Dynamic Responses of Jacket-Type Offshore Wind Turbines using Decoupled and Coupled Models

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SINTEF

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Overview of Presentation

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  - SIMO-RIFLEX-AeroDyn (SRA)
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- Results and discussion of coupled nonlinear and decoupled linear models
  - Eigen-frequency analysis
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  - Decoupling method
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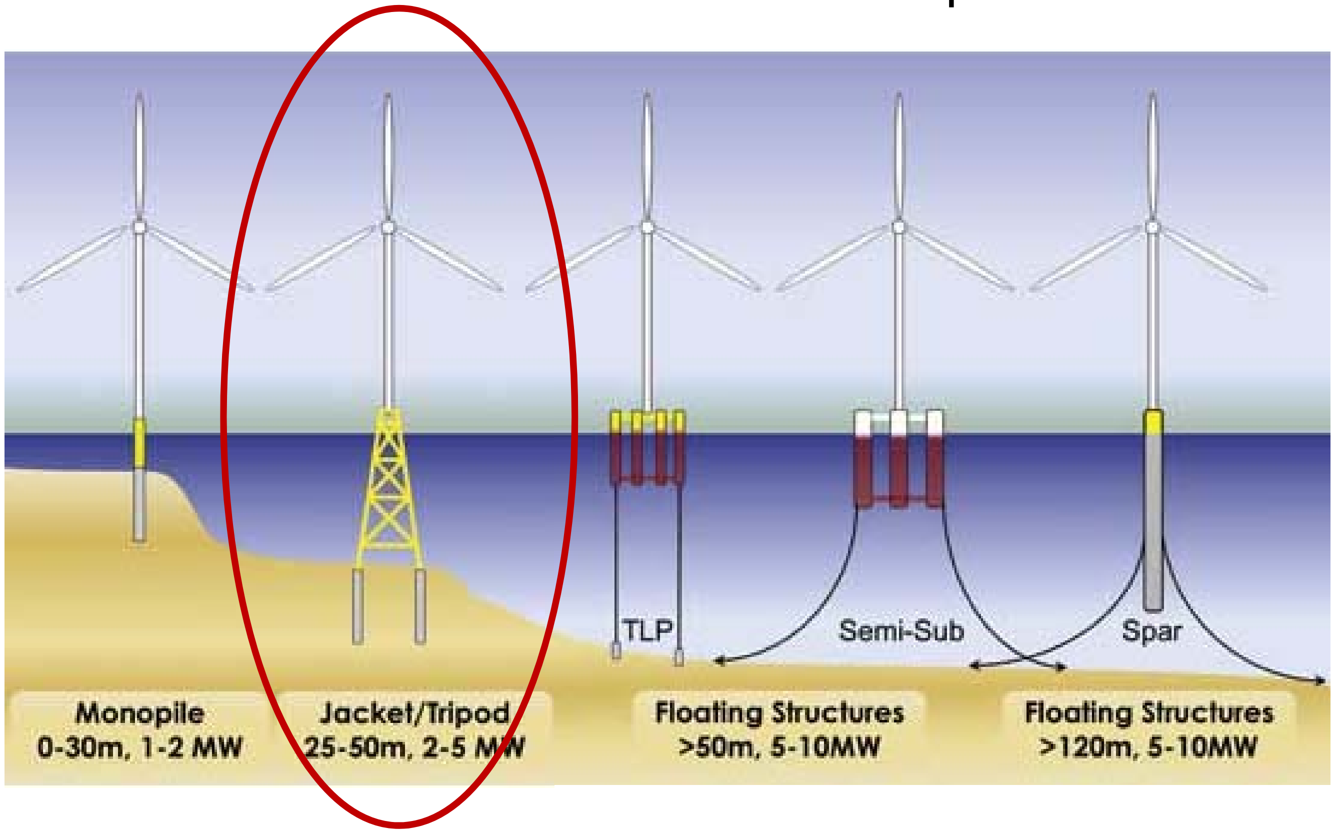
Introduction

Types of Offshore Wind Turbines

- Bottom-fixed Wind Turbines:
  - Monopile
  - Tripod
  - Lattice
- Floating Wind Turbines:
  - TLP
  - Semi-submersible
  - Spar

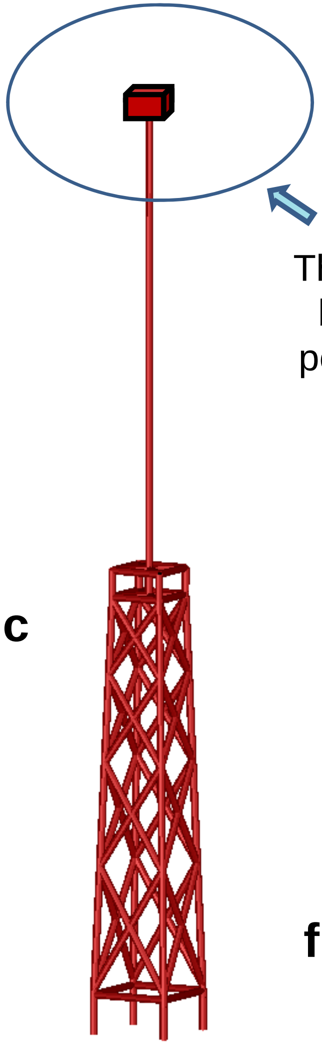


Objectives

- The objective of this study is to evaluate the applicability of a computationally efficient linear decoupled model by comparing with results obtained from a nonlinear coupled model.
- The aerodynamic and hydrodynamic loads are calculated for several environmental conditions.
- The decoupled analysis was carried out using NIRWANA, whereas the coupled analysis was performed using SIMO-RIFLEX-AeroDyn. Both programs are based on time-domain FE methods.

Description of Dynamic Models

OC4 5 MW Jacket Wind Turbine



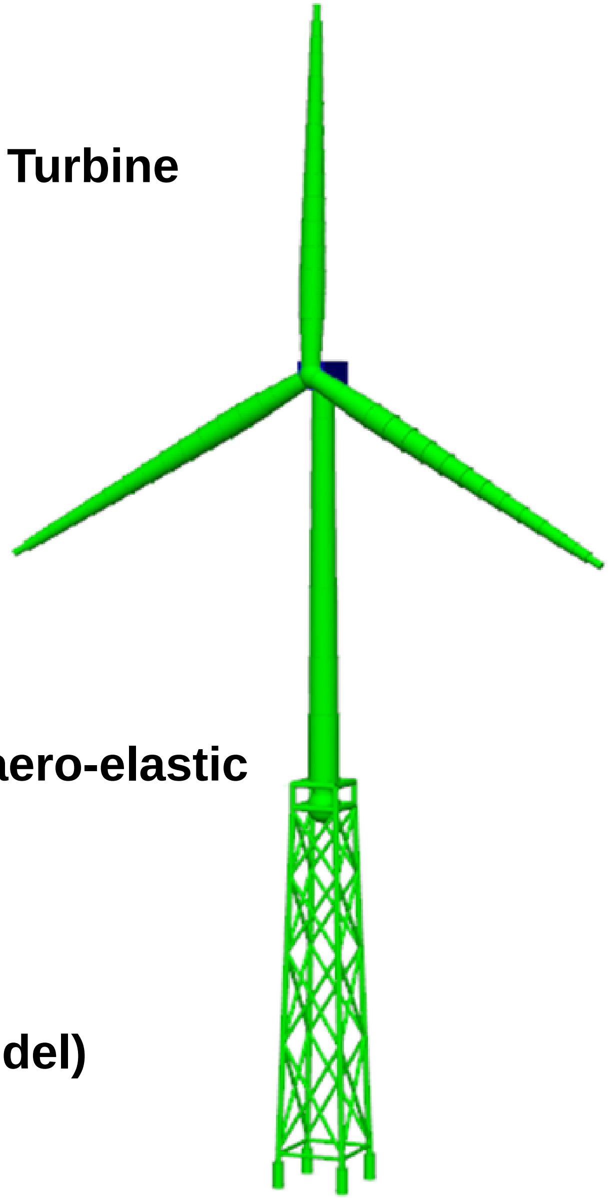
The turbine will be mimicked
by equivalent point loads,
point masses and a damper

- **Linear**
- **Hydroelastic**
- **Decoupled**

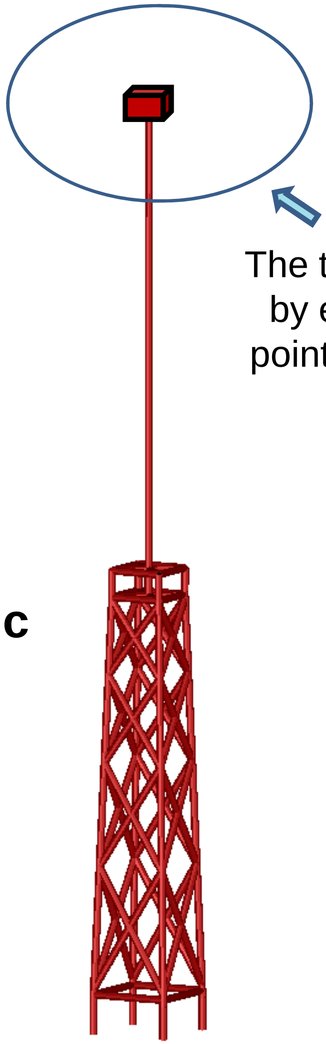
NIRWANA

- **Non-linear**
- **Hydro-servo-aero-elastic**
- **Coupled**

50m water depth,
fixed bottom (no soil model)



SIMO-RIFLEX-AeroDyn (SRA)

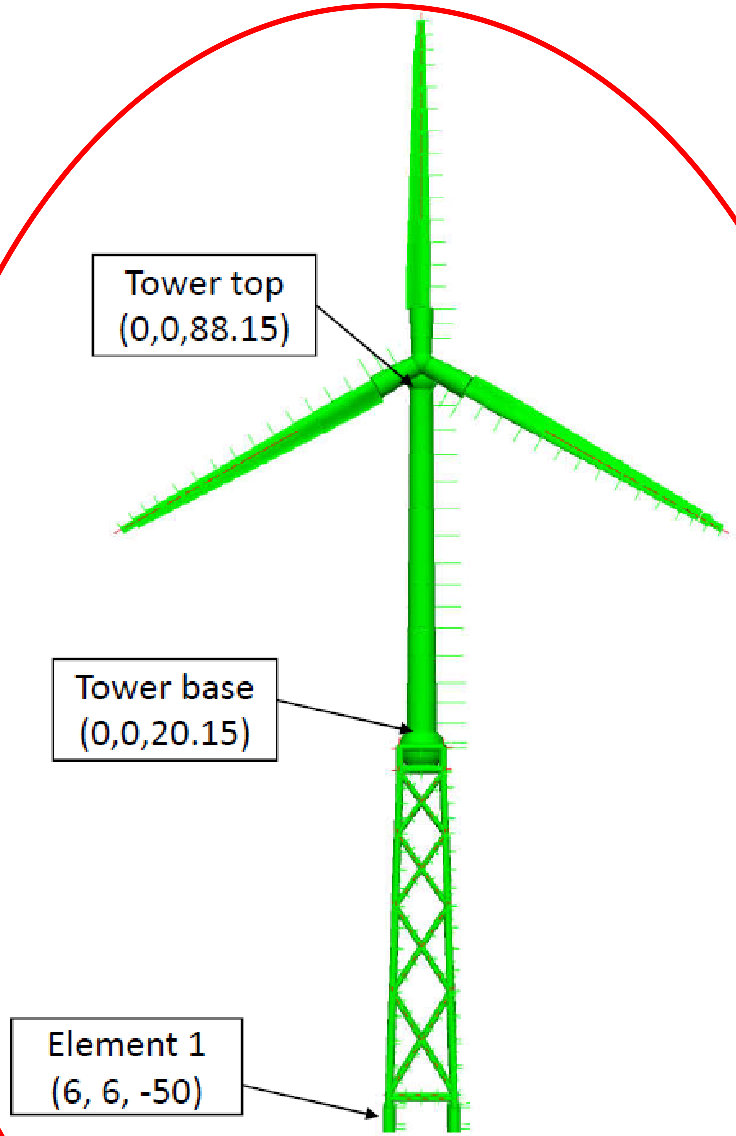


The turbine will be mimicked
by equivalent point loads,
point masses and a damper

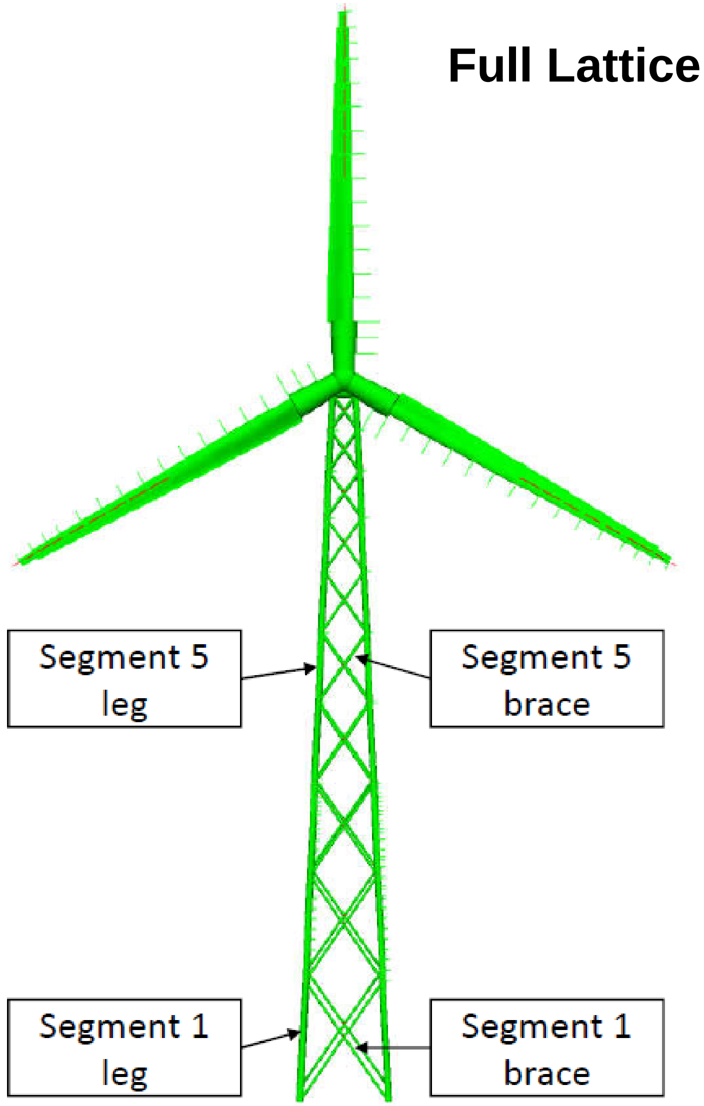
- **Non-linear**
- **Hydroelastic**
- **Decoupled**

Decoupled SIMO-RIFLEX-AeroDyn

SRA*



50m water depth,
Hub Height = 90.55m



35m water depth,
Hub Height = 87.4m
Long et al. (2012), Ong et al. (2017)

Environmental Conditions

Index	Wind speed at the hub V_{hub} (m/s)	Linear Random Waves	
		H_s (m)	T_p (s)
EC1	7	0.63	4.03
EC2	11.4	1.69	6.55
EC3	15	2.85	8.27
EC4	20	4.67	10.47

The wave conditions were obtained using a wind-wave model proposed by Ong et al. (2013) based on the corresponding wind speeds.

Results and Discussion

1. Eigenfrequency analysis

2. Decay test

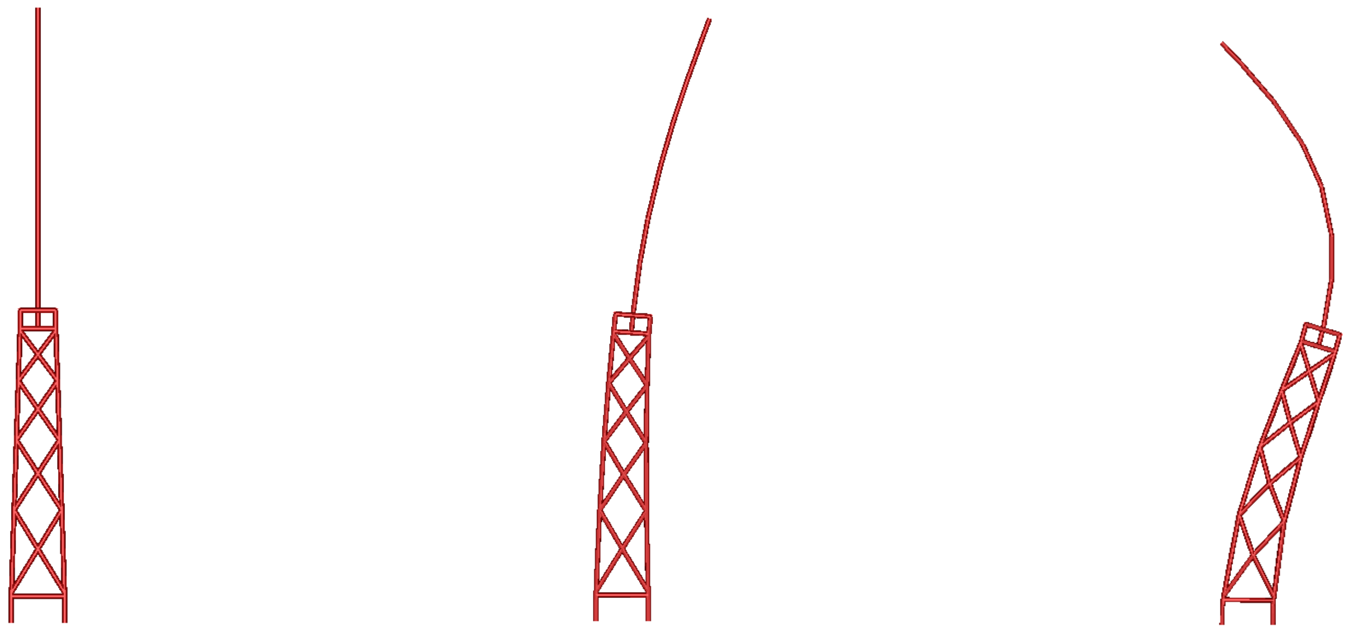
3. Wave-only simulations

4. Decoupling method 2 (Selected forces and moments from the isolated rotor + aerodynamic damper)

5. Computational efficiency

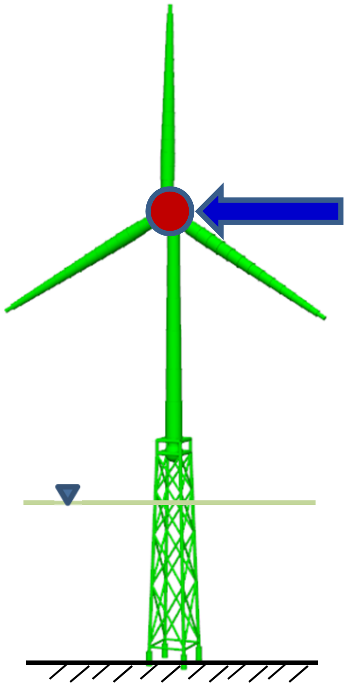
1) Eigenfrequency Analysis

Items	Natural Periods (s)		
	NIRWANA	SIMO-RIFLEX-AERODYN	Popko et al. (2012)
1st Fore-Aft	3.31	3.34	3.13-3.34
1st Side-Side	3.33	3.35	3.13-3.33
2nd Fore-Aft	0.90	0.840	0.820.93
2nd Side-Side	0.88	0.82	0.76-0.90
1st Flapwise blade	-	1.60	1.43-1.75
1st Edgewise blade	-	0.94	0.90-1.06



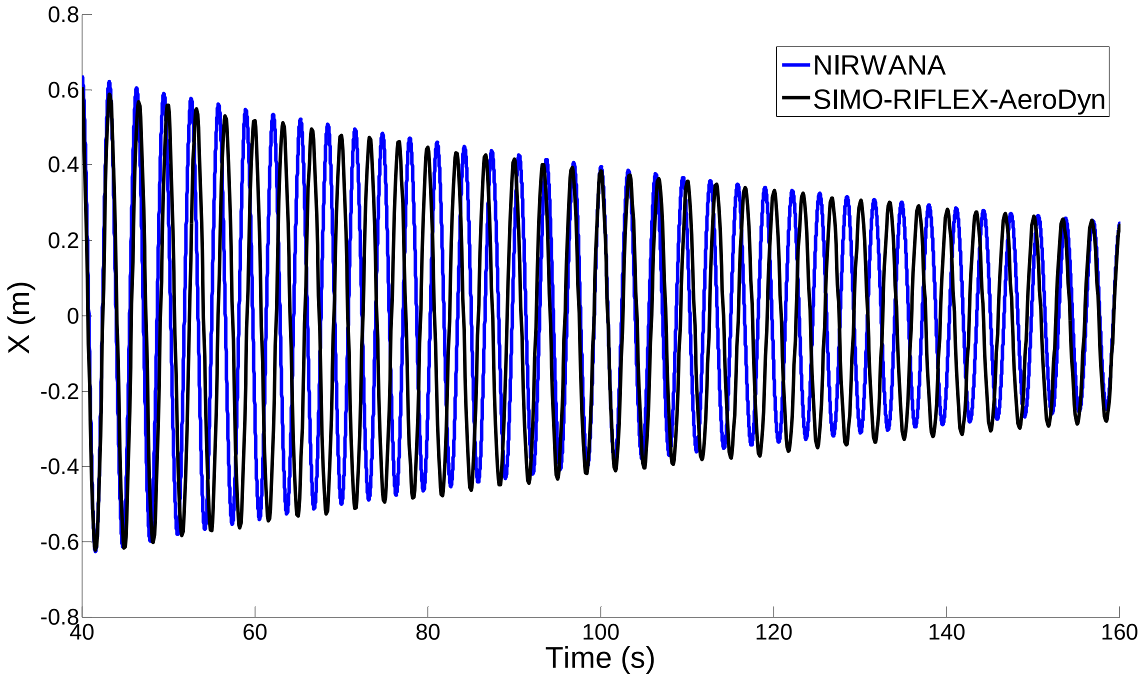
Initial   1st Fore - Aft   2nd Fore - Aft

2) Decay Test



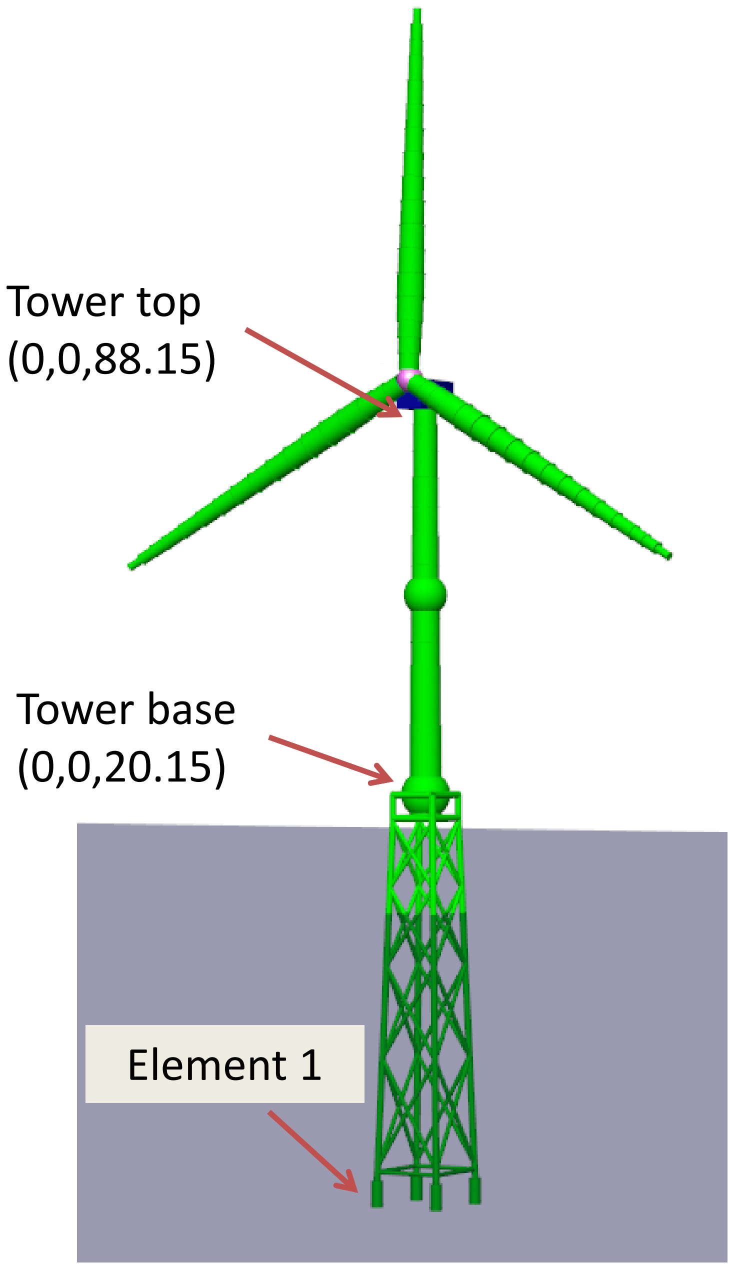
1) Increase the load slowly to 900kN.
2) Hold the load for the static equilibrium, then remove the load.
3) Let the decay occur.

	Observed structural damping λ (% critical)
NIRWANA	0.36
SIMO-RIFLEX	0.38

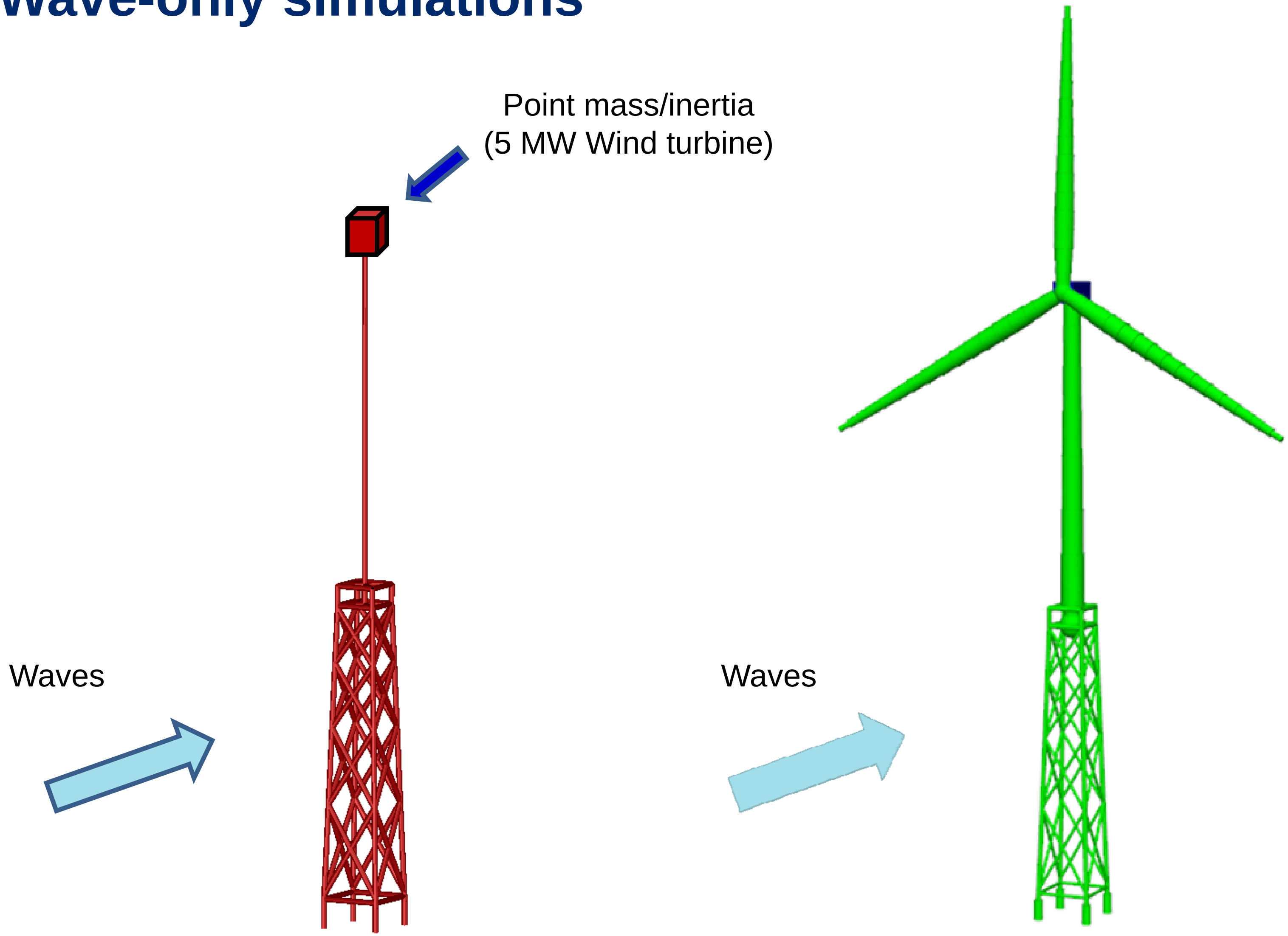


Stiffness-proportional damping is applied.

Locations for decoupled and coupled model result comparisons



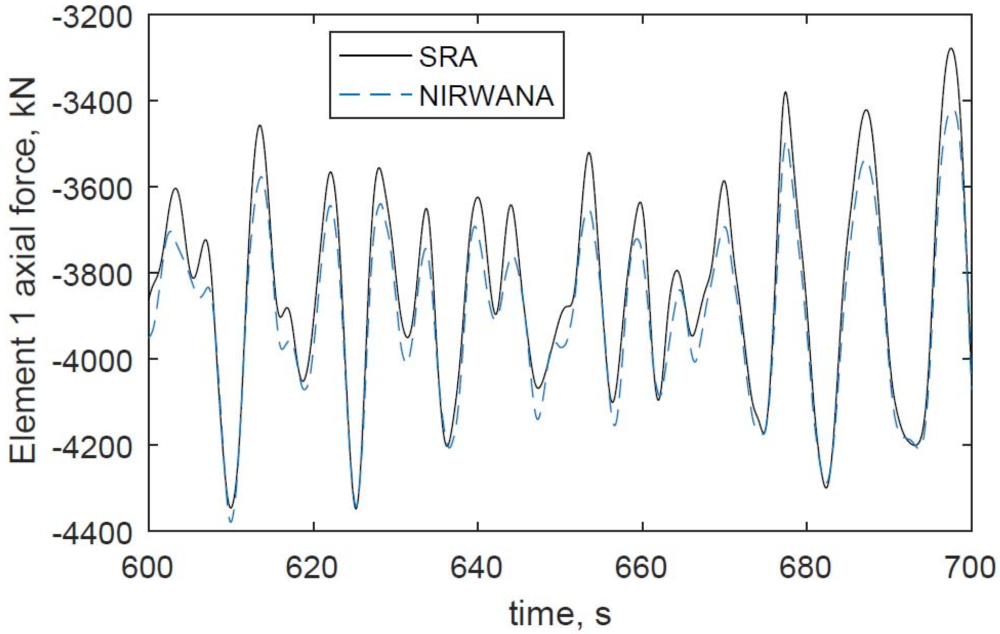
3) Wave-only simulations

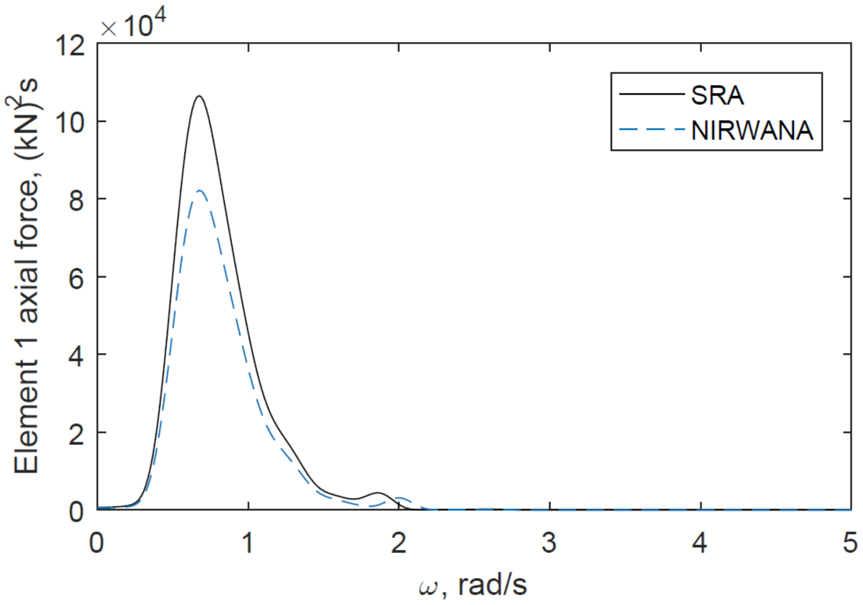


NIRWANA

SIMO-RIFLEX-AeroDyn

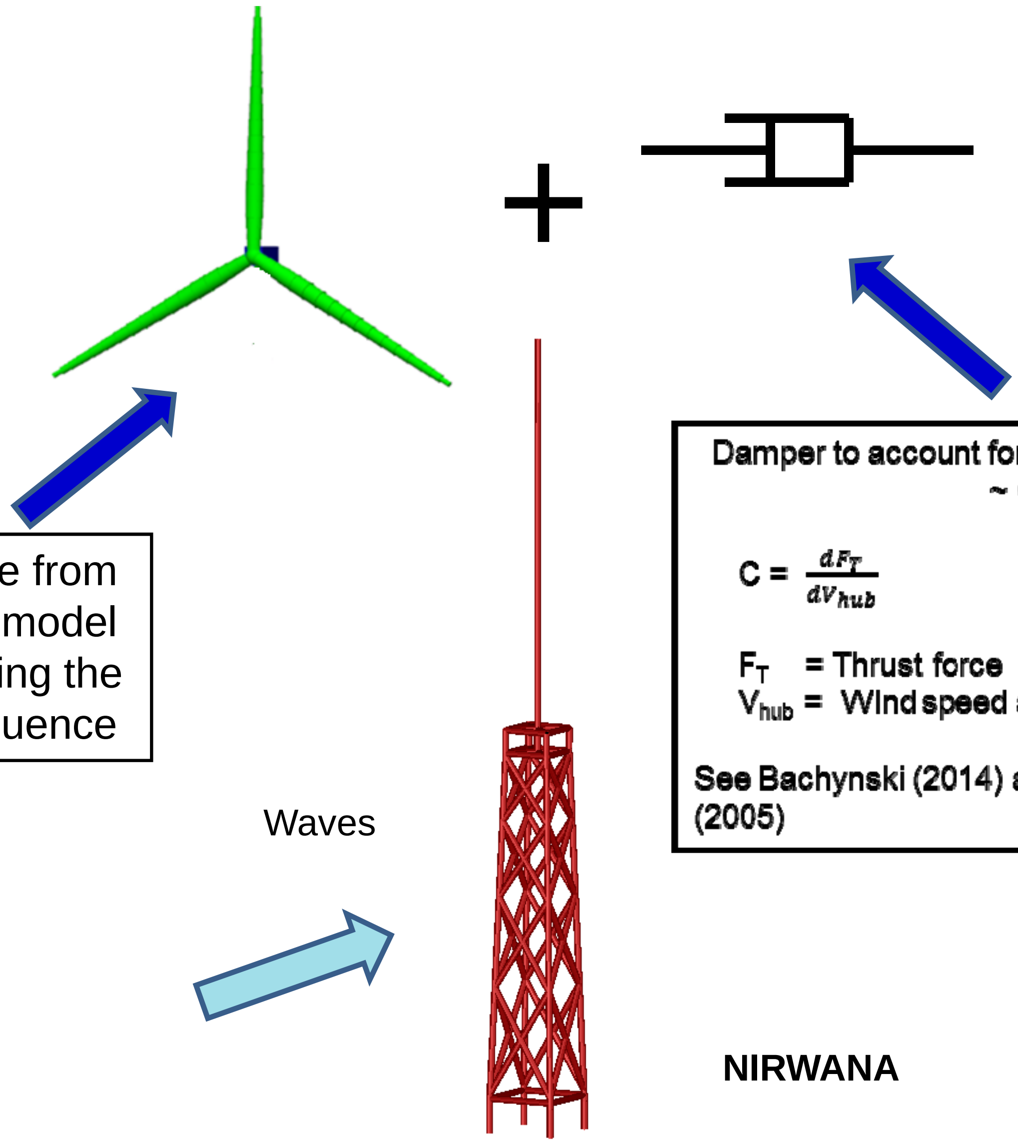
EC4 Largest Waves





Element 1 Axial Force				
Index	Mean (kN)		Standard Deviation (kN)	
	NIRWANA	SIMO-RIFLEX-AeroDyn	NIRWANA	SIMO-RIFLEX-AeroDyn
EC3	-3.91×10^3	-3.86×10^3	1.45×10^2	1.63×10^2
EC4	-3.91×10^3	-3.86×10^3	2.14×10^2	2.43×10^2

4) Decoupling method (NIRWANA)



Thrust and torque from an isolated rotor model (AeroDyn) including the upwind tower influence

Damper to account for Aerodynamic damping
~ CU_s

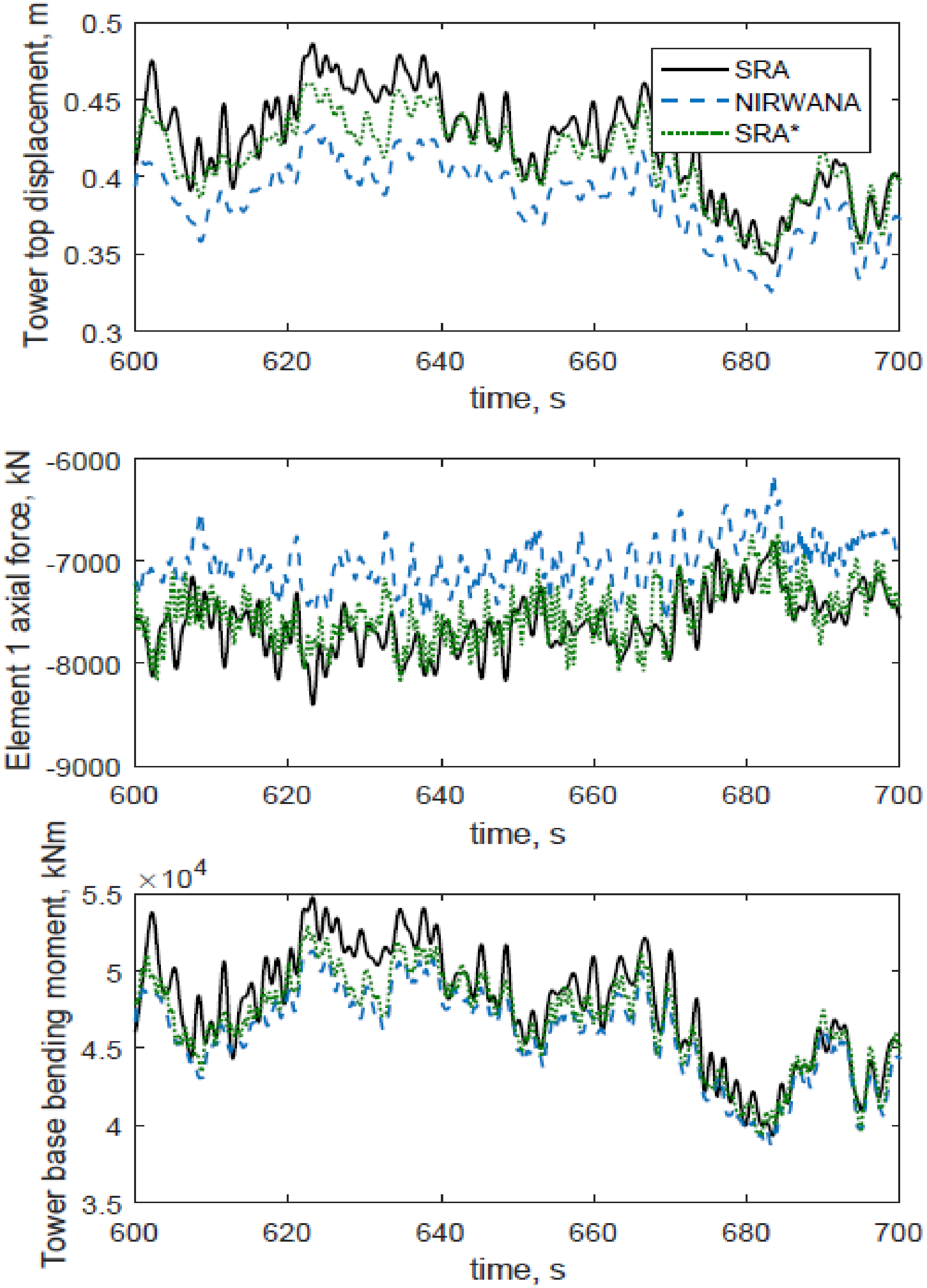
$C = \frac{dF_T}{dV_{hub}}$

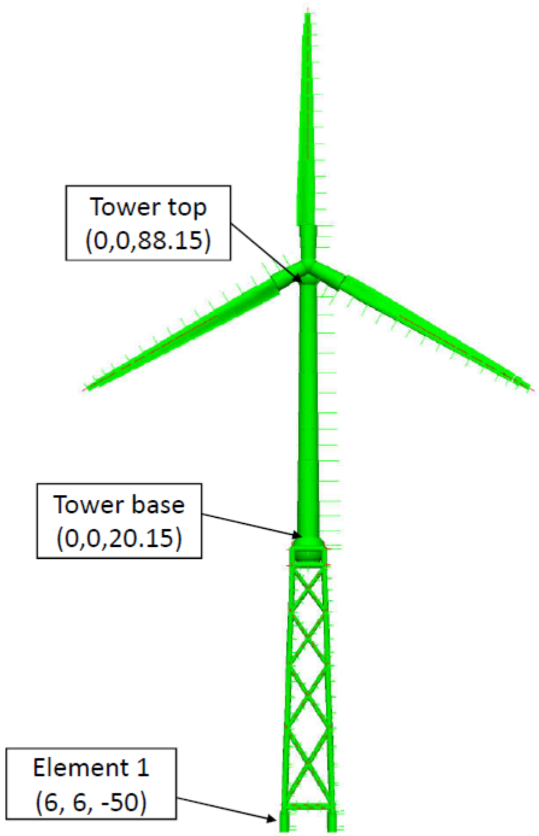
F_T = Thrust force
V_{hub} = Wind speed at hub height

See Bachynski (2014) and Salzman and Tempel (2005)

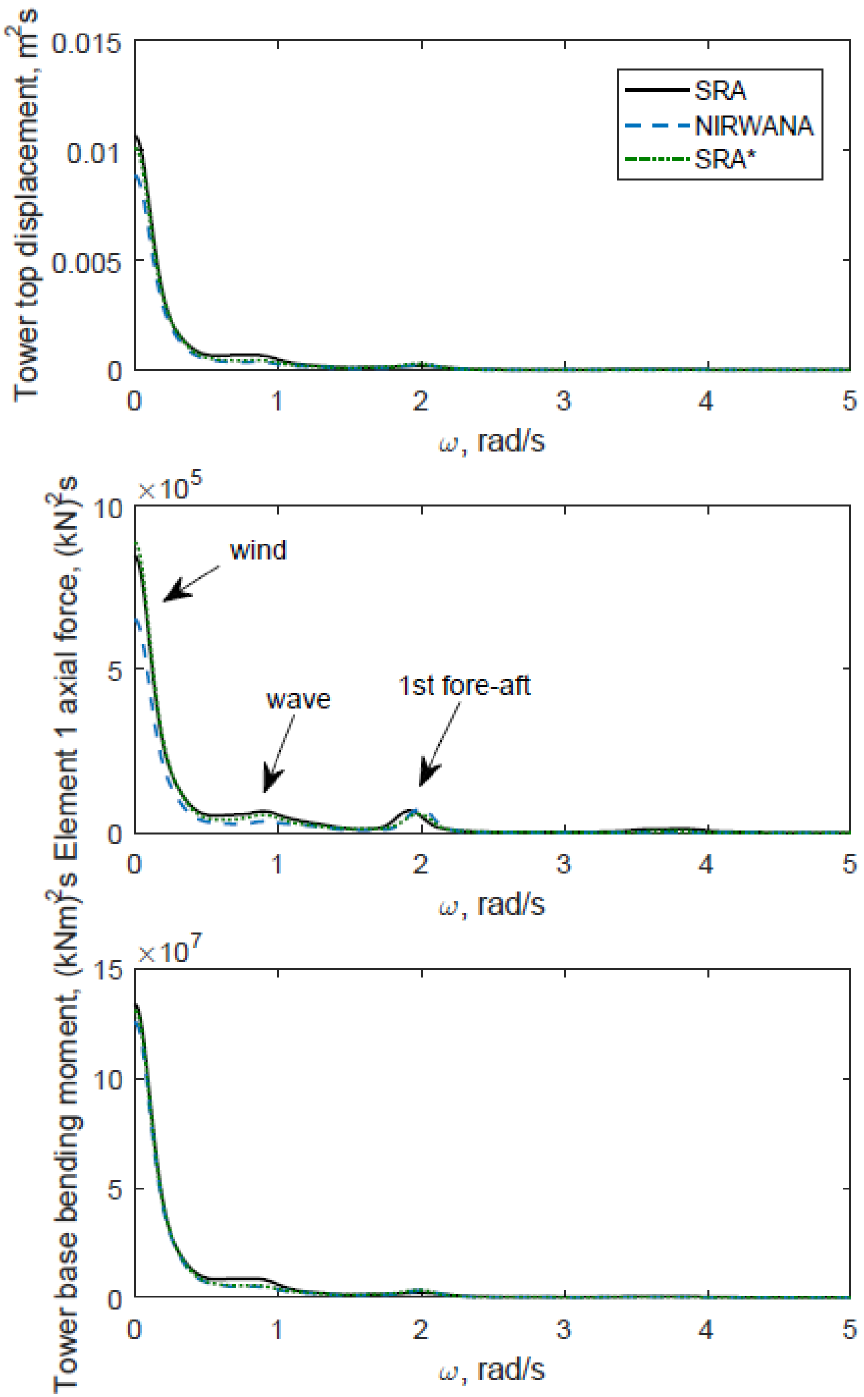
EC2 Largest Thrust

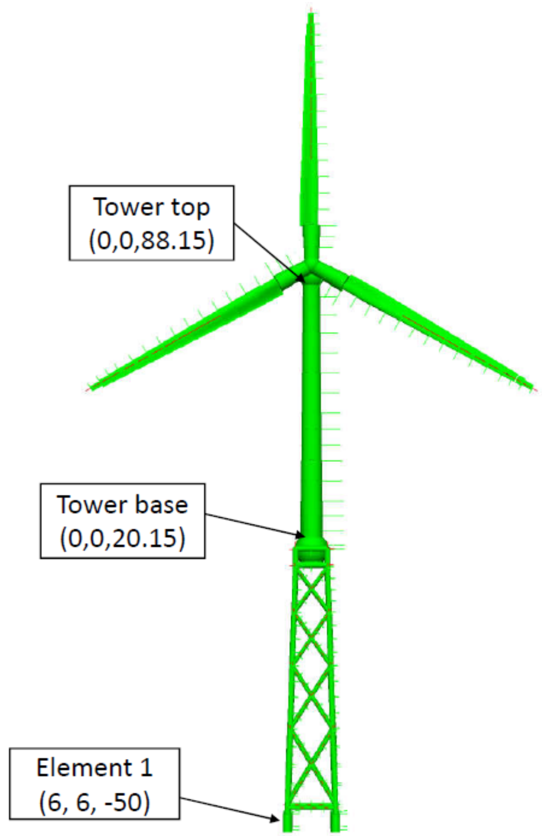
Time-Series Plots





Spectral Analysis





Summary

Element 1 Axial Force				
Index	Mean (kN)		Standard Deviation (kN)	
	NIRWANA	SIMO-RIFLEX-AeroDyn	NIRWANA	SIMO-RIFLEX-AeroDyn
EC2	-6.79×10^3	-7.39×10^3	4.05×10^2	4.76×10^2
EC4	-5.27×10^3	-5.80×10^3	4.33×10^2	5.25×10^2

The results of the decoupling method 2 (NIRWANA) and the coupled model (SIMO-RIFLEX-AeroDyn) are generally in good agreement.

Slight under-prediction of Standard Deviation due to the limited accuracy in modelling the actual aerodynamic damping (linear damper)

5) Computational Efficiency (Decoupling Method 2)

Number of elements: 137
Number of nodes : 74

Computer CPU : Intel i7CPU 1.73GHz
RAM : 16GB

Number of total simulated time steps : 8192

Actual dynamic simulation time required:
NIRWANA (Linear Model) : 8.2s
SIMO-RIFLEX (Nonlinear Model) : 64.5s

If the nonlinear response of the investigated structure is not significant, NIRWANA can be a good engineering tool for dynamic analyses.

Conclusion

- Coupled and decoupled models of jacket-type wind turbines were developed and compared for several environmental conditions.

- Applying the thrust force from an isolated rotor model in combination with a linear aerodynamic damping gives reasonable mean and standard deviation results compared to fully-coupled simulation for environmental conditions where wind force is dominating.

- If the nonlinear behavior of the investigated structure is not significant, a linear model can be used to save computational time.