 2 The WaveSpring system is well represented in CFD simulation
- 3 The numerical study shows 5-10% uncertainty

Thanks for your attention!