Research of Support Structure in Offshore Wind Farm

Renewable Energy Department

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Background

- Proposed Offshore Wind Farms
  - MOEA to invest NT$ 684 billion (US$ 23 b)*
  - >30 Wind Farms totalling 5.5 GW capacity
- Target Offshore Wind Farm
  - Formosa I → 32 × SWT-4.0-120
  - Fixed type Offshore Wind Turbine with four-legged jacket foundation
- Typhoon extreme loads (ULS)
- **Strong prevailing NNE wind (FLS)**

Research procedure

Wind Condition

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Short-term wind loads

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Nominal & hot spot stress evaluation

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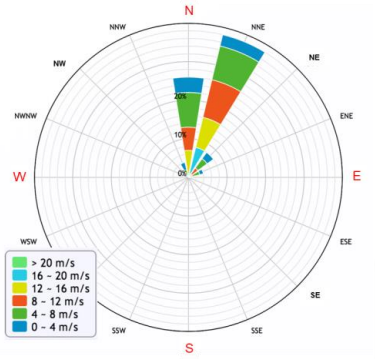
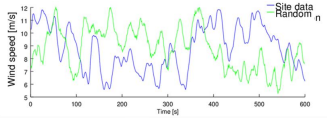
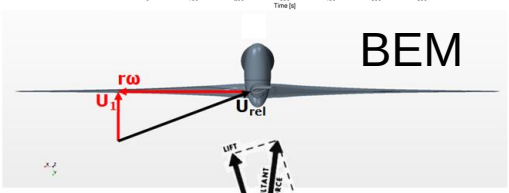
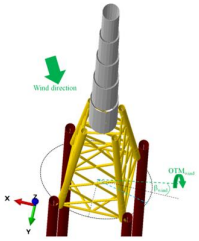
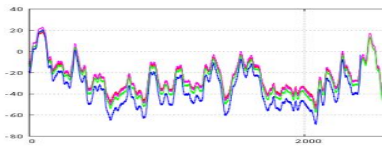
Fatigue life assessment

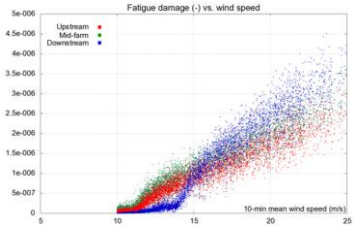


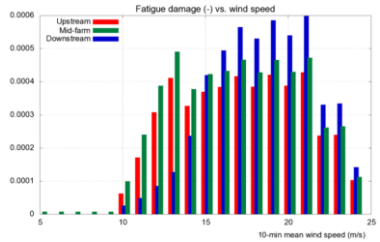






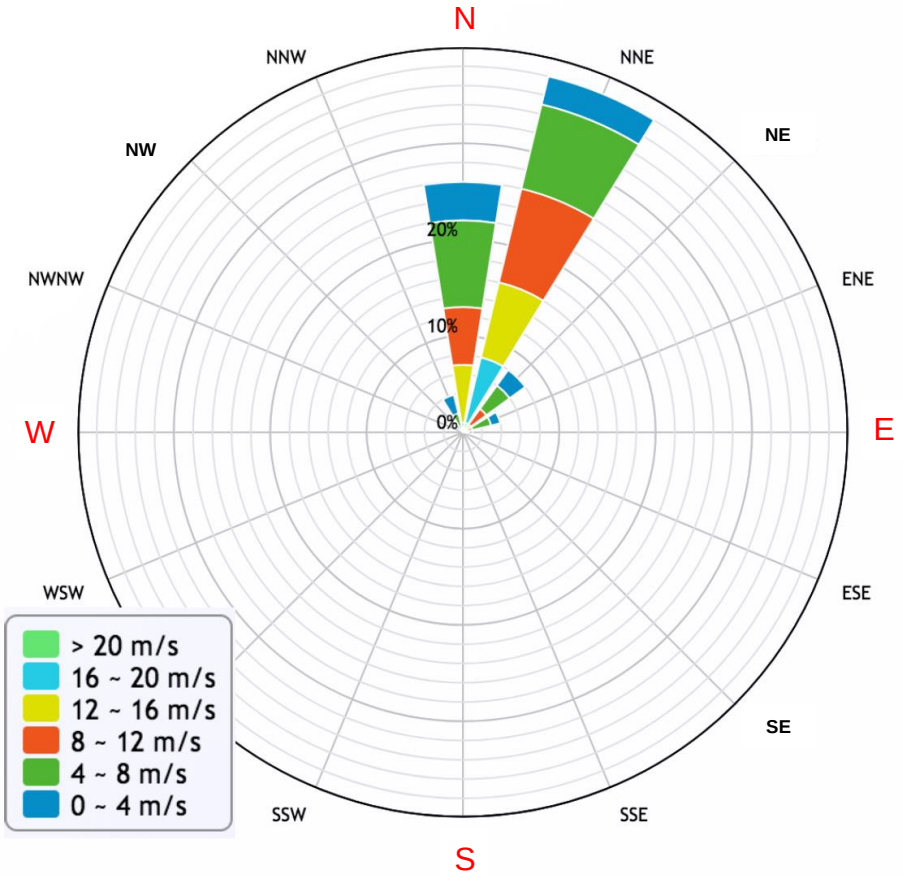






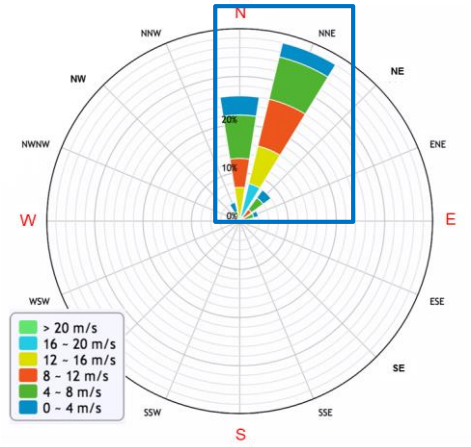
Wind Condition

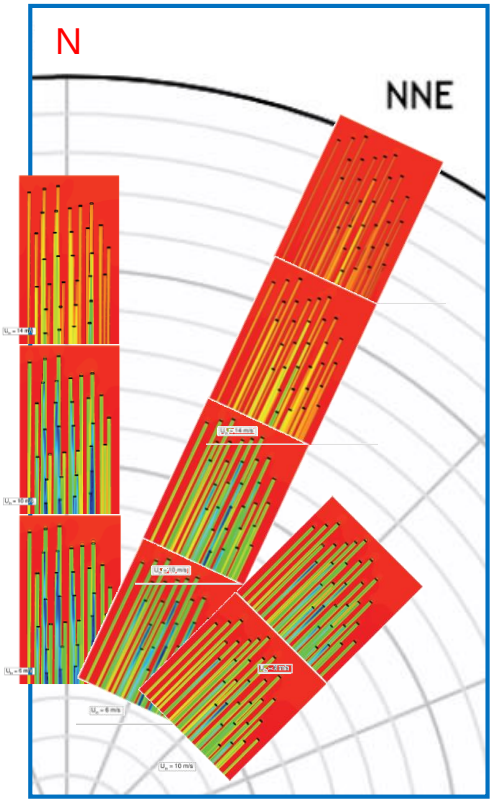
- Winter
- Main direction：NNE, N

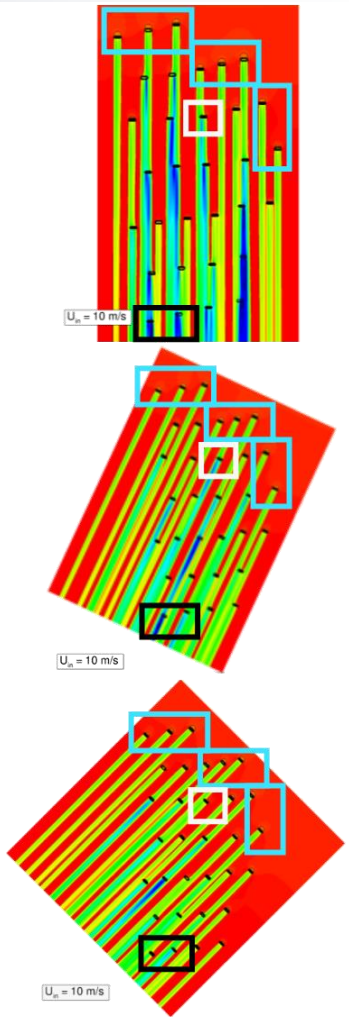


Wind Condition

- Identification of flow regimes
  - ▶ WiFa3D (house-code)
    - RANS-based
    - *k-ε* turbulence
    - Actuator disks
    - Validated against Horns Rev OWF

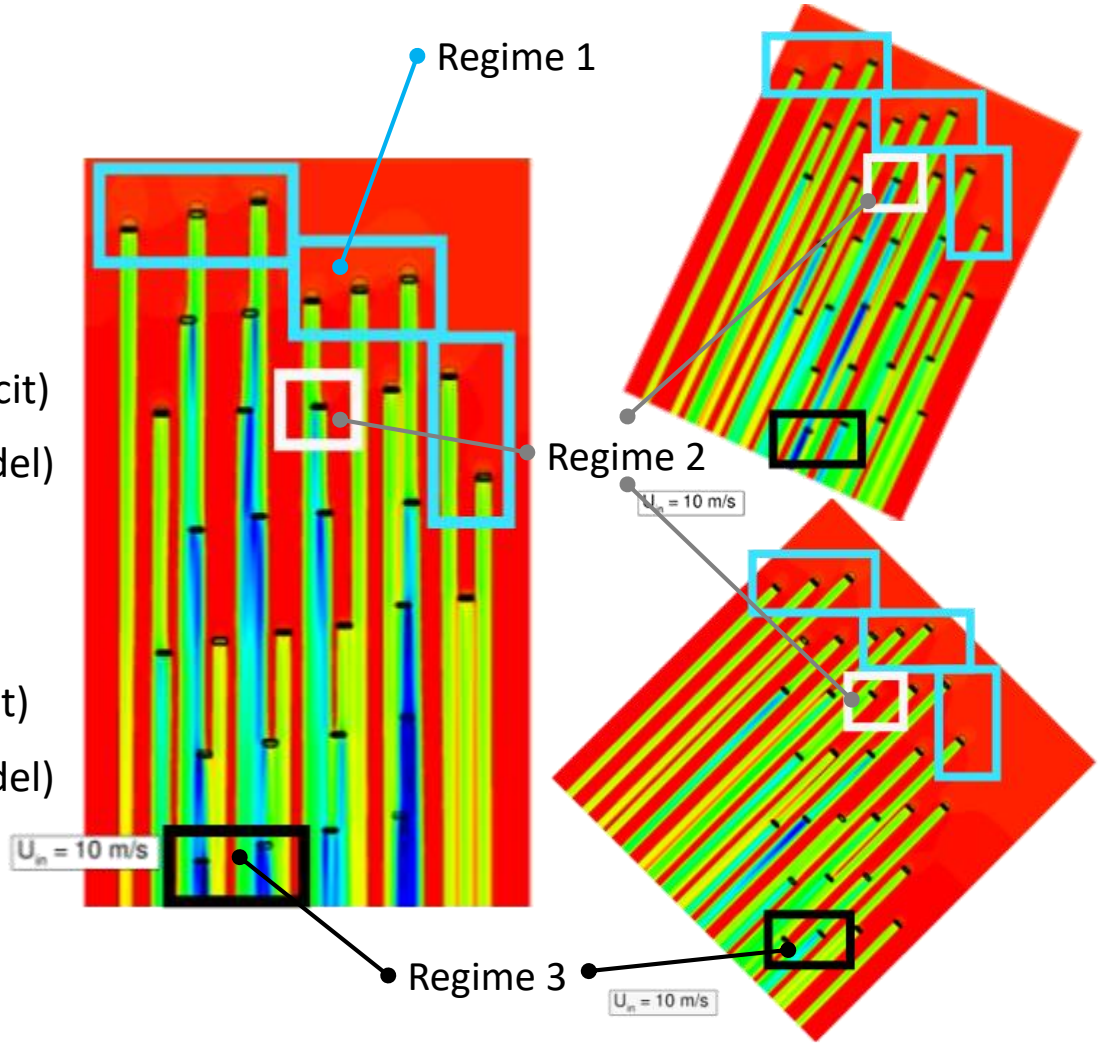






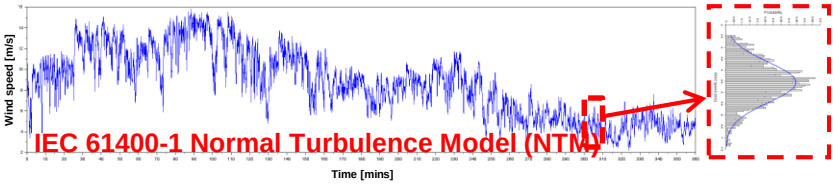
Wind Condition

- Regime 1: Upstream
  - homegeneous inflow
  - normal turbulence model (NTM)
- Regime 2: Mid-farm
  - sinusoid inflow profile (wake deficit)
  - increased turbulence (Larsen model)
  - wake meander
- Regime 3: Down-stream
  - homegeneous inflow (wake deficit)
  - increased turbulence (Larsen model)

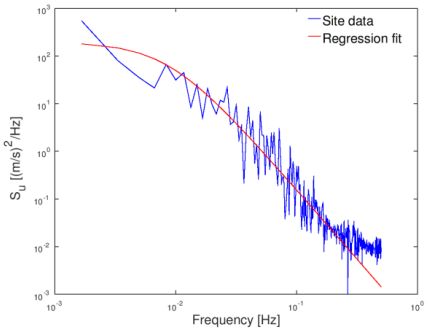


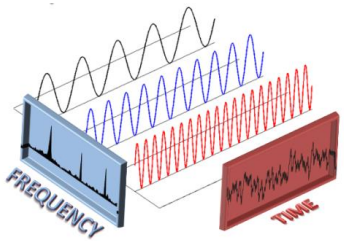
Wind Conditions

- IEC 61400-1 Normal Turbulence Model (NTM)
  - Class 1A: $I_{ref} = 0.16$
  - $\sigma_U = I_{ref}(0.75\,U_{10} + 3.8)$



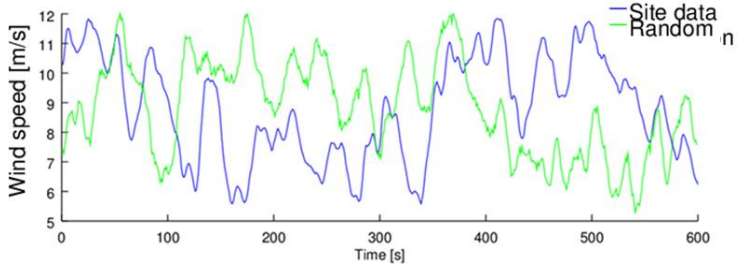
- Fourier analysis (DFT)
  - $X_k = \sum_{n=0}^{N-1} x_n \cdot [\cos(2\pi kn/N) - i \cdot \sin(2\pi kn/N)]$





- Wake-added turbulence (Larsen model)
  - $I_w = 0.29\,S^{-1/3}\sqrt{1-\sqrt{1-C_T}}$

$$I_{total} = \sqrt{I_{ref}^2 + \sum I_{w_i}^2}$$



Wind Condition

- Wake Meander

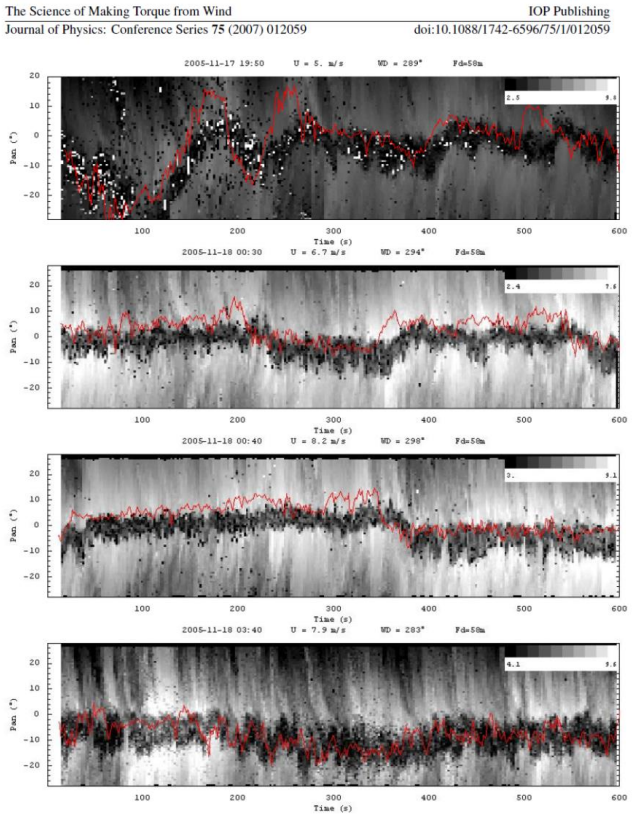
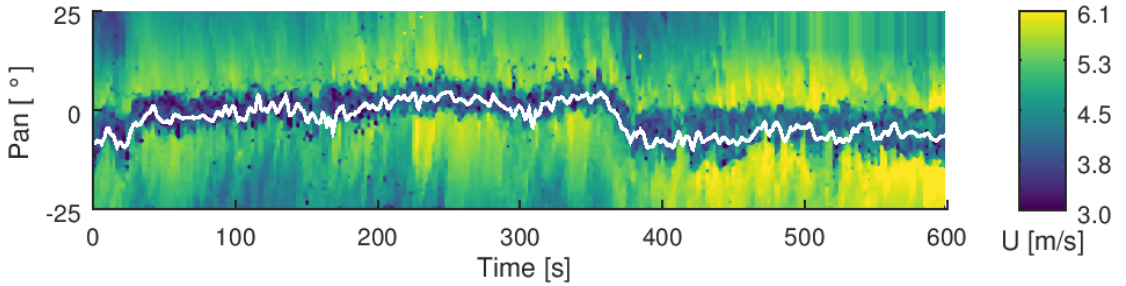
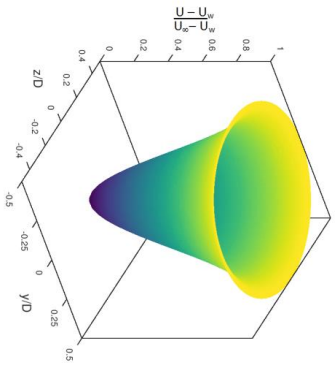


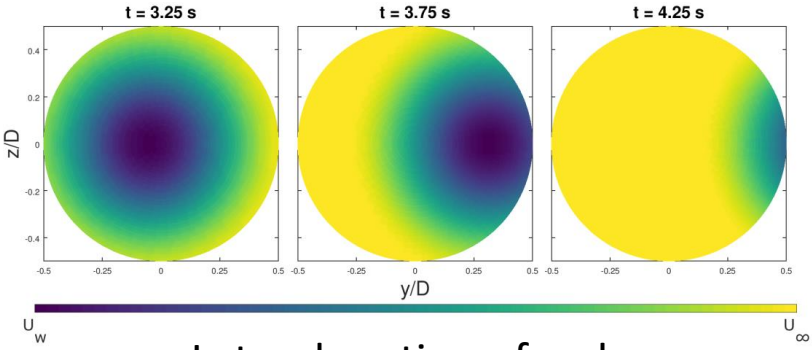
Figure 6. Line Scan data plotted in gray scale as function of time. Low wind speed is shown as black and higher wind speed is shown as white. Focus distance is 3 diameters (58 m).



Data extraction by image processing



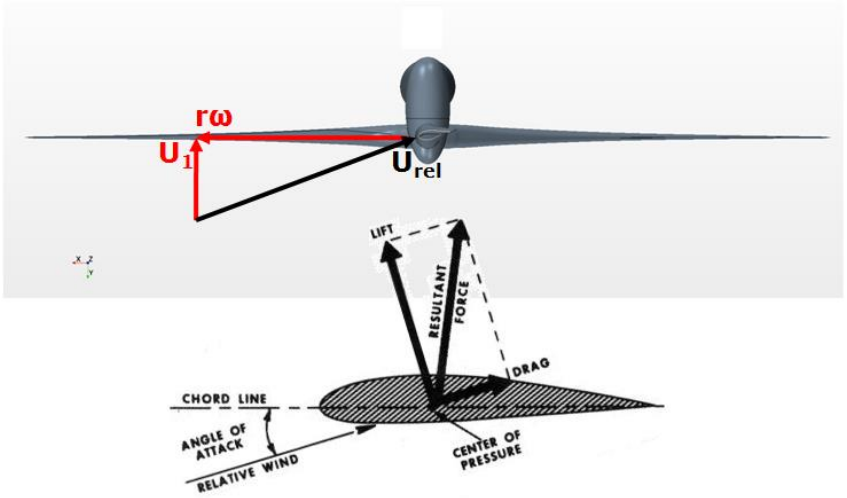
3D velocity profile:
Sinusoidal depression

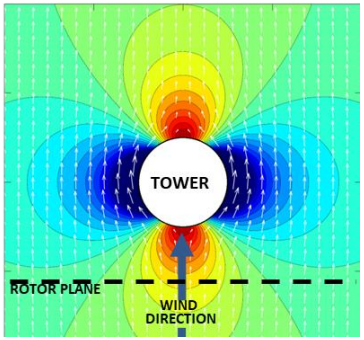


Lateral motion of wake deficit

Short-term wind loads-calculate method

- Wind loads calculation
  - Blade Element Momentum (BEM)
  - Industry standard – adopted by:
    - Bladed (DNV GL)
    - Fast (NREL)
    - HAWC2 (DTU)
    - Qblade (DT Berlin)

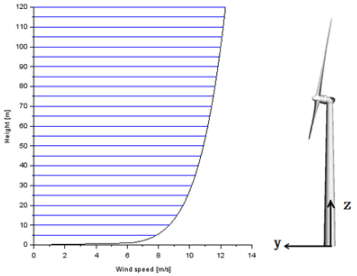




Tower effects:

$$U_r = U_\infty \left(1 - \frac{R^2}{r^2}\right) \cos\theta$$

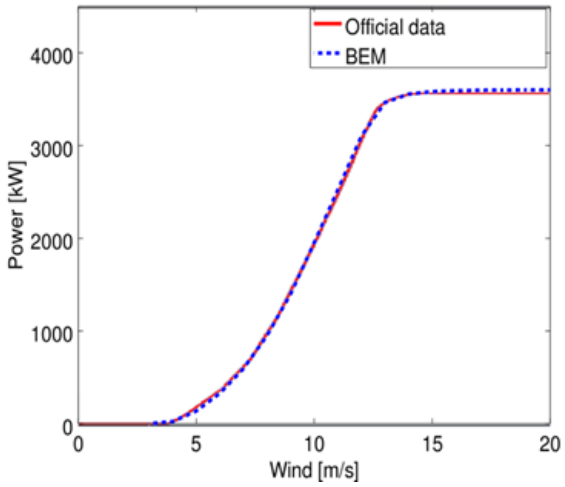
$$U_\theta = -U_\infty \left(1 + \frac{R^2}{r^2}\right) \sin\theta$$



Wind profile:

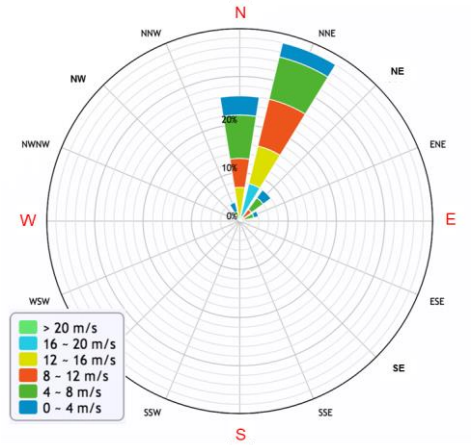
$$U(z) = U(H)\left(\frac{Z}{H}\right)^{\alpha}$$

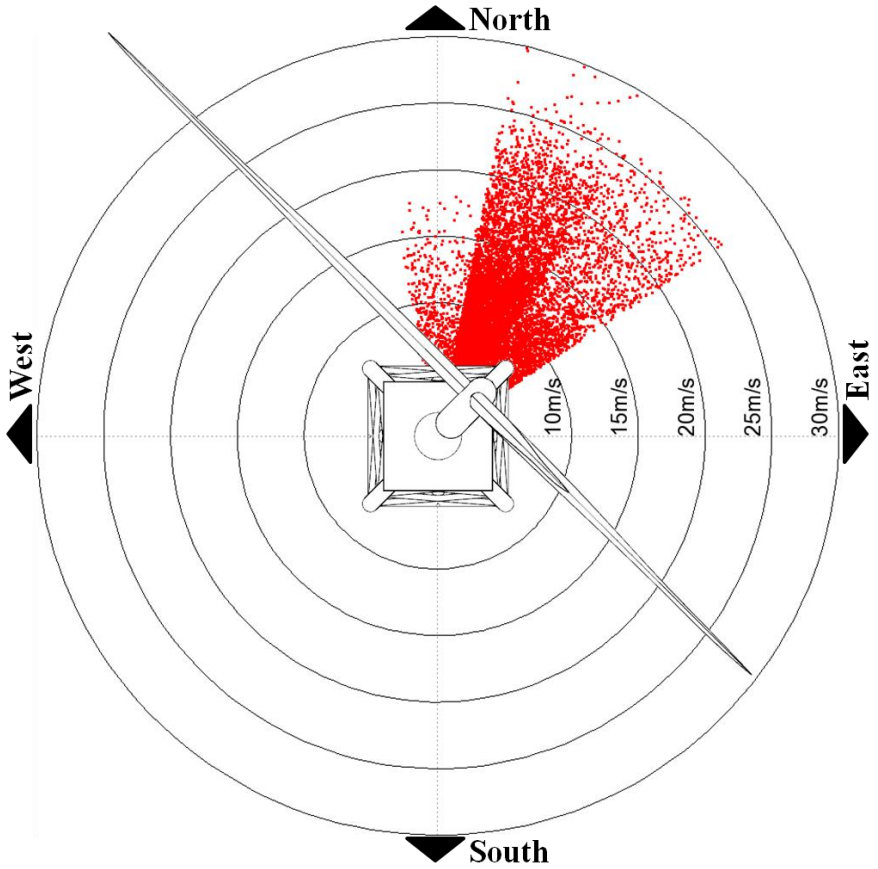
where α = 0.14



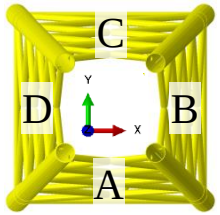
Short-term wind loads-cases

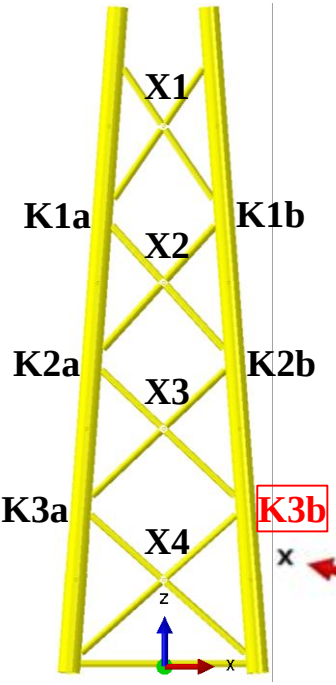
- Cases
  - 10 minute short-term each case
  - Total time：3 months
  - Wind conditions
    - Monte Carlo simulation
    - based on local wind statistics

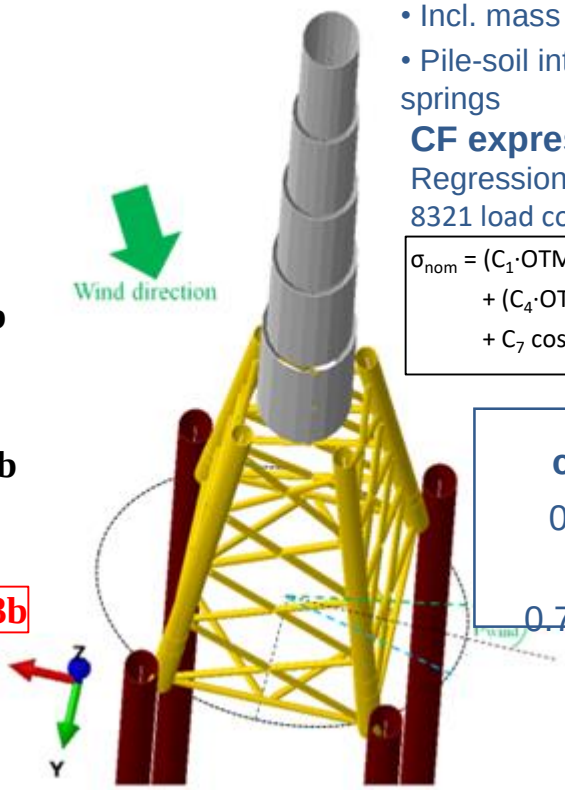




Nominal & hot spot stress evaluation







Finite Element Model:

- 1D beam elements – jacket + tower
- Incl. mass of rotor/nacelle assembly
- Pile-soil interaction as nonlinear springs

CF expressions:

Regression curve fit to static FEA results for 8321 load combinations:

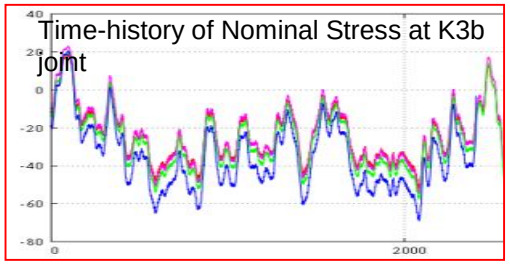
$$\sigma_{nom} = (C_1 \cdot OTM_{wind} + C_2)\cos(\beta_{wind}+C_3) + (C_4 \cdot OTM^2_{hydro} + C_5 \cdot OTM_{hydro} + C_6) + C_7 \cos(\beta_{hydro} + C_8)$$

Time per computation:

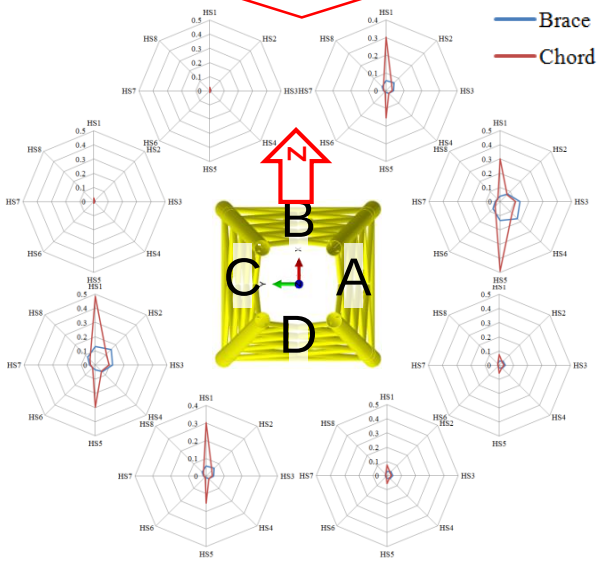
0.5 s/time step

↓

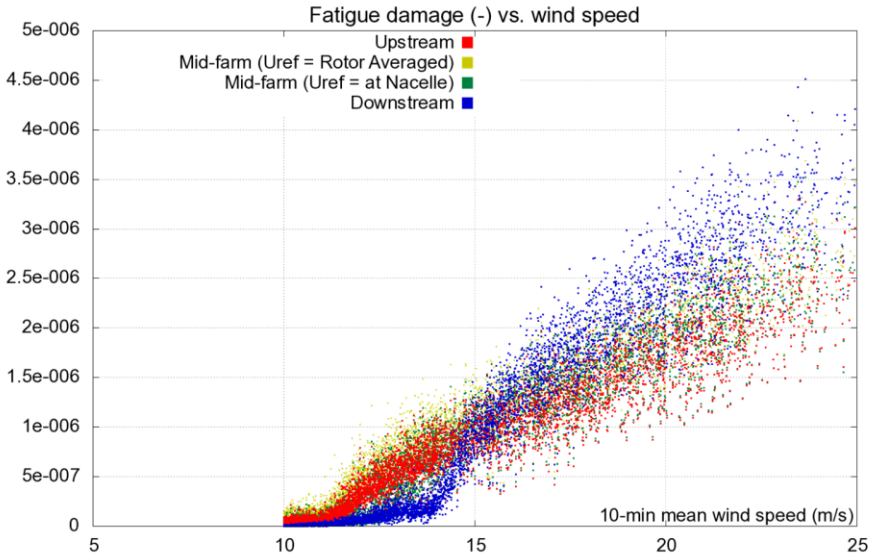
0.72 ms/time step



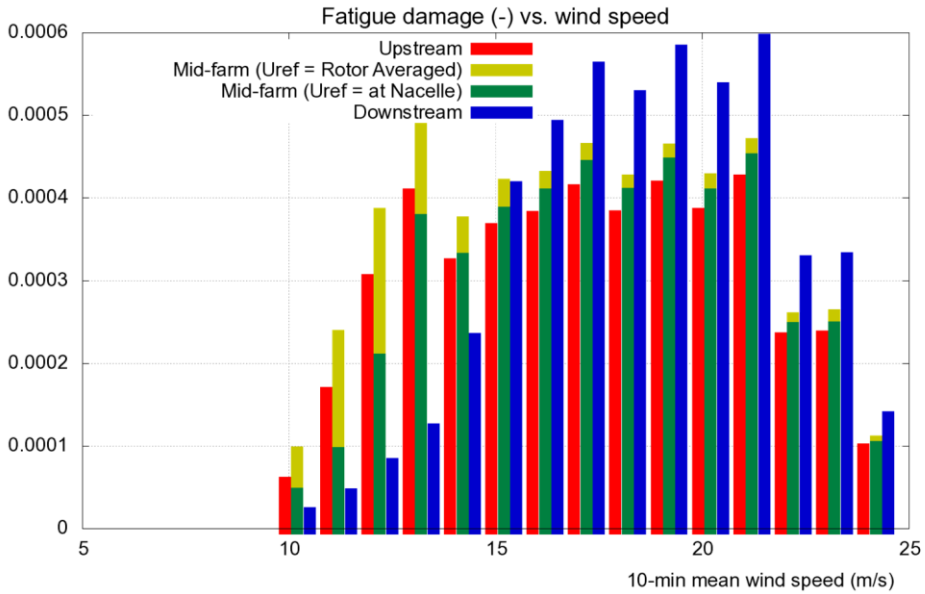
Rainflow cycle counting S-N curves



Fatigue life assessment



Fatigue damage evaluation for 3 month simulated life time



Accumulated fatigue damage distribution for 3 month simulated life time

Location	Damage	Exacerbation
Upstream	0.00454	~
Downstream	0.00495	+9%
Mid-farm (rotor-avg)	0.00524	+15%
Mid-farm (nacelle)	0.00457	+1%

Conclusions

- Fatigue life evaluation methodology for OWT foundations using time-domain simulations and Rainflow Cycle Counting method.

- The exacerbated fatigue loading due to unsteady wind farm wake effects was found to impact the fatigue lives of the downstream turbines with
  - a 9% increase in fatigue damage of the far downstream units
  - a 15% increase in the fatigue damage of the mid-farm units.

Location	Exacerbation
Upstream	~
Downstream	+9%
Mid-farm (rotor-avg)	+15%
Mid-farm (nacelle)	+1%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