



Cyber-physical testing of floating wind turbine farm with shared mooring

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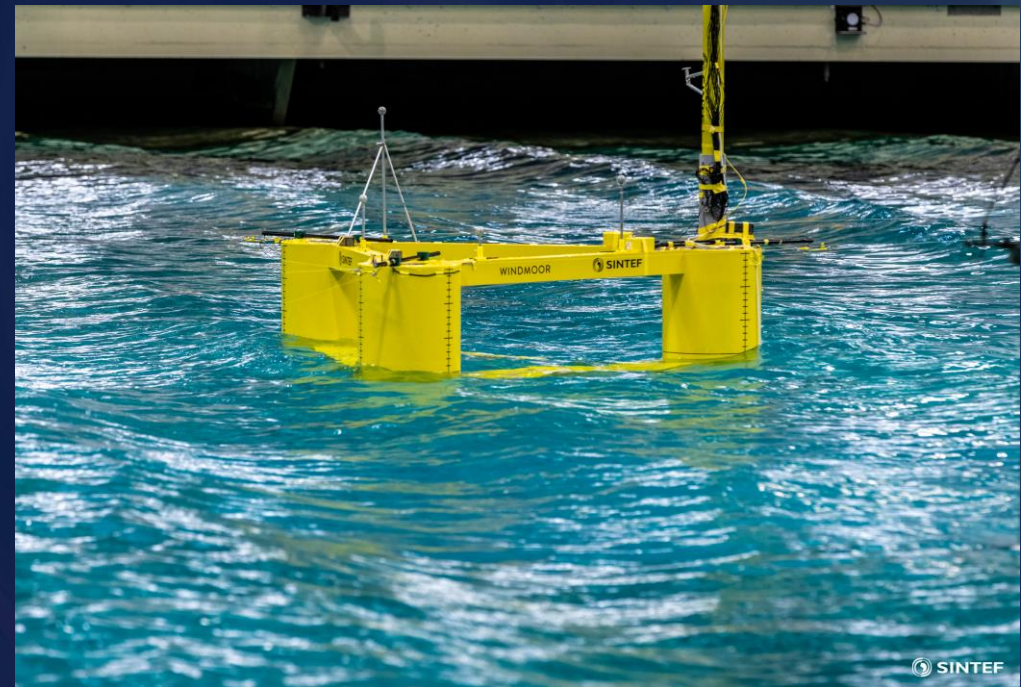
Background – the CYBERLAB project

- 4 years: 2022-2025
- Objective: understand the dynamic behaviour of floating wind parks with shared mooring
- Challenges:
 - Understanding the physics
 - Develop good analysis methods and numerical tools
 - **Upgrade our experimental methods ← subject of this talk**



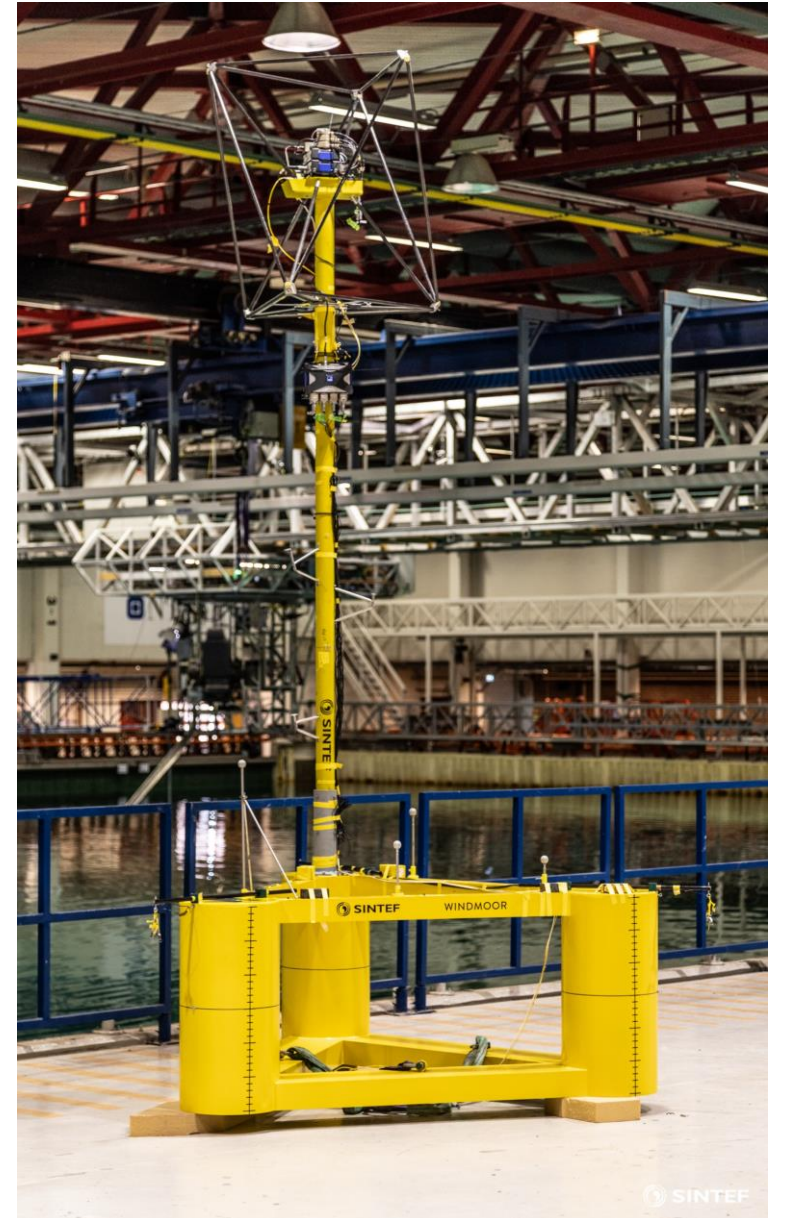
CYBERLAB Model test setup

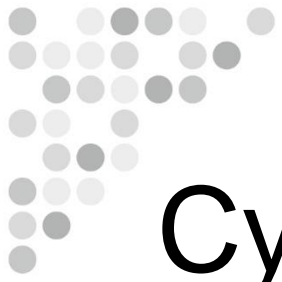
- KPN CYBERLAB Project
- Model: INO WINDMOOR 12 MW
- Cyber physical testing and its control system
- Performance of the setup



Model: INO WINDMOOR semisubmersible

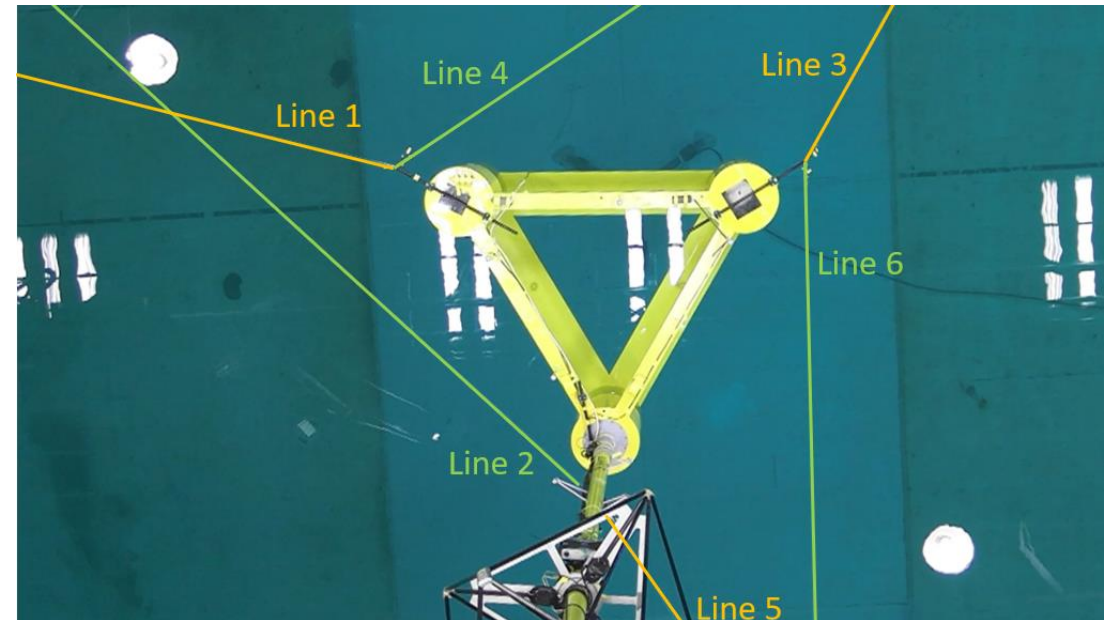
- Scale: 1:40
- Draft T = 15.5 [m]
- Mass = 14104 t
- Column diameter = 15 [m]
- Water depth: 200 [m]
- **Instrumentation**
 - 6DOF Motion Capture (MoCap)
 - 6x Mooring line forces transducers
 - 1x Gyro (3 axis)
 - Tower
 - 2x Accelerometer (3 axis)
 - Tower
 - Floater



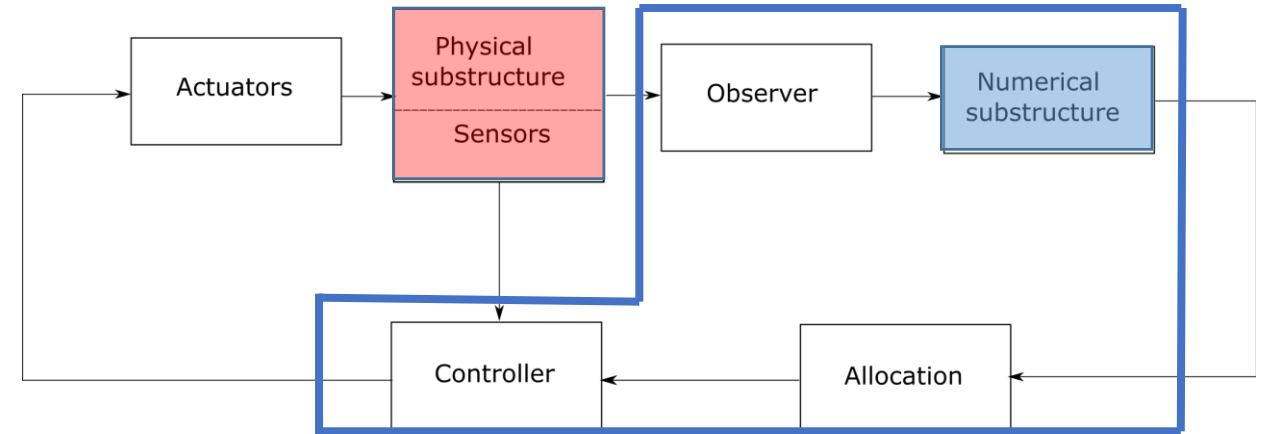


Cyber-Physical test setup

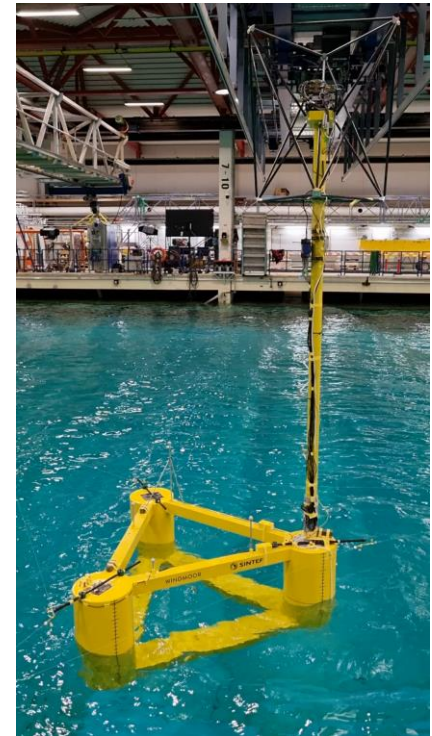
- 6x actuators placed around the basin
- Active horizontal mooring
 - Mooring forces are defined using a control system. Surge, Sway and Yaw (3DOF)
- Two main configurations:
 - Virtual mooring system with control of stiffness, damping and equilibrium position
 - External force input from a simulation
- Setup is configured to allow headings from 0-90 degrees



Control system

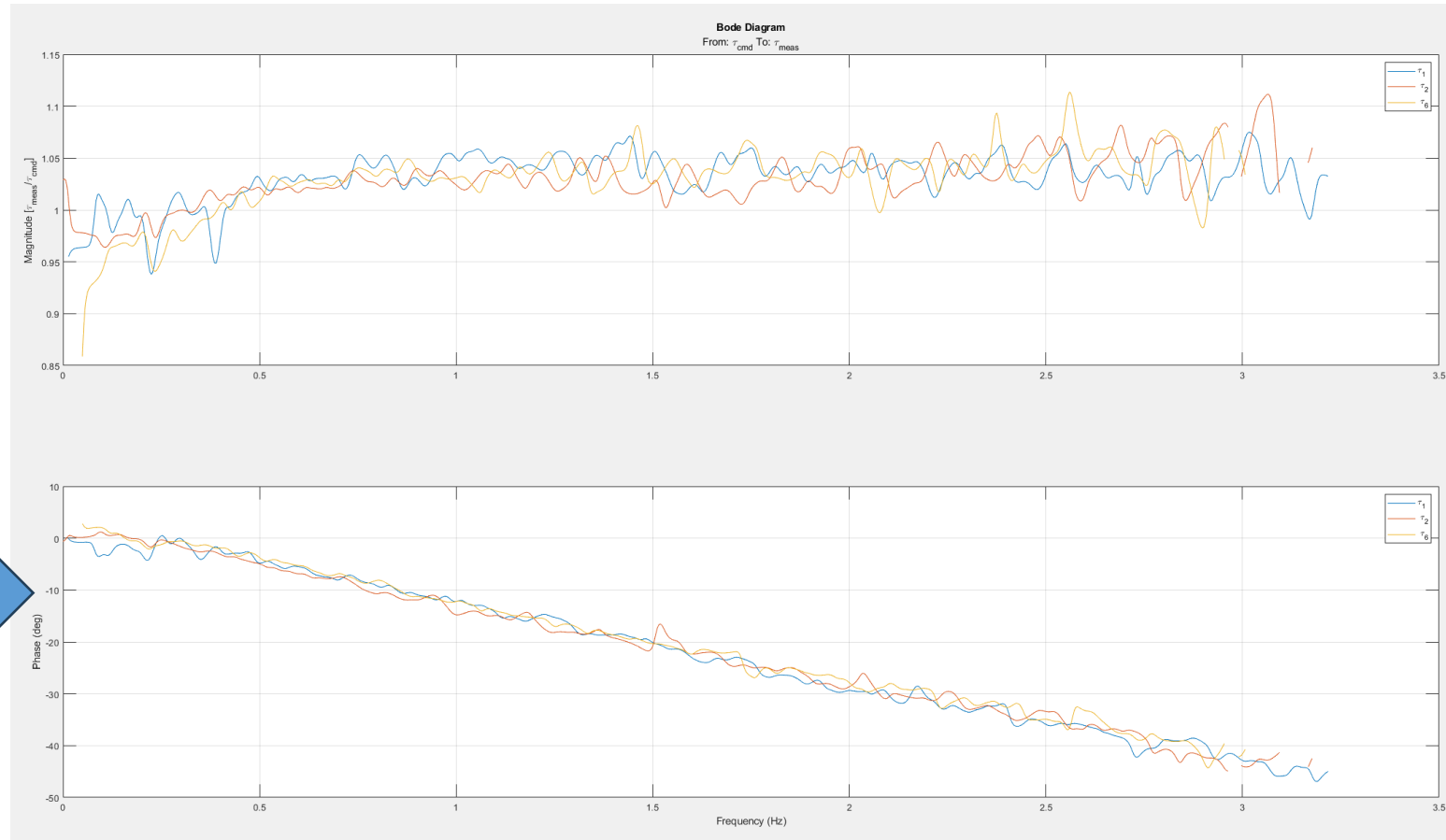
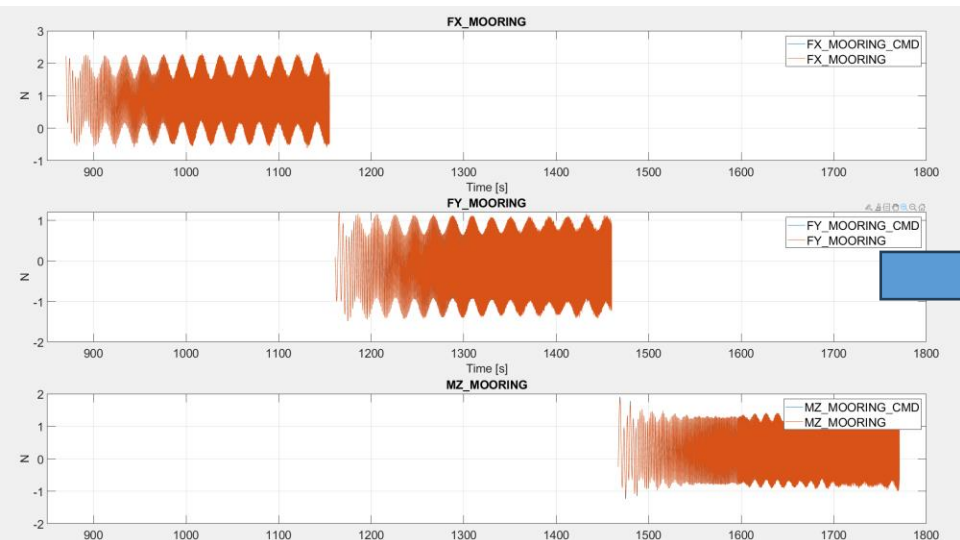


- Observer
 - Estimates position and velocity of origin
- Mooring “simulation”
 - Simulates forces based on position and velocity input
- Numerical model
 - FMU from SIMO (floating wind park)
- Allocation
 - $\tau_{cmd} \rightarrow T_{1-6}$
- Winch force controller (Controller)



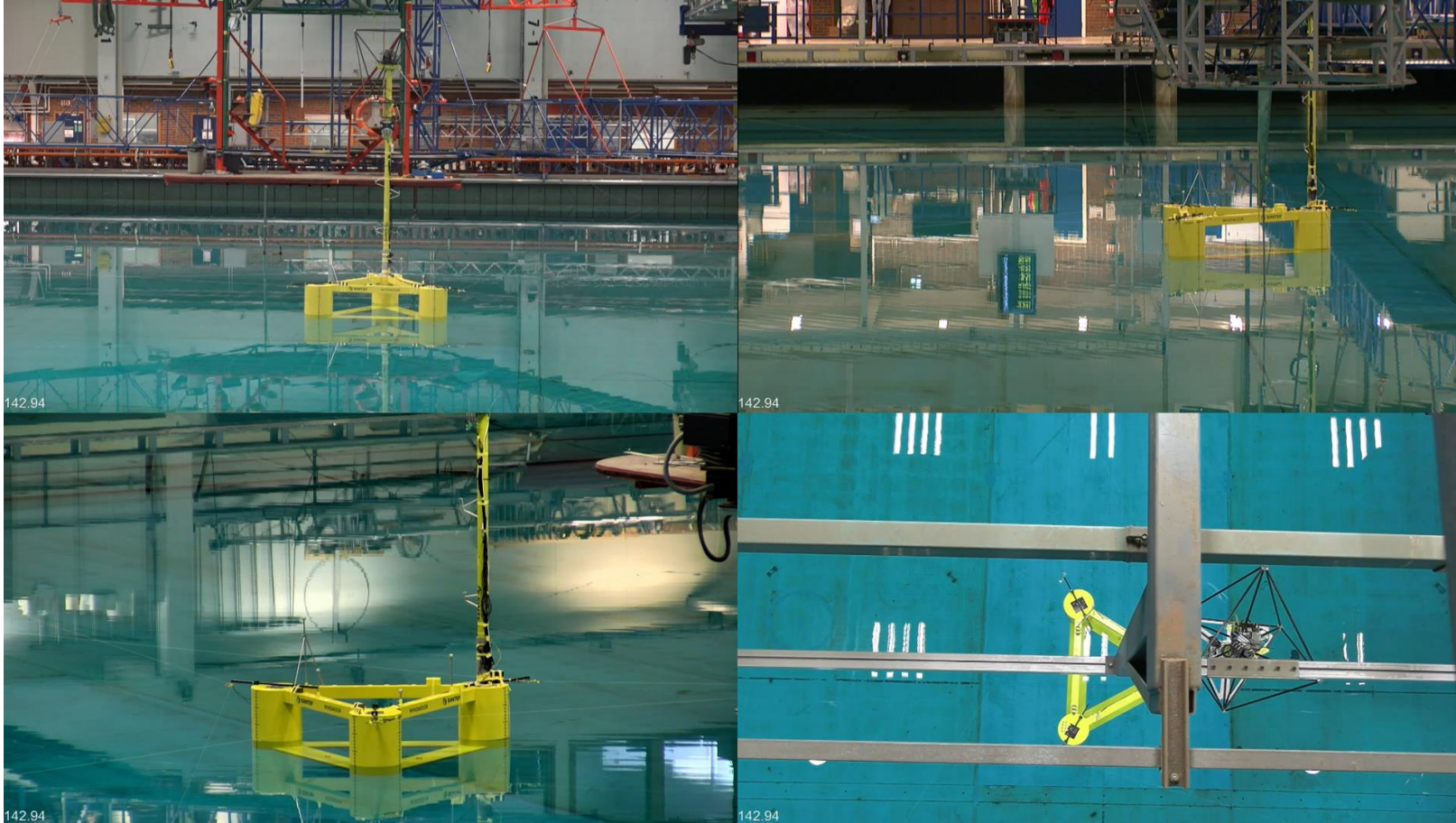
System performance

- Chirp in all DOF (0.2 → 4 [Hz])
 - Surge, sway and yaw
- Bode diagram → Approximately 40 ms delay





Heading change, $90^\circ \rightarrow 10^\circ$



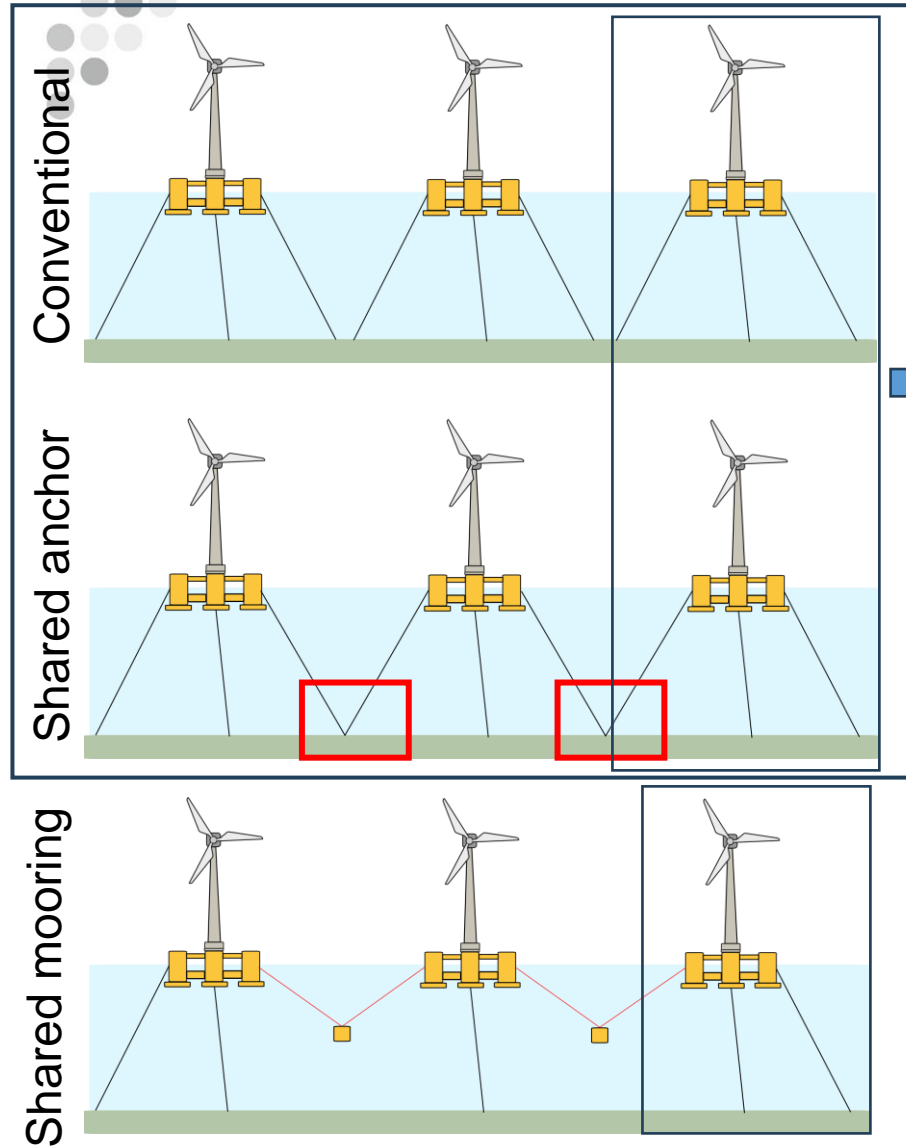


Shared mooring farm tests

- Shared mooring
- Substructures
- Tested farm configurations
- Pullout/Decay Tests
- Line breakage tests
- Conclusions

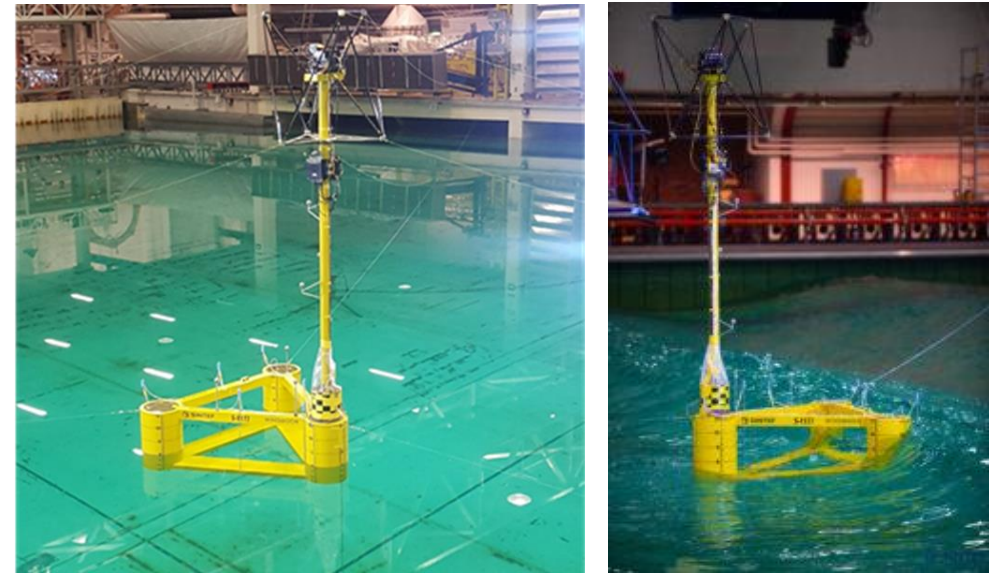


Shared mooring



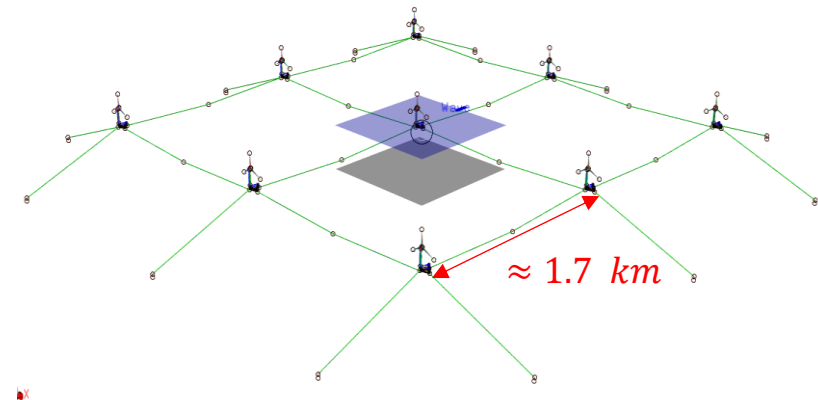
Model test ?

Decoupled platforms



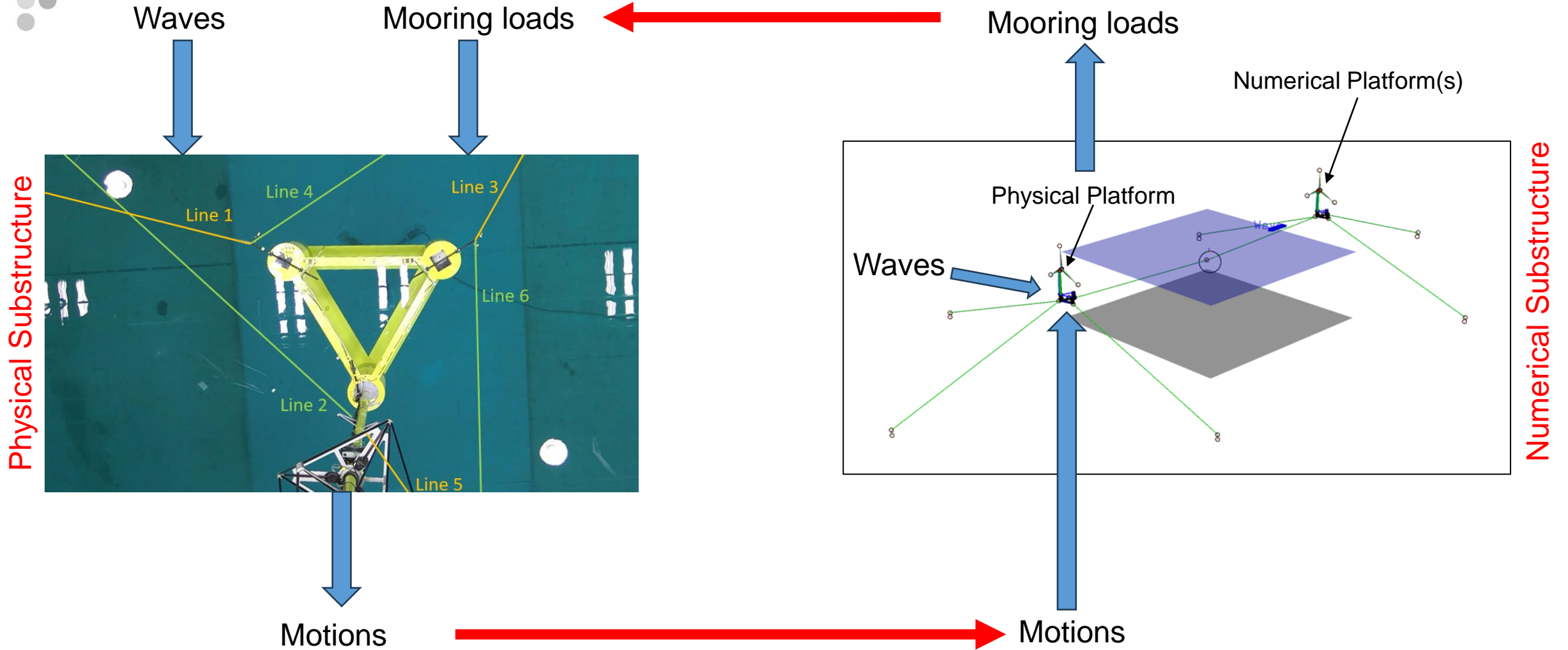
Coupled platforms

Scale down the farm ?



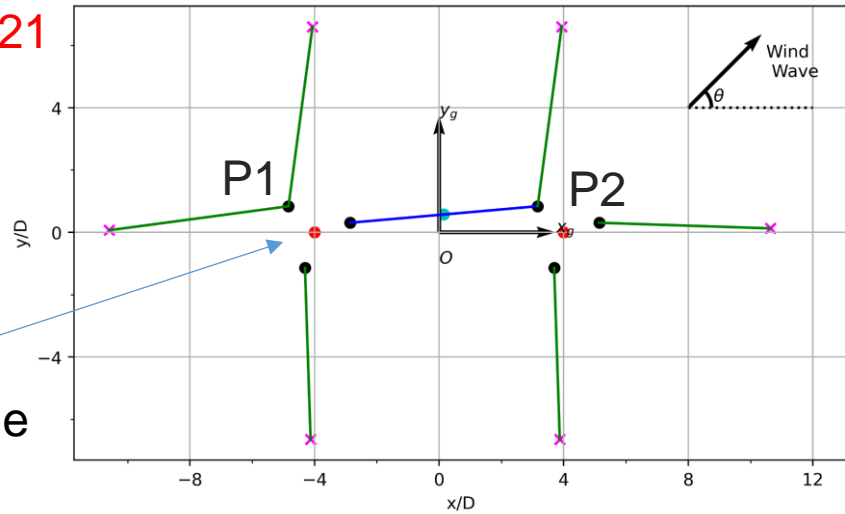


Substructures

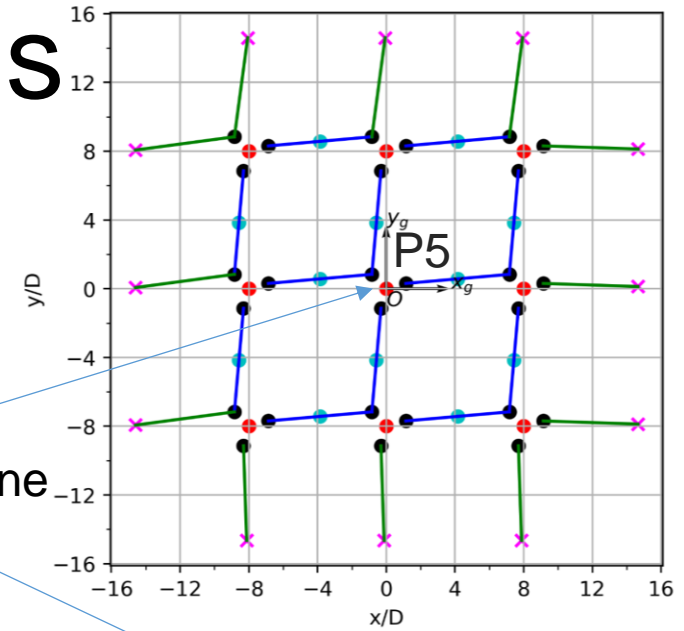


Tested farm configurations

Grid21

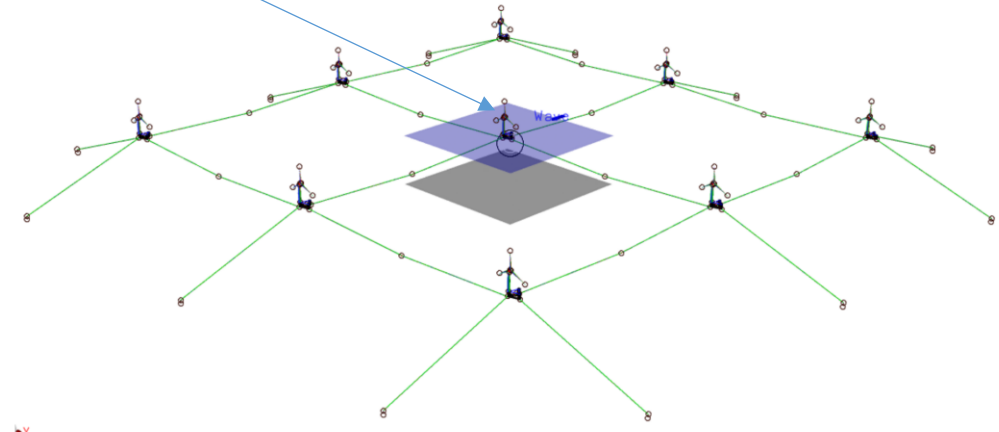
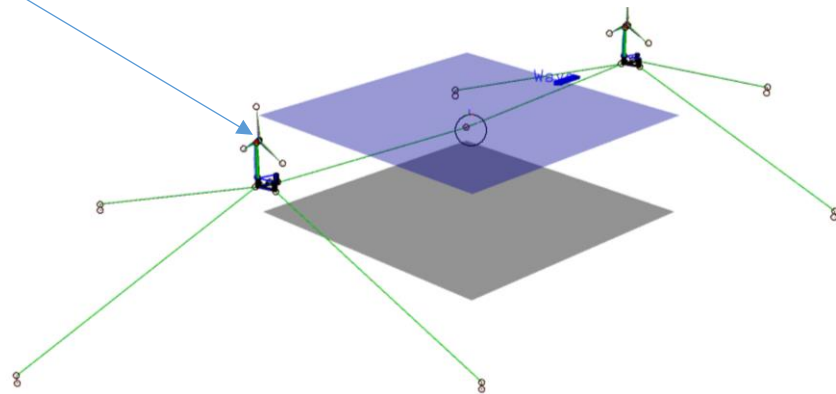


Grid33



Physical turbine

Physical turbine

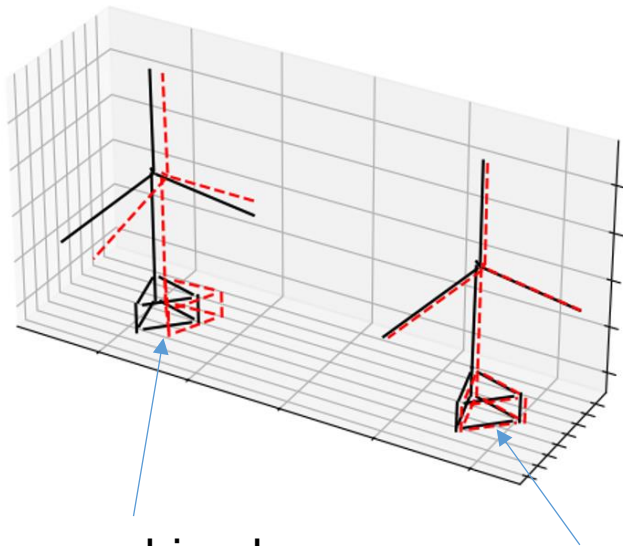


- x anchor
- fairlead
- shared line
- clump
- platform centre
- anchor line

Pullout/Decay tests

Eigenvalue analysis

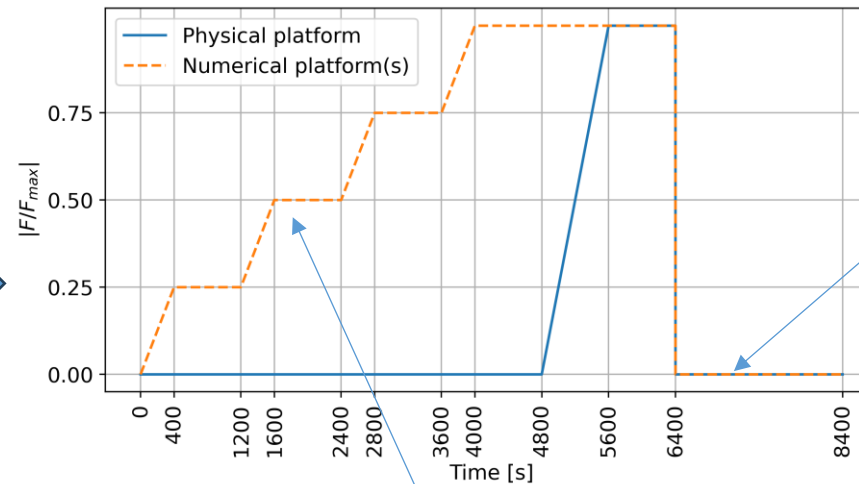
Mode : 1 | Period : 101.06 s



P1 – combined surge and yaw

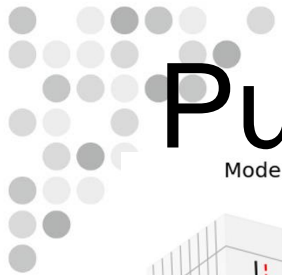
P2 – surge in phase with P1

Calculate the 'external' force which will produce the desired mode shape



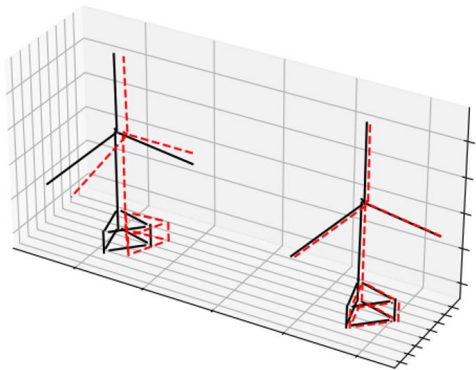
Drop the forces to zero to initiate decay

Apply the forces in steps → combine pullout tests with decay

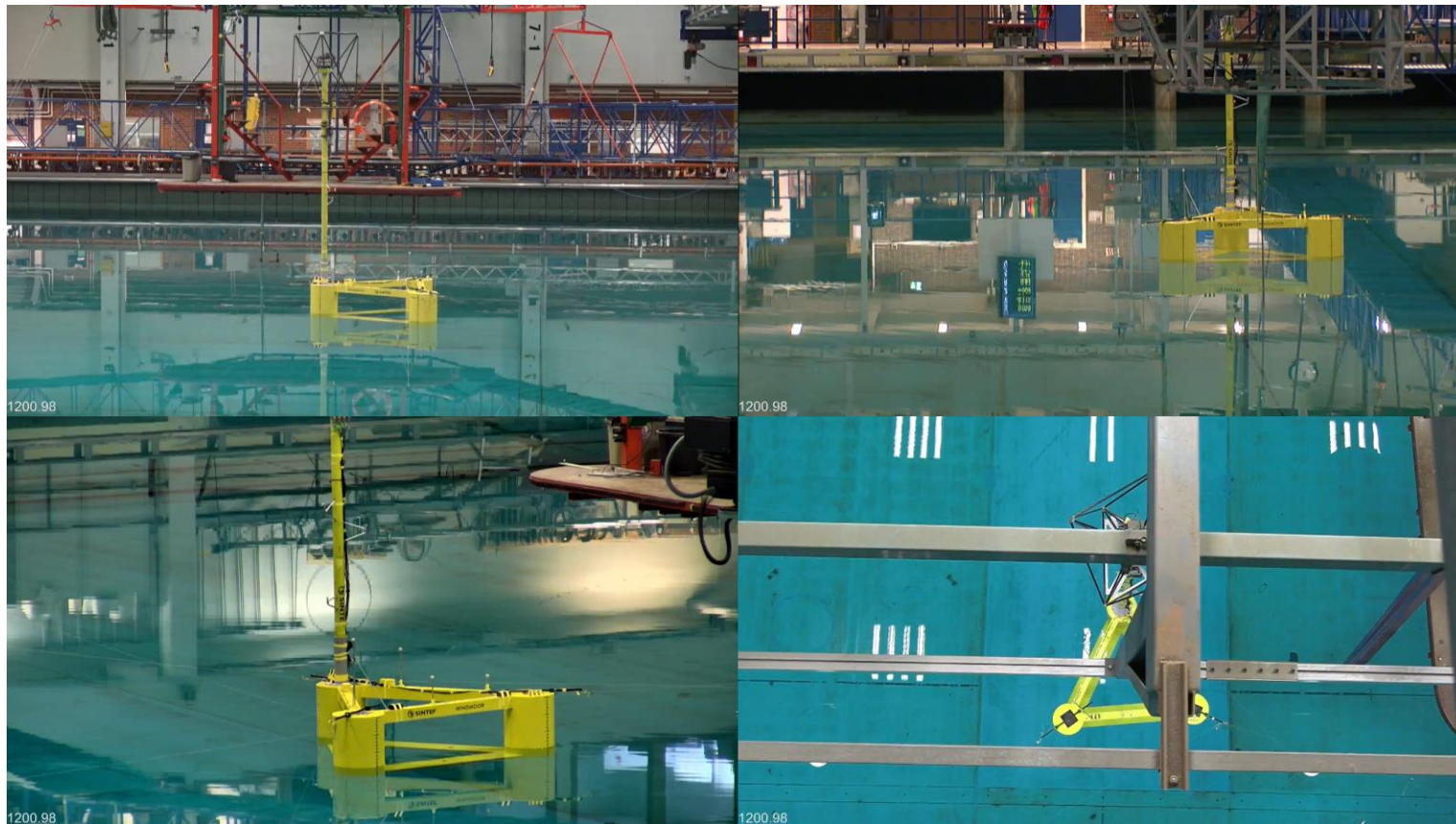
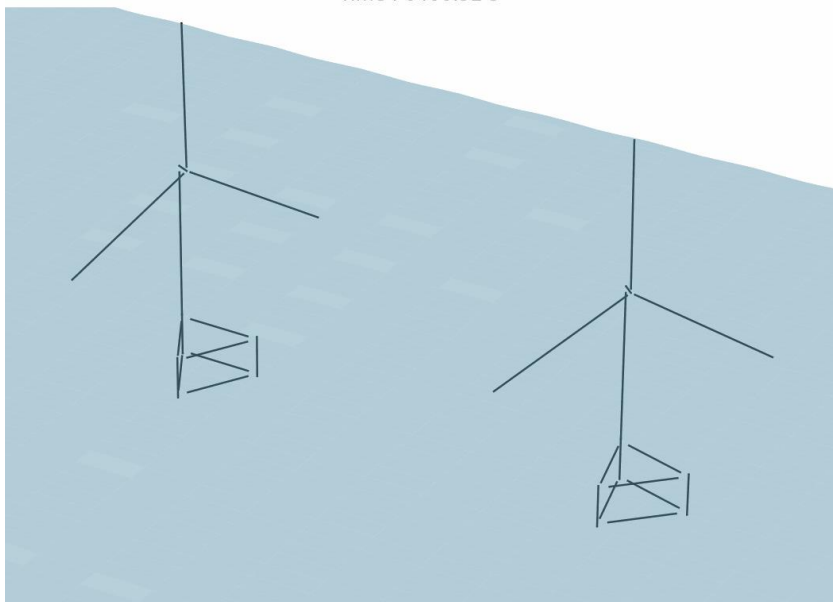


Pullout/Decay tests

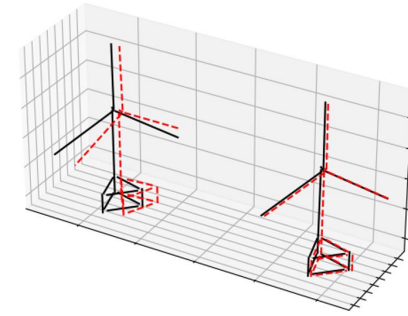
Mode : 1 | Period : 101.06 s



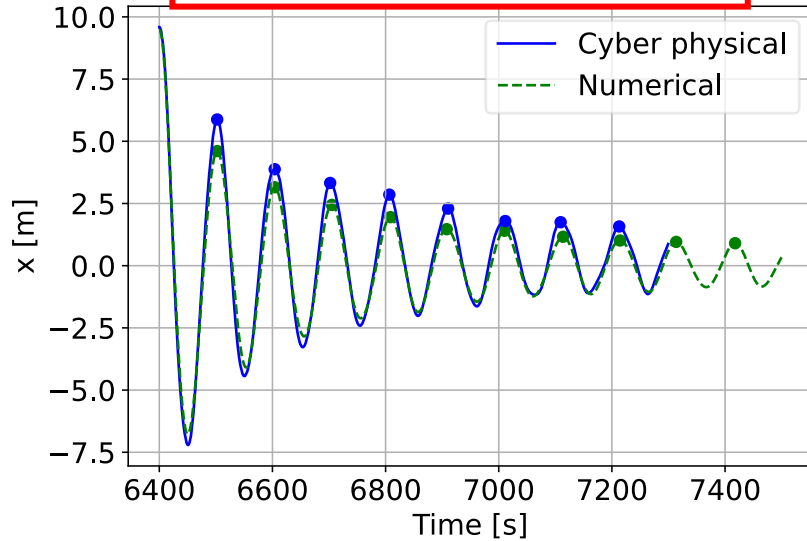
Time : 6400.92 s



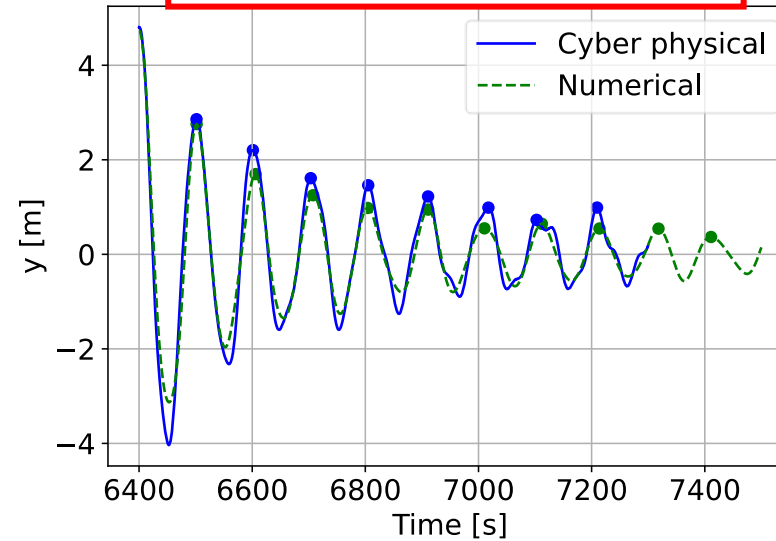
Pullout/Decay tests



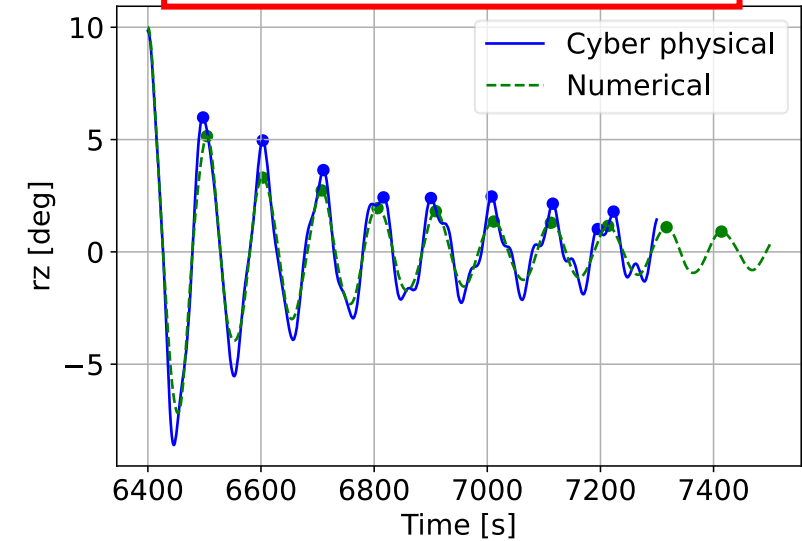
P1 x
Natural period sima : 101.71 s
Natural period exp: 101.52 s
variaton: -0.19%



P1 y
Natural period sima : 101.03 s
Natural period exp: 101.14 s
variaton: 0.11%



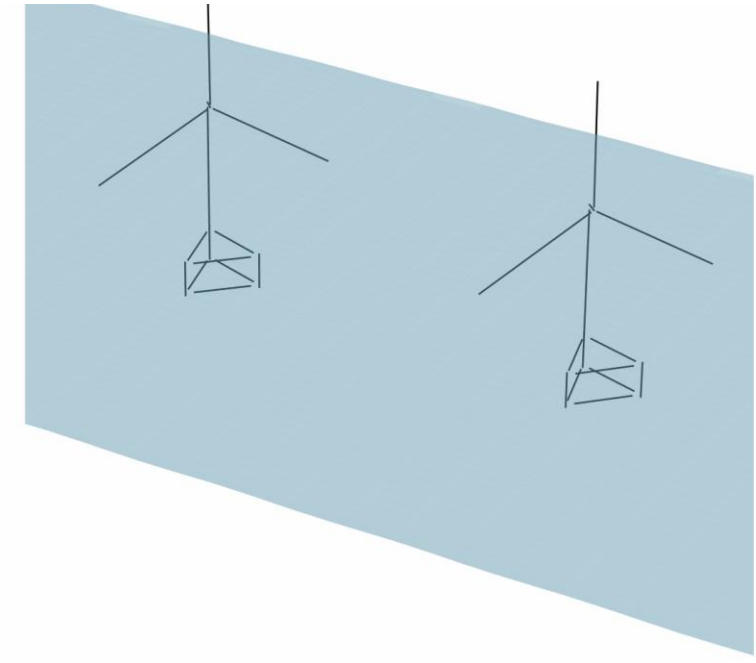
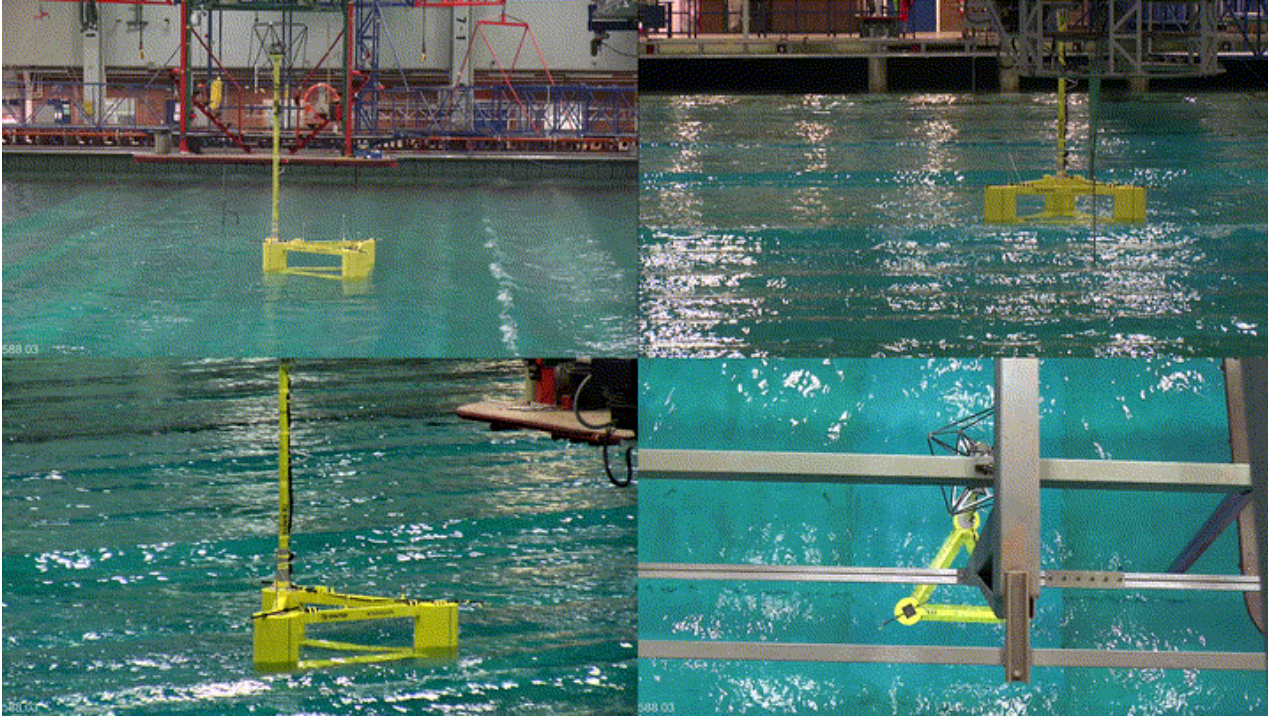
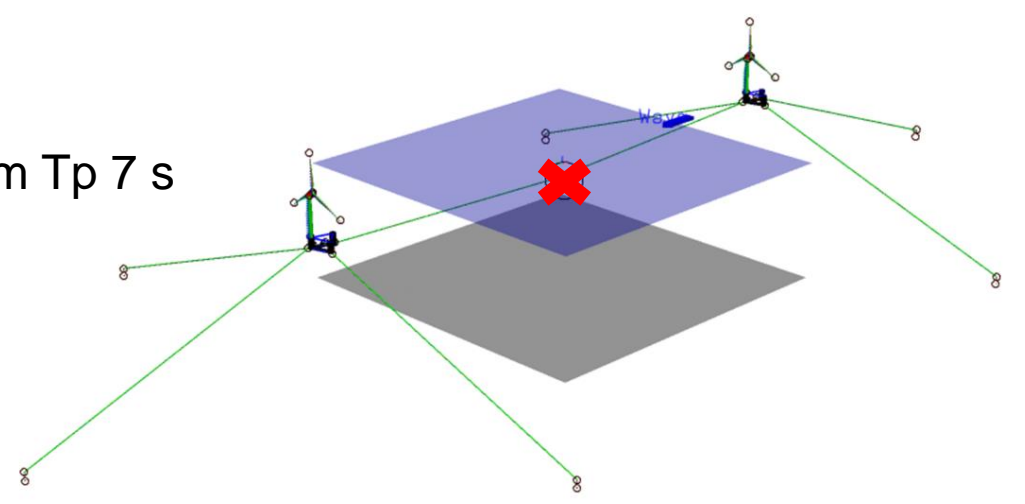
P1 rz
Natural period sima : 101.04 s
Natural period exp: 90.71 s
variaton: -10.22%

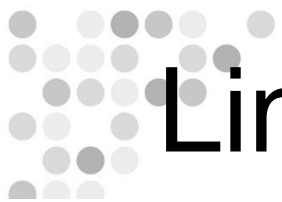


Good agreement between numerical simulations and results from cyber-physical tests.

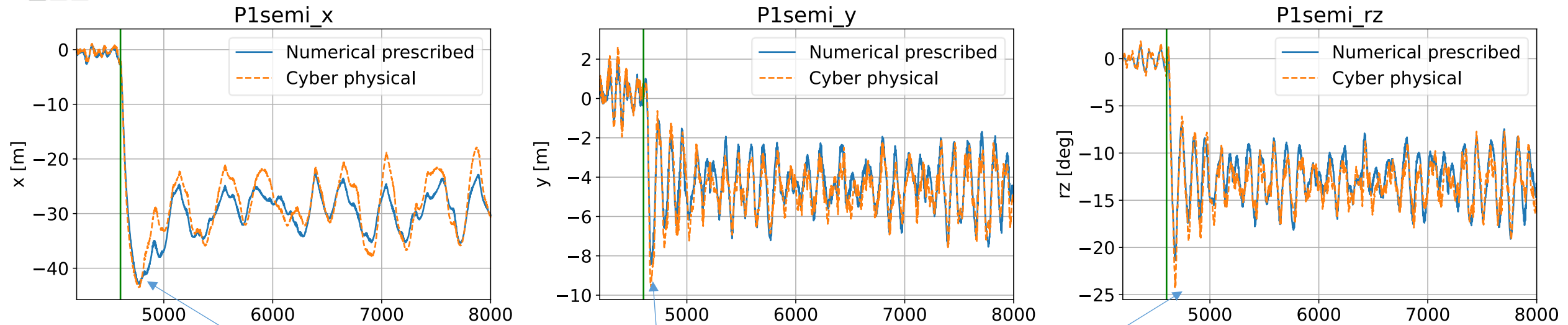


Line breakage tests Hs 3.75 m Tp 7 s





Line breakage tests Hs 3.75 m Tp 7 s



Transient extreme and damping well captured in the numerical model as well



Conclusions

Test	Conclusion
Laboratory methods	<ul style="list-style-type: none">• Active mooring system → applied to test shared mooring lattice
Pullout/Decay tests	<ul style="list-style-type: none">• Excited the exact modes of the lattice by applying respective modal loads• Good agreement seen between eigenvalue analysis, numerical decay and cyber-physical pullout and decay tests
Irregular wave tests	<ul style="list-style-type: none">• Good agreement is seen in the wave frequency region between the physical turbine and prescribed motion simulations.• Discrepancies are seen in the low frequency region.
Line breakage tests	<ul style="list-style-type: none">• Good agreement is seen between the motions of physical turbine and prescribed motion simulations in terms of the extreme transient response and damping.



Thank you

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