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CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Validation of a time-domain numerical approach for determining forces and moments in floaters by using measured data of a semi-submersible wind turbine model test

Chenyu Luan[a,b,c], Valentin Chabaud[a,d], Erin E. Bachynski[b,c,d], Zhen Gao[b,c,d] and Torgeir Moan[a,b,c,d]

[a]Norwegian Research Centre for Offshore Wind Technology (NOWITECH)
[b]Centre for Ships and Ocean Structures (CeSOS), NTNU
[c]Centre for Autonomous Marine Operations and Systems (AMOS), NTNU
[d]Department of Marine Technology, NTNU

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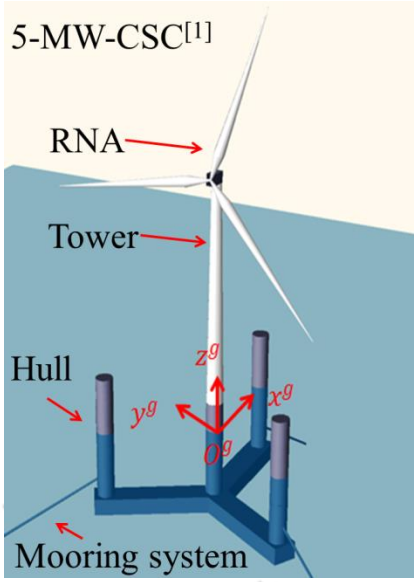
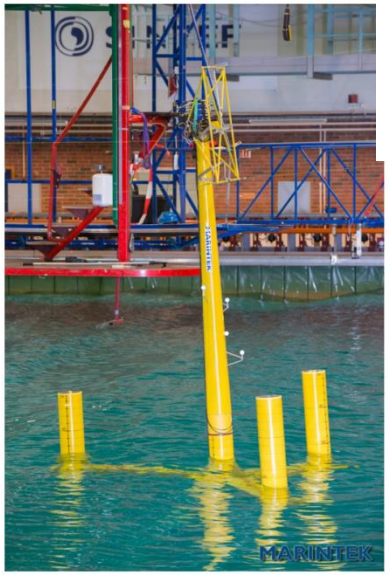
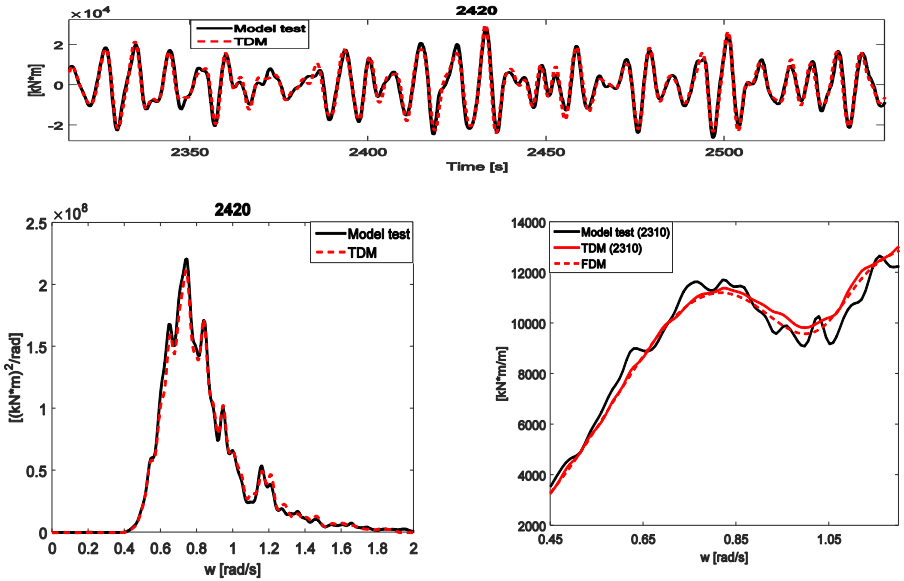
Content

- Development of a time-domain numerical approach for determining forces and moments in floaters [2]
- Real-time hybrid testing of a braceless semisubmersible wind turbine [3, 4]
- Validation







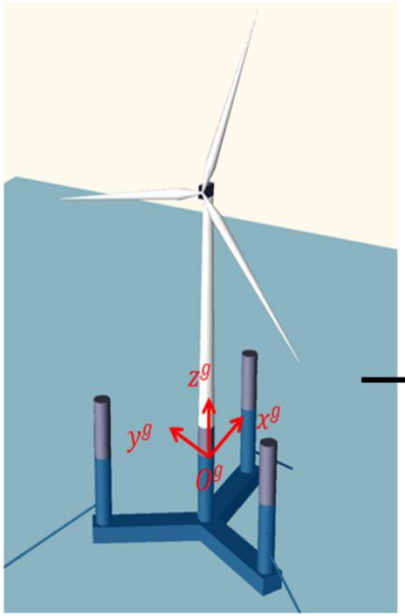
Development of a time-domain numerical approach for determining forces and moments in floaters

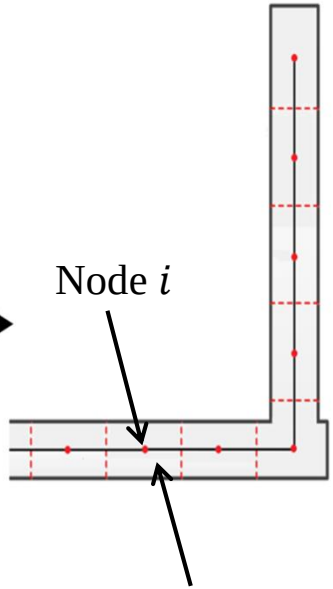
A beam element finite element model for the hull

External and inertial loads on the structural component 1

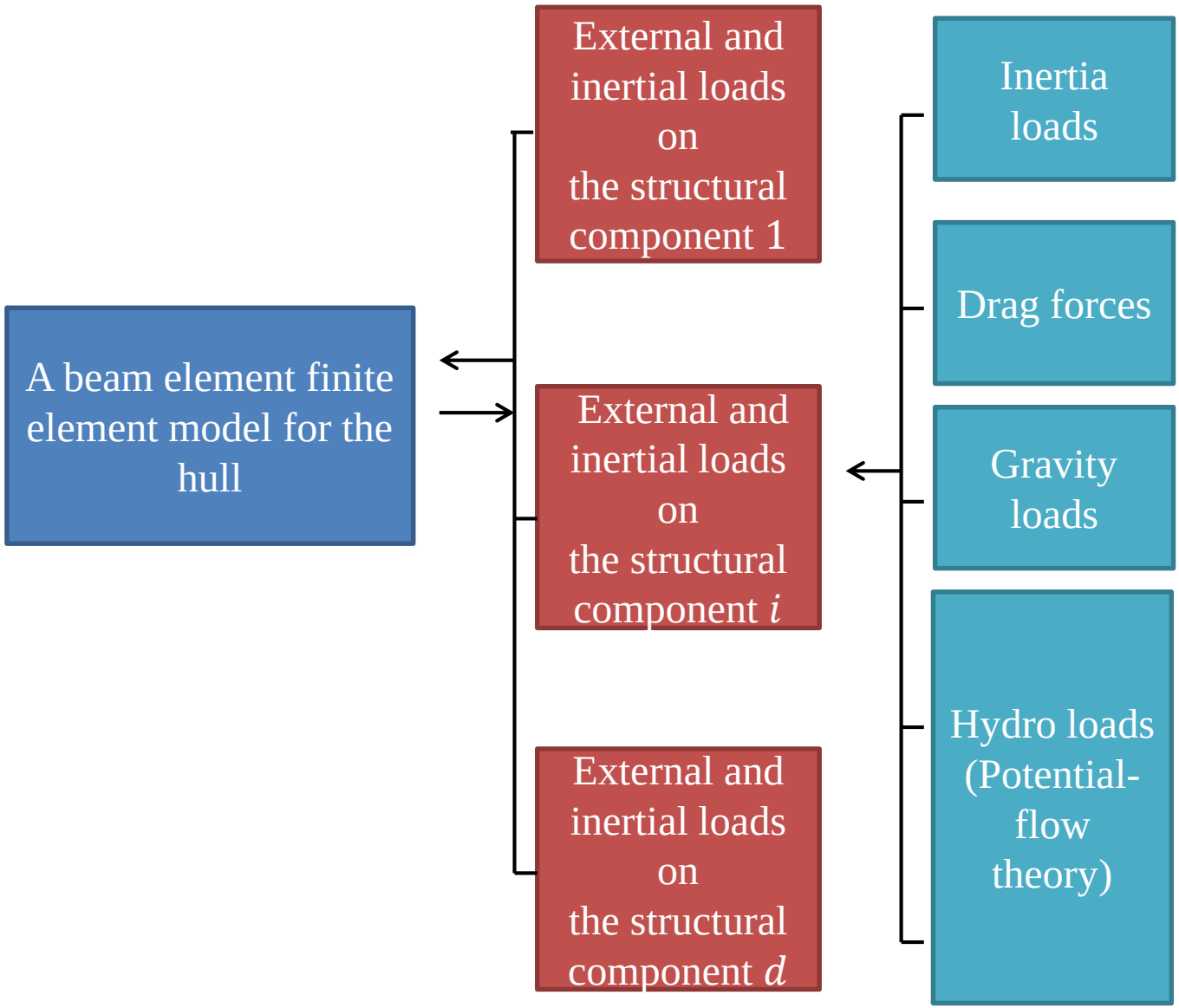
External and inertial loads on the structural component *i*

External and inertial loads on the structural component *d*





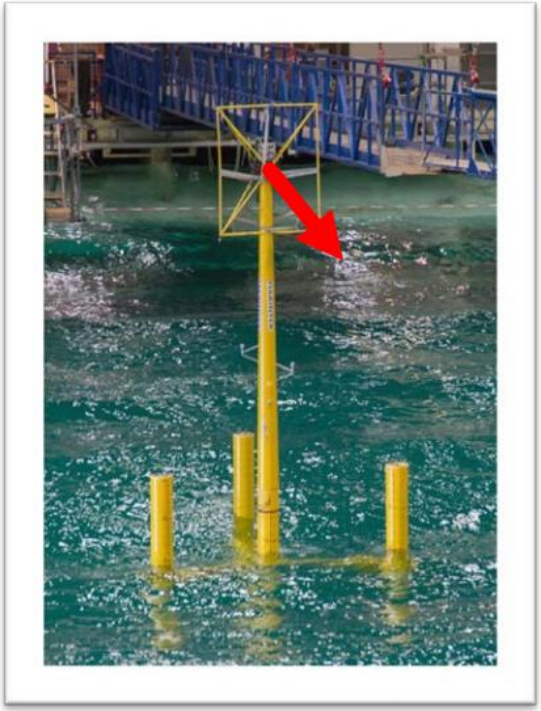
Development of a time-domain numerical approach for determining forces and moments in floaters



Relevant approaches are developed to derive the corresponding coefficients for modeling the external and inertial loads on each structural component. Details are available in [2].

Real-time hybrid testing

The Hybrid System



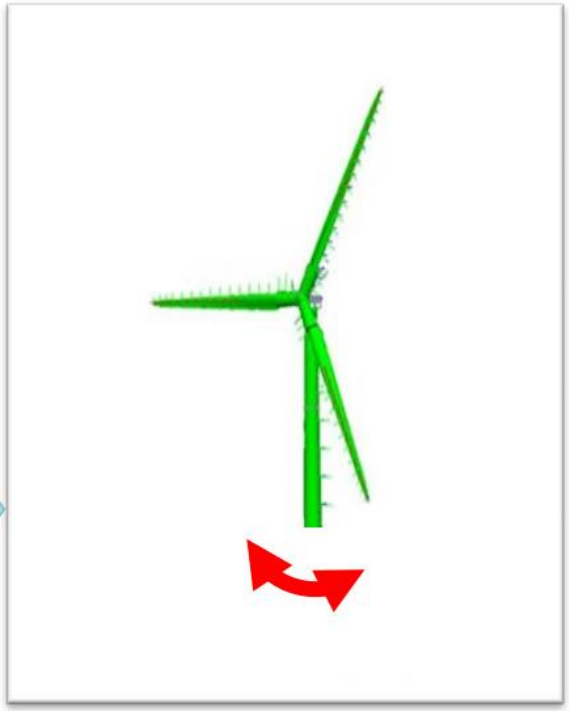
Physcial waves and current

Froude Scale:
1/30

Actuated Aero loads

Real-Time interaction

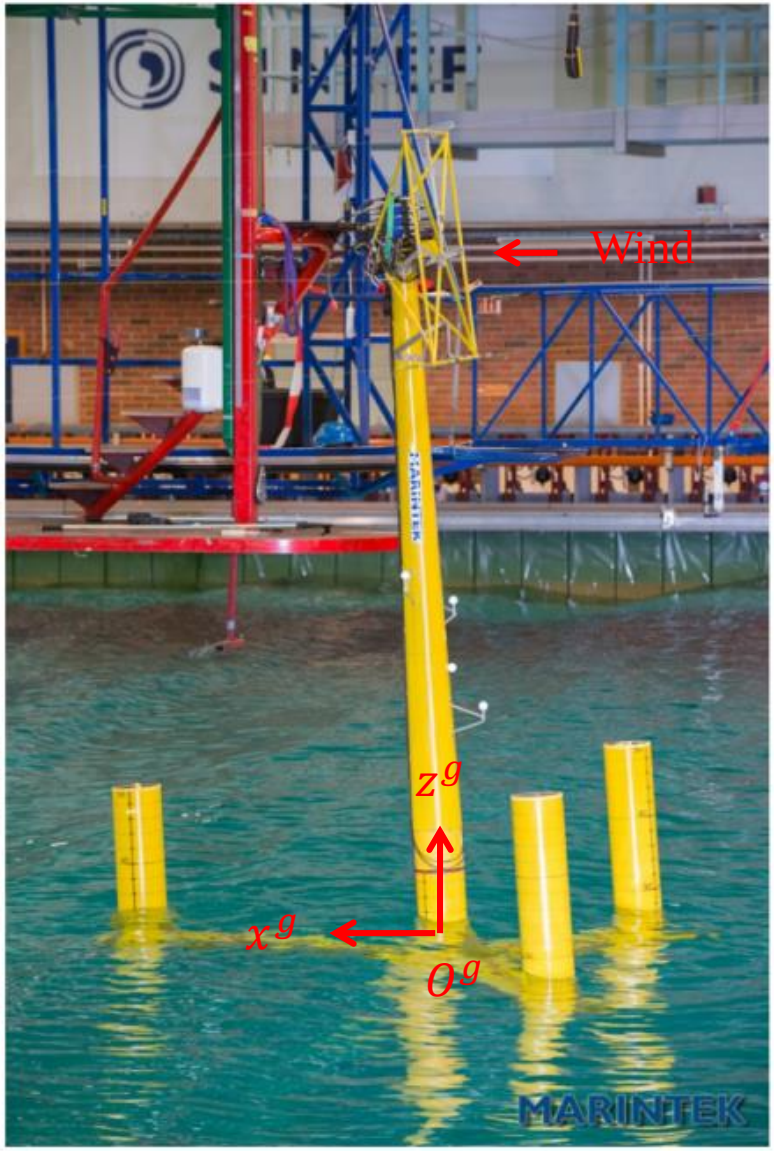
Measured platform motions

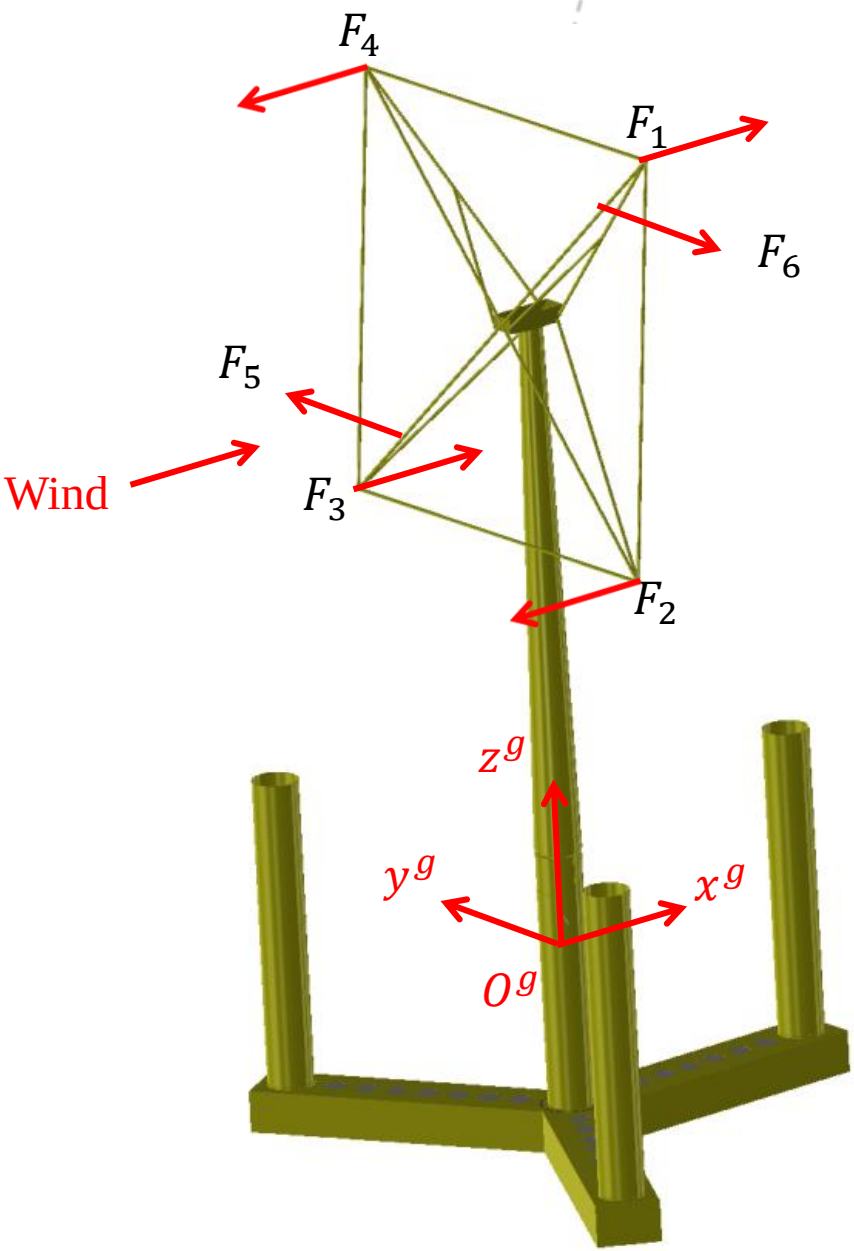


Simulated aerodynamic loads

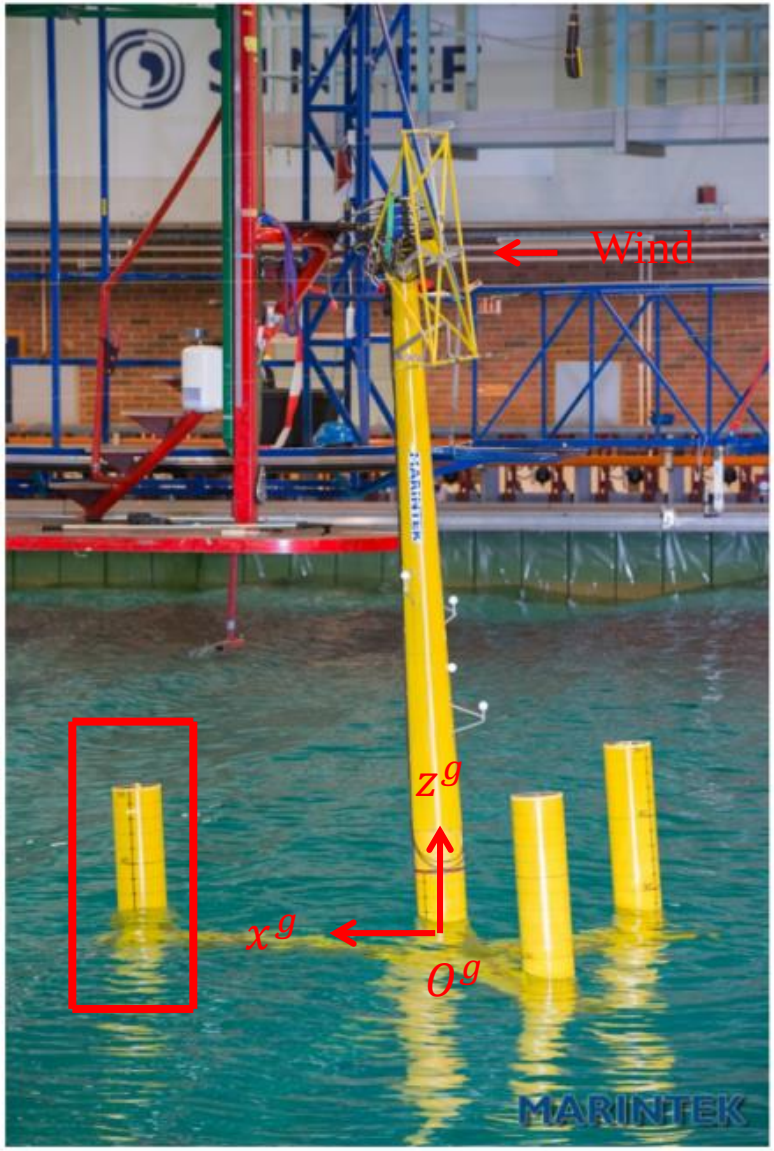
- Thrust
- Aerodynamic sway force
- Aerodynamic pitch and yaw moment
- Generator torque

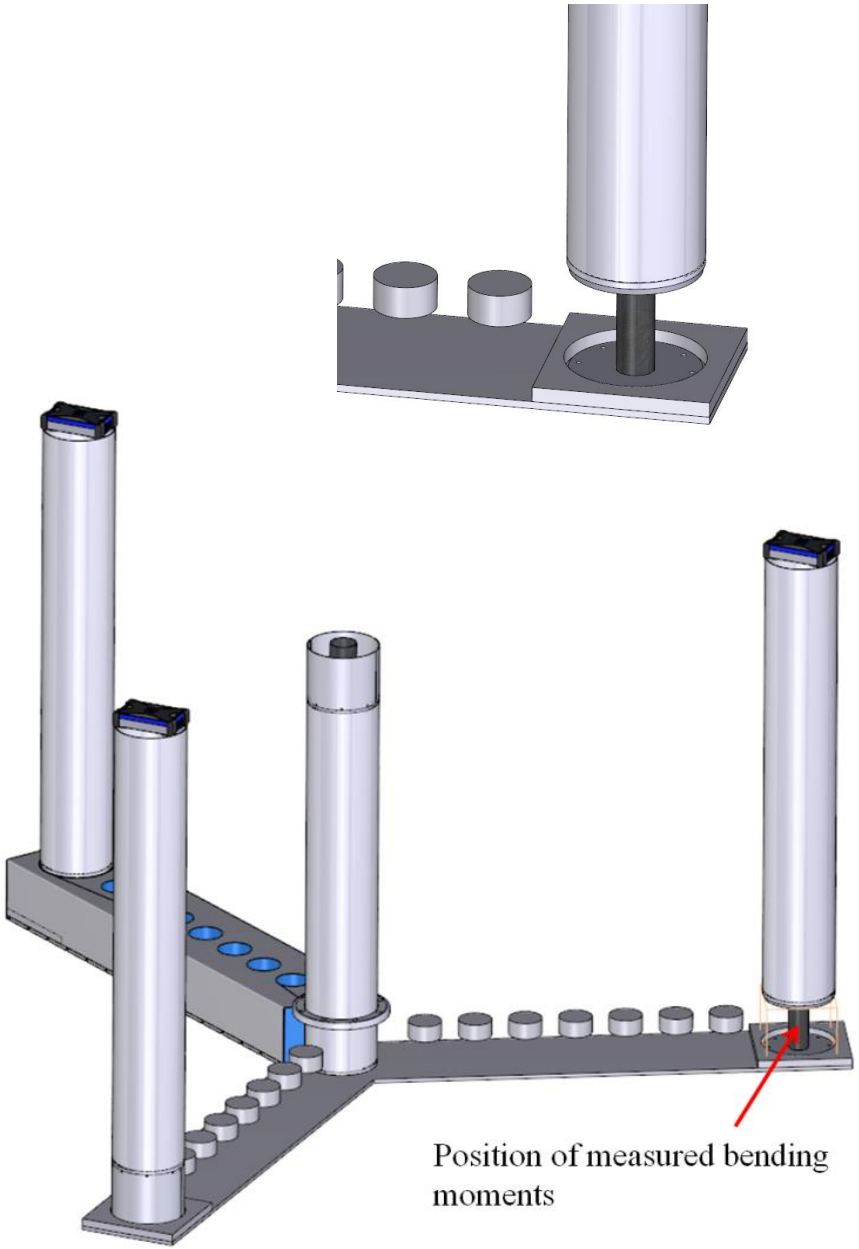
Real-time hybrid testing





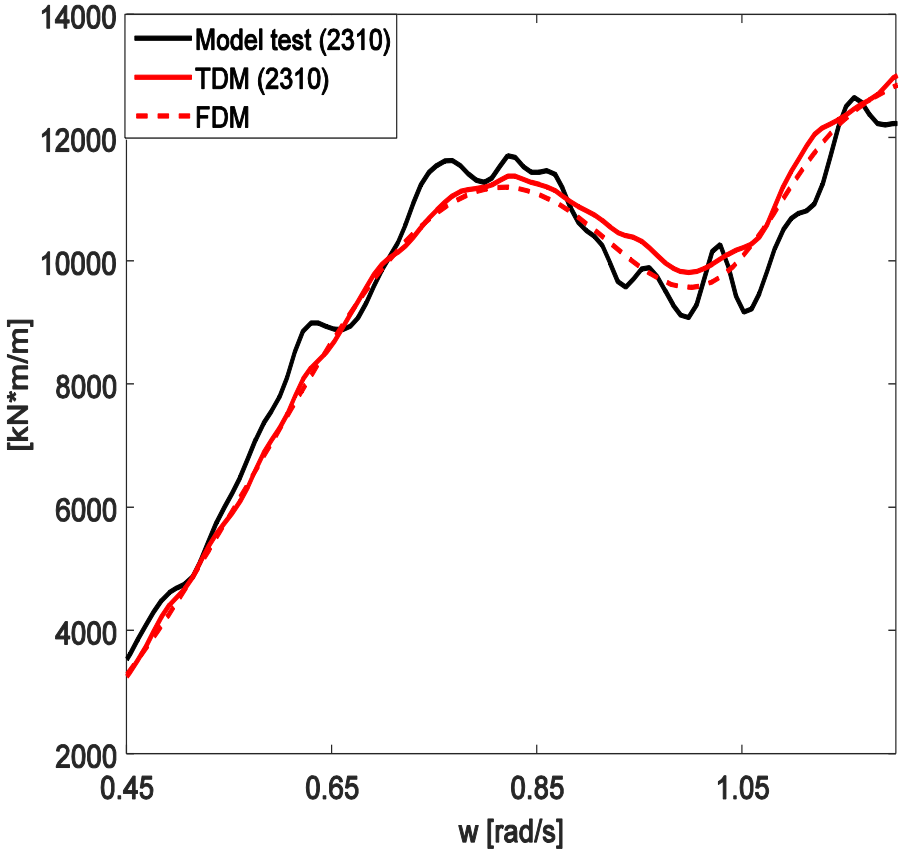
Real-time hybrid testing





Provided by Mr. Fredrik Brun from SINTEF Ocean

Wave induced transfer function moduli

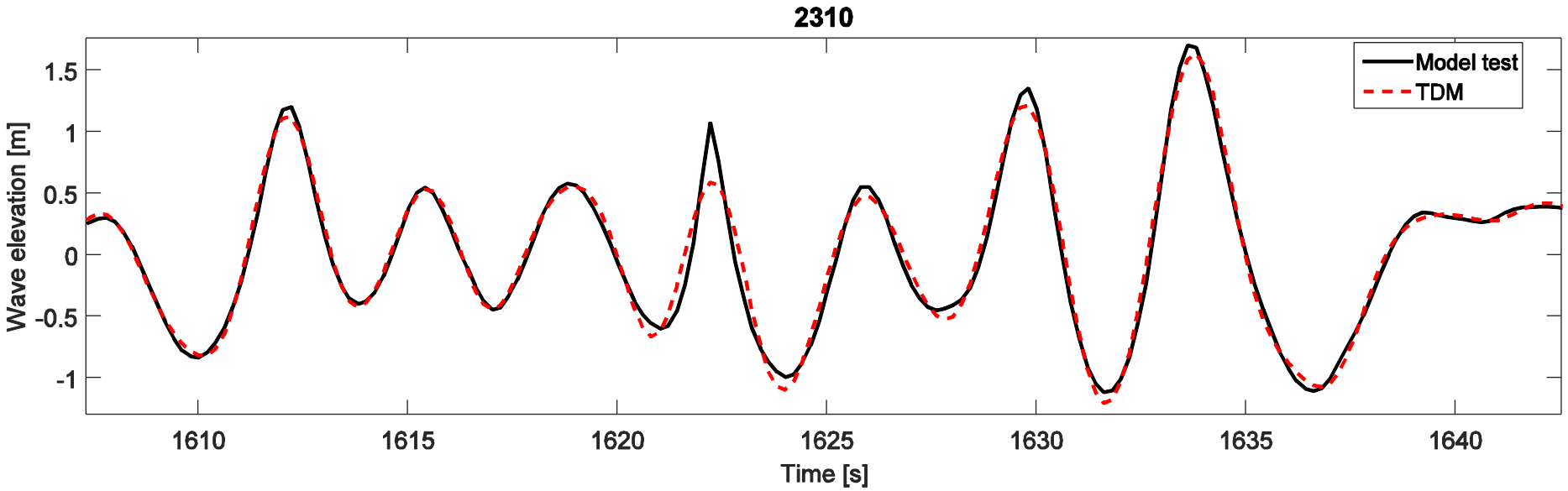


Fore-aft bending moment (M_y) 0-degree-wave in Pink noise model test, $H_s = 2$ m

- 6 d.o.f.s rigid-body motions
- Fore-aft and side-to-side bending moments
- Good agreement
- Non-linear effects, noise and uncertainties

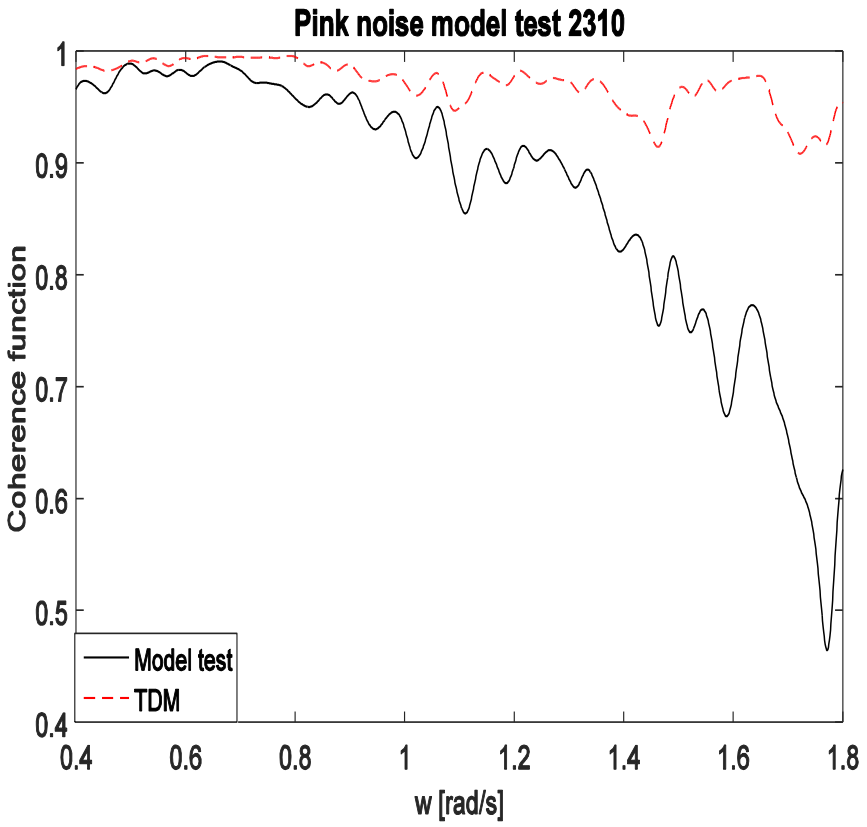
Wave kinematics

	2310	2321	2331	2340	2410	2420	4121	4221	4310	4410
Std	0.47	1.00	0.99	0.98	3.79	0.92	1.48	1.40	0.92	1.35
Std	0.47	0.99	0.99	0.97	3.78	0.92	1.47	1.40	0.92	1.35
Max	1.89	3.89	4.79	4.35	17.93	4.00	6.37	5.39	3.99	6.31
Max	1.78	3.15	4.26	4.34	18.36	3.89	5.94	5.30	3.88	6.15
Min	-1.62	-3.08	-3.44	-3.02	-12.39	-3.03	-5.48	-4.44	-3.03	-4.48
Min	-1.63	-3.33	-3.42	-3.05	-11.64	-3.02	-5.41	-4.52	-3.01	-4.46



Airy wave theory v.s. measured realizations of wave elevation

Wave induced transfer function moduli



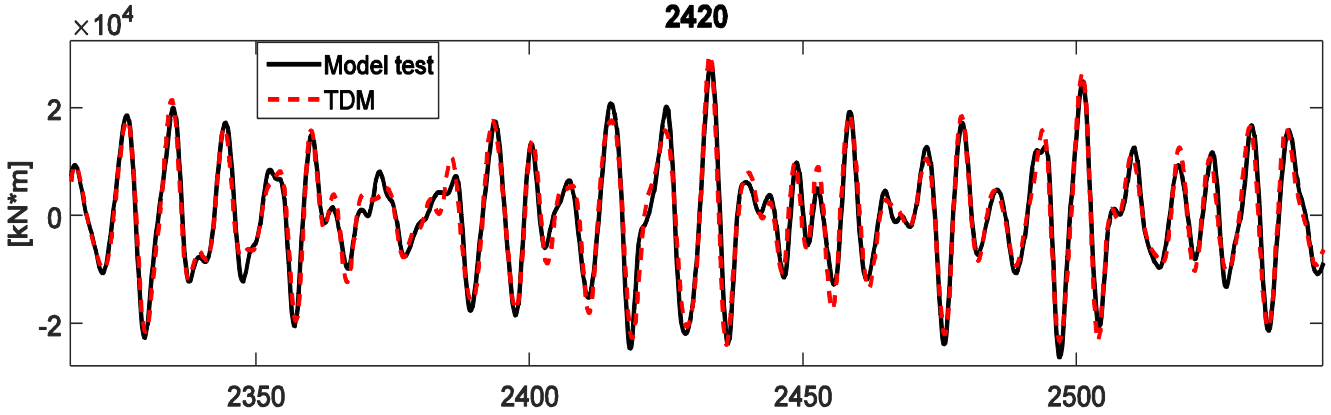
Coherence function: 1-hour wave elevation and the fore-aft bending moment (M_y) . Pink noise model test , $H_s = 2$ m

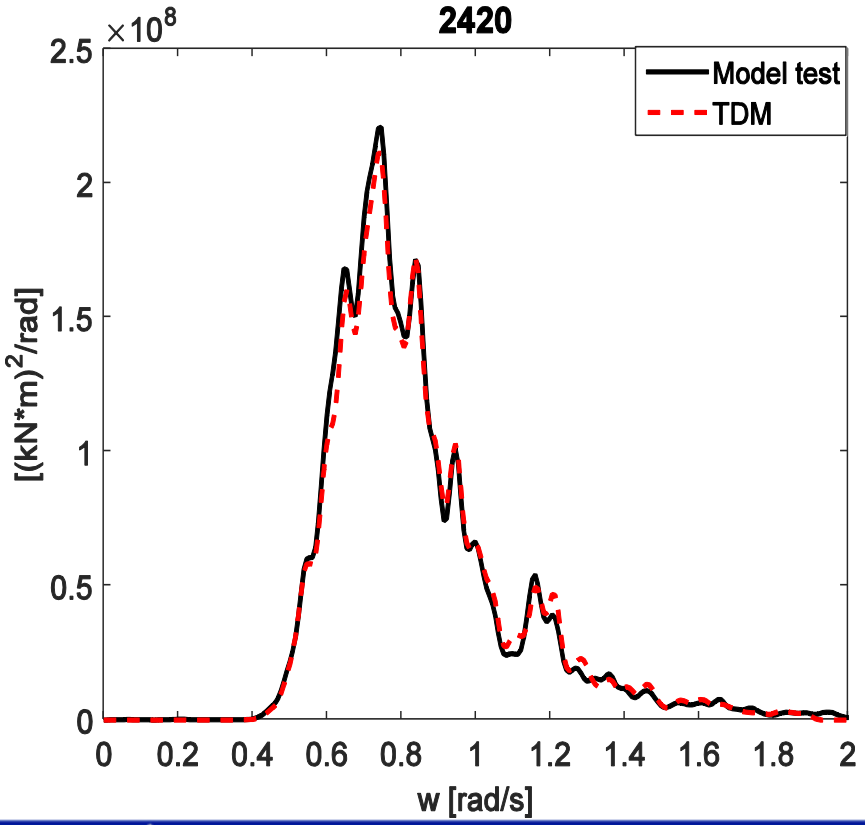
- Non-linear effects, noise and uncertainties

$$\gamma^2_{x_i y_i}(\omega) = \frac{|G_{x_i y_i}(\omega)|^2}{G_{x_i x_i}(\omega) G_{y_i y_i}(\omega)}$$

$$0 \leq \gamma^2_{x_i y_i} \leq 1$$

Responses in moderate waves





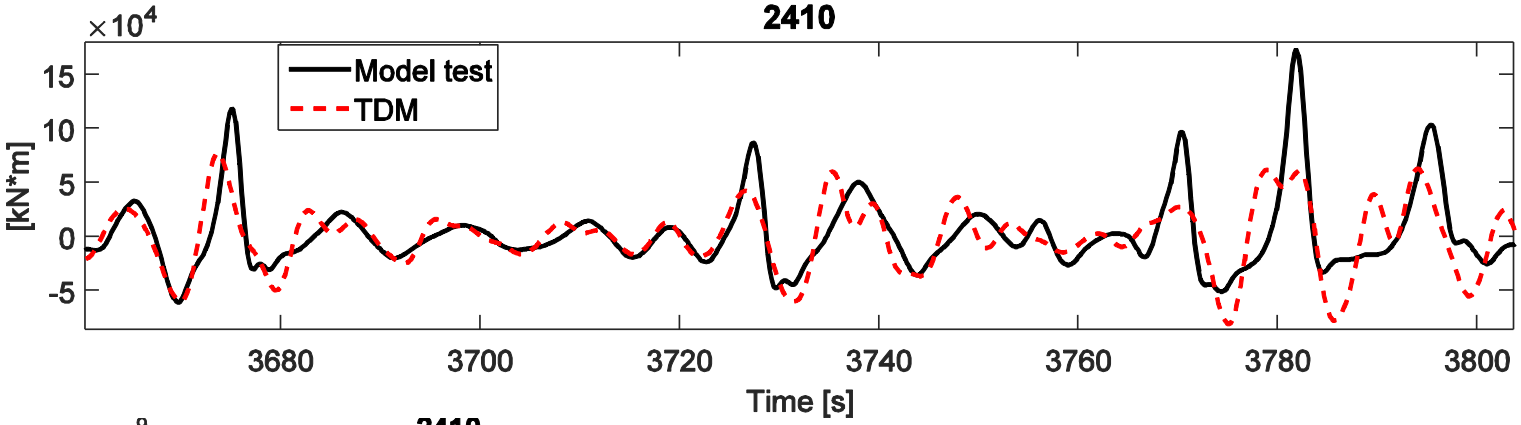
M_3

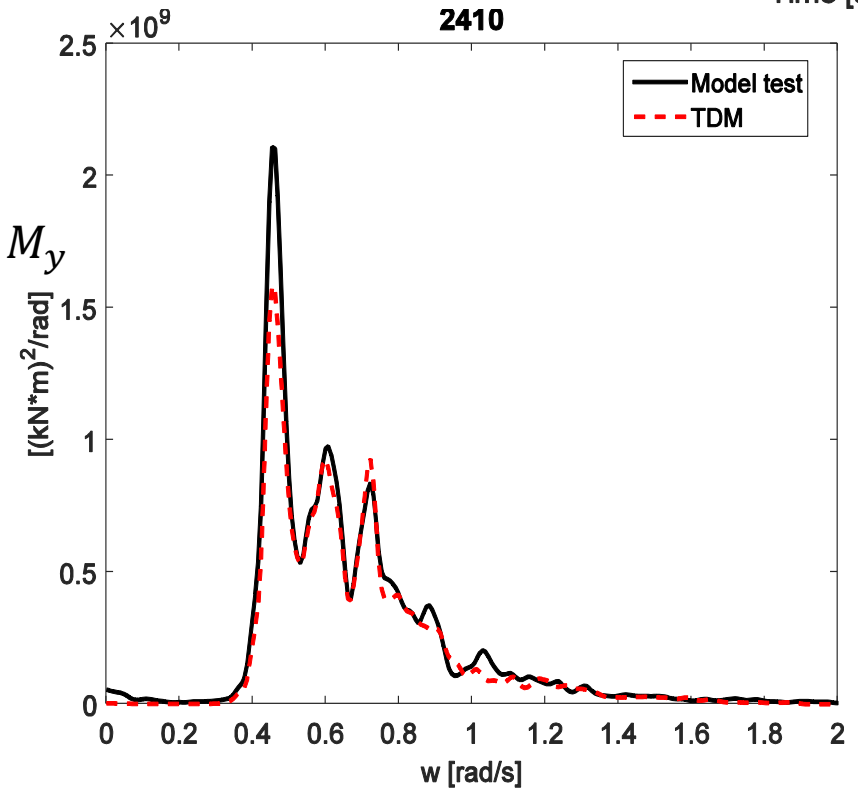
Moderate waves

Good agreement

$H_s = 3.6$ m and $T_p = 10.2$ s.

Responses in extreme waves





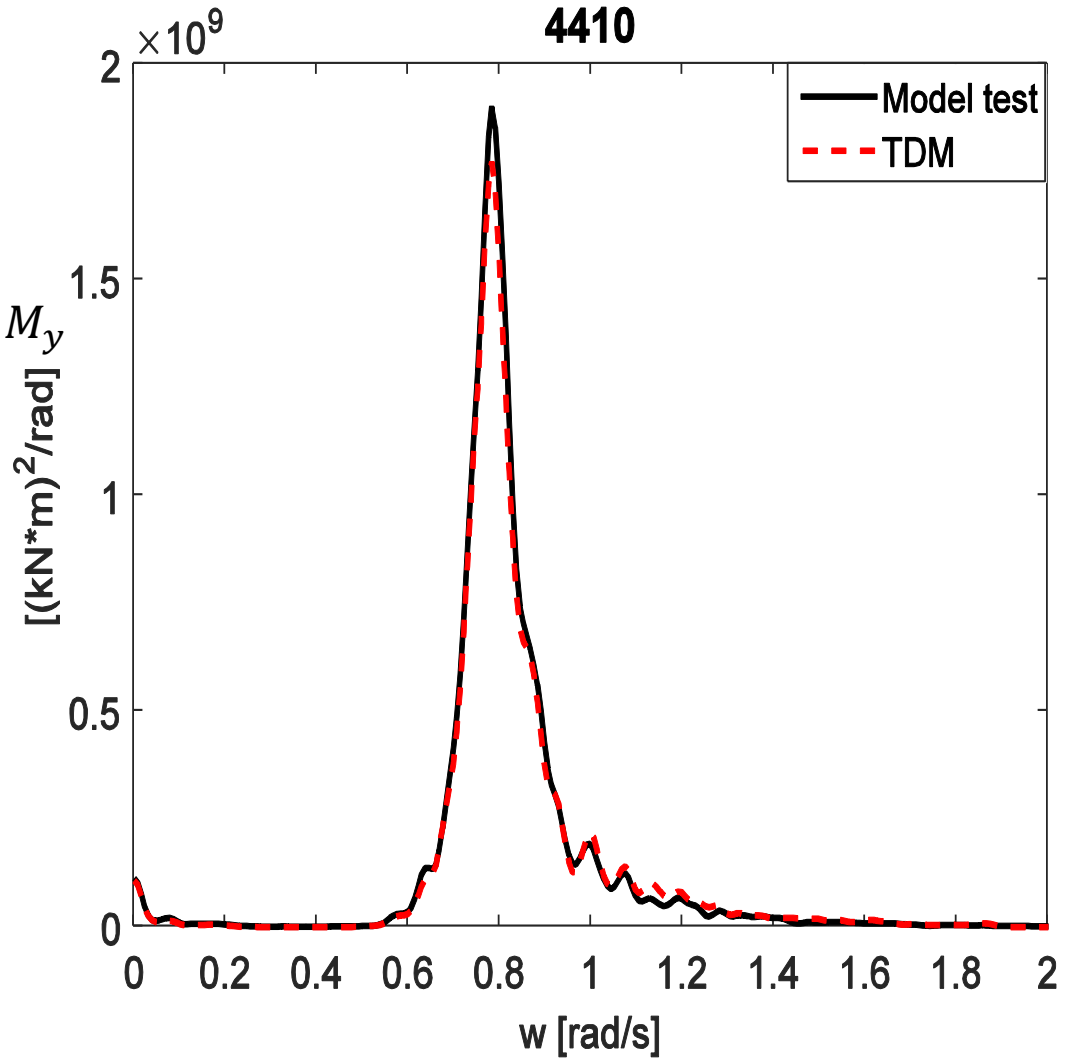
$H_s = 15.3$ m and $T_p = 14$ s.

Extreme waves

2nd and higher order wave loads
(not included in the TDM)

Non-linear wave kinematics
(not included in the TDM)

Responses in wind and waves



Turbulent winds, mean wind speed = 8 m/s
$H_s = 5.2$ m and $T_p = 8$ s.

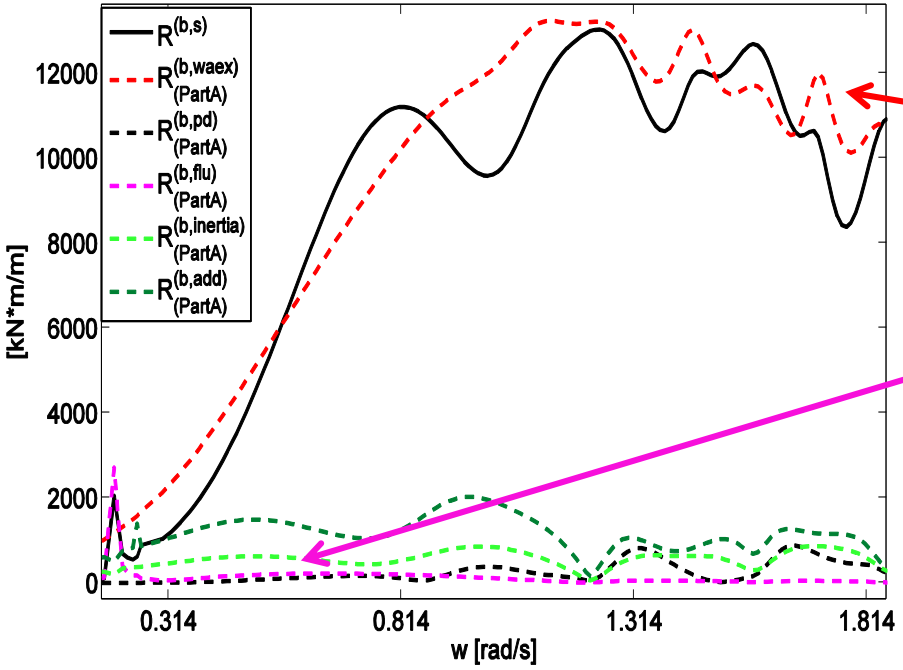
2^{nd} and higher order wave loads
(not included in the TDM)

Aerodynamic damping [5]

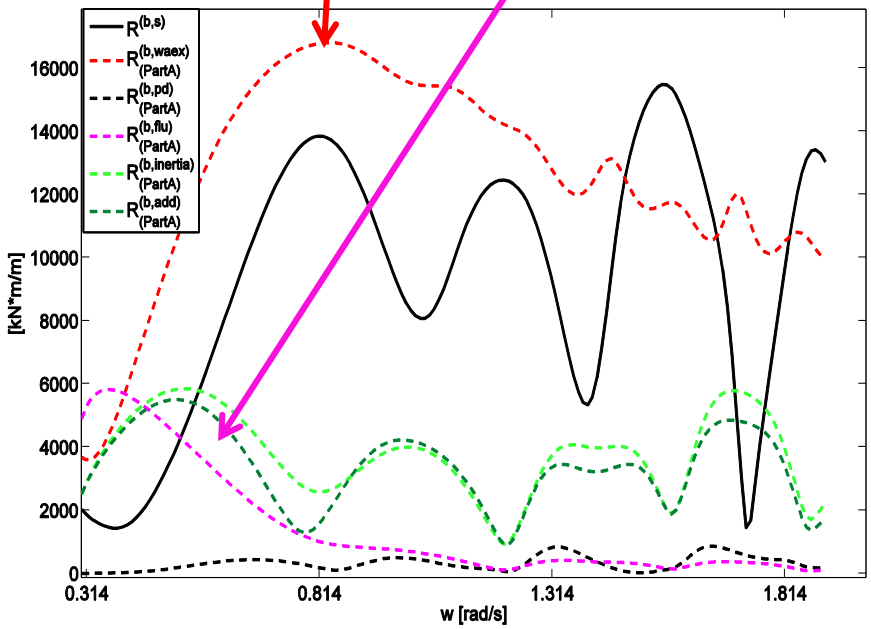
Drag forces

Transfer function modulus curves for the fore-aft bending moment and components of the corresponding external and inertial loads

Base of the side column 1



$$\boldsymbol{R}^{b,s}(\omega,t) = \boldsymbol{R}^{b,inertia}_{PartA}(\omega,t) + \boldsymbol{R}^{b,add}_{PartA}(\omega,t) + \boldsymbol{R}^{b,pd}_{PartA}(\omega,t) + \boldsymbol{R}^{b,flu}_{PartA}(\omega,t) - \boldsymbol{R}^{b,waex}_{PartA}(\omega,t)$$



A given cross section in the Pontoon 1

Conclusions

- The time-domain approach has been validated.
- Good agreement between simulations and measurements
- Non-linear effects (e.g. 2^{nd} and higher order wave loads and wave kinematics)
- Uncertainties, noise and unknown errors in the measurements
- Comparisons of the simulated and measured global forces and moments in the pontoons and the central column are considered future work.
- Achieving consistent aerodynamic damping in the experimental and numerical model is challenging

ACKNOWLEDGEMENT

The authors acknowledge Mr. Fredrik Brun from SINTEF Ocean for providing the figures in the slide 7 and the financial support provided by the Research Council of Norway through the Centre for Ships and Ocean Structures; the Norwegian Research Centre for Offshore Wind Technology (NOWITECH), NTNU; and the Centre for Autonomous Marine Operations and Systems (AMOS), NTNU.

REFERENCE

[1] Luan, C., Gao, Z., and Moan, T., (2016). “Design and analysis of a braceless steel 5-mw semi-submersible wind turbine”. Proceedings of the 35th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2016-54848, Busan, Korea, June 19–24.

[2] Luan, C., Gao, Z. and Moan, T., (2017), “Development and verification of a time-domain approach for determining forces and moments in structural components of floaters with an application to floating wind turbines”. Marine Structures. vol. 5 pp 87-109.

[3] Bachynski, E. E., Thys, M., Chabaud, V., and Sauder, T., (2016). “Realtime Hybrid Model Testing of a Braceless Semi-submersible Wind turbine. Part II: Experimental Results”. In 35th International Conference on Ocean, Offshore and Arctic Engineering, no OMAE2016-54437.

[4] Sauder, T., Chabaud, V., Thys, M., Bachynski, E. E., and Sæther, L. O., (2016). “Real-time hybrid model testing of a braceless semi-submersible wind turbine: Part I: The hybrid approach”. In 35th International Conference on Ocean, Offshore and Arctic Engineering, no. OMAE2016-54435.

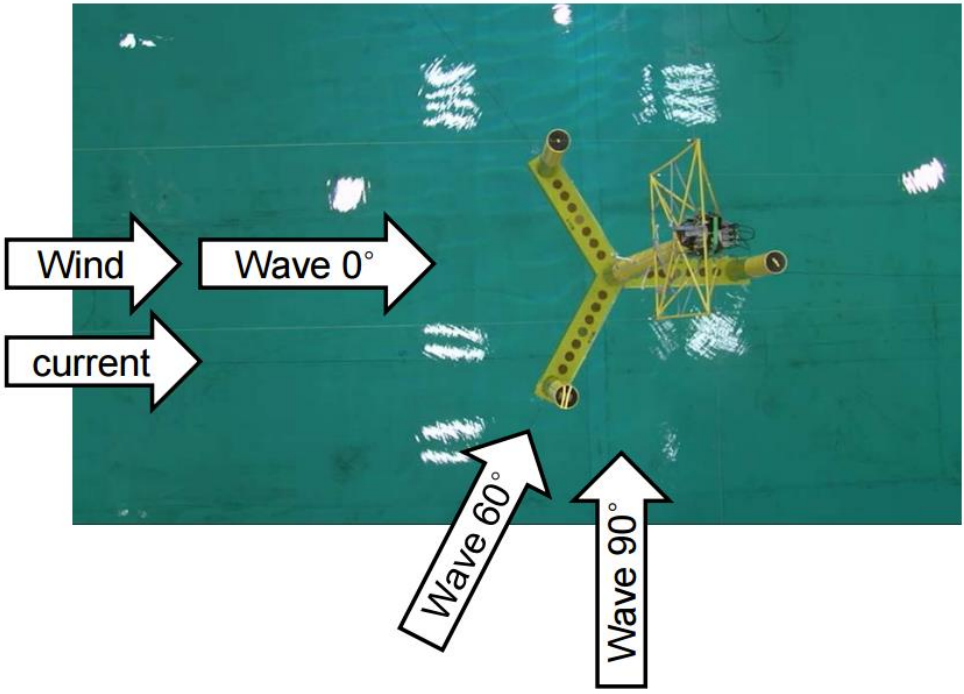
[5] Stewart, G. and Muskulus, Michael., (2016). “Aerodynamic Simulation of the MARINTEK Braceless Semisubmersible Wave Tank Tests”. WindEurope Summit. Journal of Physics: Conference Series 749 (2016) 012012.

Thank you for your attention

Real-time hybrid testing

Model Test program:

- Tests without hybrid system
  Decay, Regular waves, Irregular waves
- Tests with zero wind
  Decay, Regular waves, Irregular waves
- Tests with constant wind
  Decay and Regular waves
- Tests with turbulent wind
  -Wind-only
  -Irregular waves
    -Below rated, rated, above rated
    -One test with current
    -Misaligned waves
  -Fault conditions

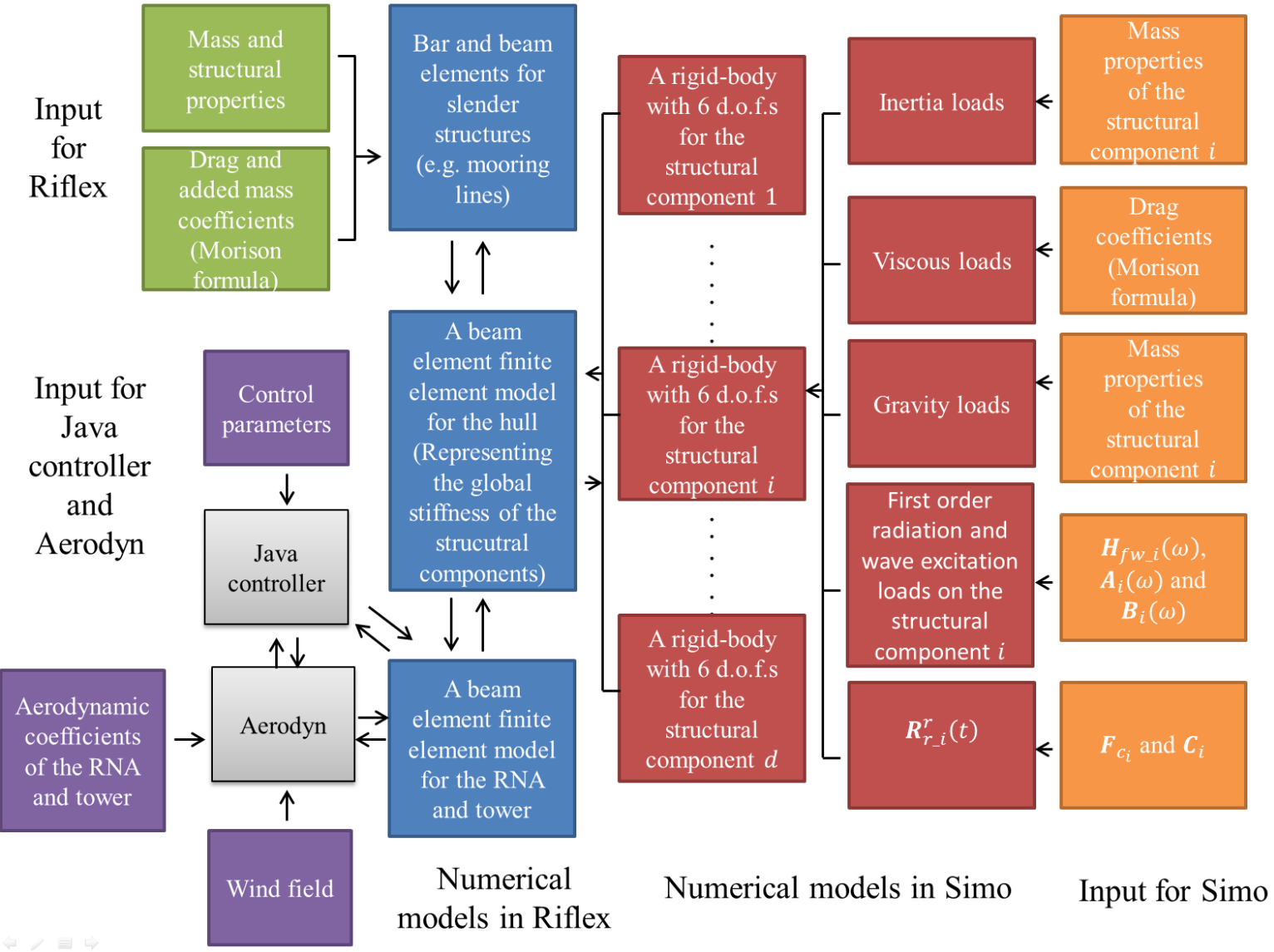


Step by step increase in complexity with repetitions and decomposed conditions

Environmental conditions of selected model tests

Reference No.	Mean wind speed at nacelle height [m/s]	H_s [m]	T_p [s]	Wind direction [degree]	Wave direction [degree]	Model test duration [hour]	Note
1713	11	-	-	0	-	3	Turbulent wind only
1733	25	-	-	0	-	3	
2310	-	2	3.5-22	-	0	3	Pink noise tests
2321	-	4	4.5-22	-	0		Wave only
2331	-	4	4.5-16	-	60		
2340	-	4	4.5-16	-	90		
2410	-	15.3	14	-	0	3	JONSWAP spectrum
2420	-	3.6	10.2	-	0	3	Wave only
4121	25	5.9	11.3	0	0	3	Turbulent wind
4221	25	5.9	11.3		60		JONSWAP spectrum
4310	11	3.6	10.2		0		
4410	8	5.2	8		0		

Development of a time-domain numerical approach for determining forces and moments in floaters



A flow chart

Simo/Riflex/ Aerodyn

A generic horizontal axis floating wind turbine