WindEurope Technology Workshop 2026

Session: Lifetime

Position-specific Lifetime Assessment for Offshore and Onshore Wind Farms using 10-minute SCADA statistics

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Agenda

1. Overview
2. Tower acceleration statistics (TAS) method
3. The ILA model
4. Method comparisons
5. Implementation

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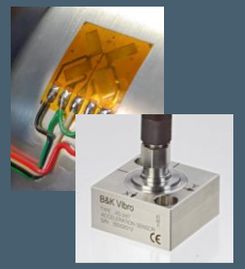
Take aways

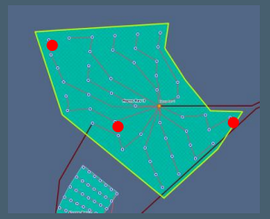
- ✓ TAS **simpler** and **faster** than traditional method.
- ✓ **No offshore** operations.
- ✓ **Position-specific** lifetime.

1. Structural Health Monitoring (SHM) overview

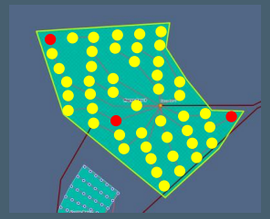
WTG Installation

Offshore SHM installation





Lifetime estimation with SHM

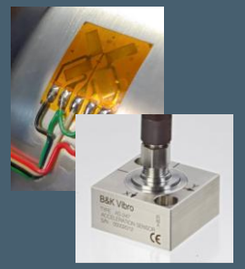


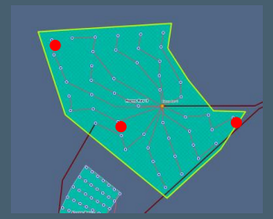
Traditional SHM method

1. Structural Health Monitoring (SHM) overview

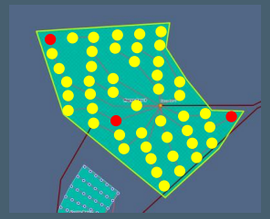
WTG Installation

Offshore SHM installation





Lifetime estimation with SHM



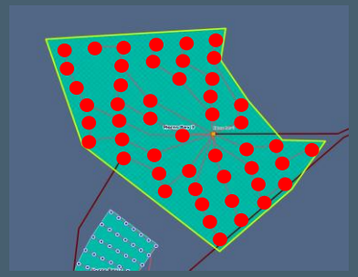
Traditional SHM method

2+ years

SHM commissioned

time

1+ **months**

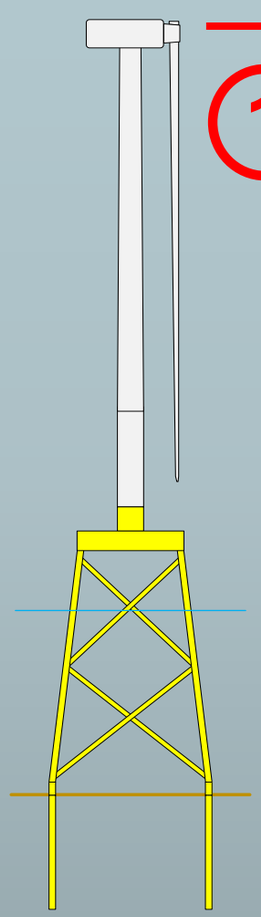


Lifetime estimation using Tower Acceleration Statistics (TAS)

Faster, simpler.

Tower Acceleration Statistics method

2. Tower acceleration statistics method



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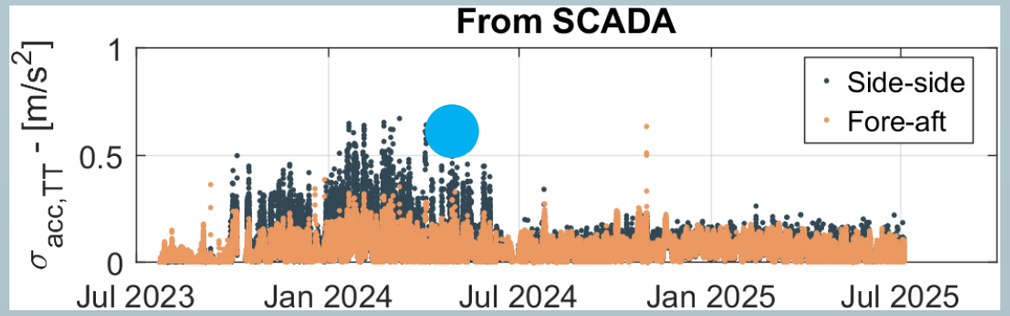

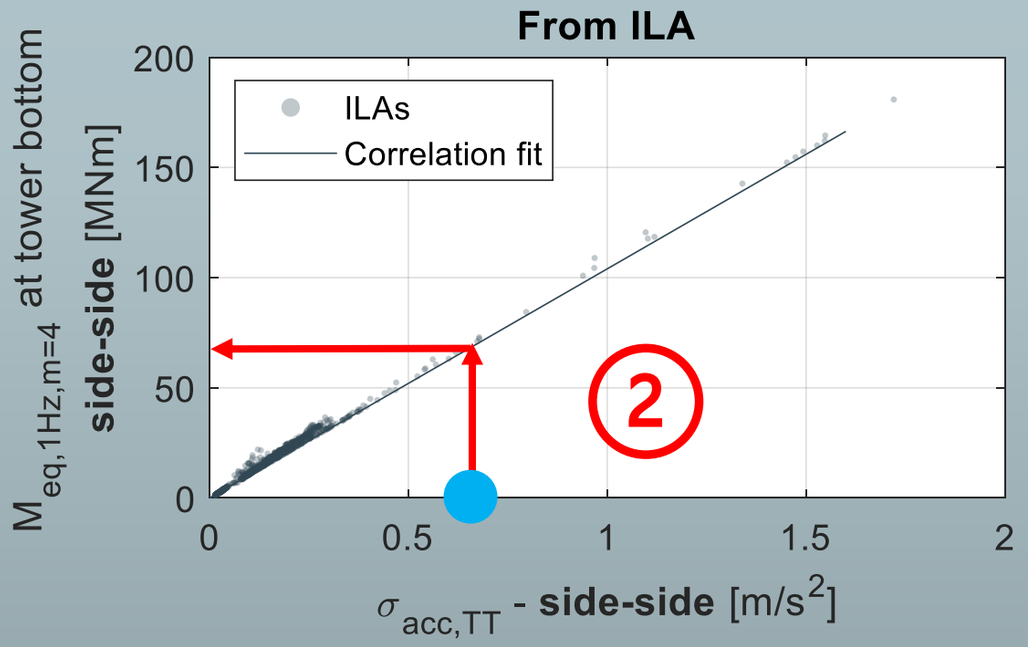

2

3

$\sum$ Duration = $\text{Lifetime}_{\text{design}}$

M_{eq}

4

Design Interface Loads

New lifetime!

1. Tower top SCADA acceleration measurements .
2. $\sigma_{\text{acc,TT}}$ correlation to $M_{\text{eq},1Hz}$.
3. Sum $M_{\text{eq},1Hz}$ to M_{eq} (DEM).
4. Compare DEM ⇒ New lifetime

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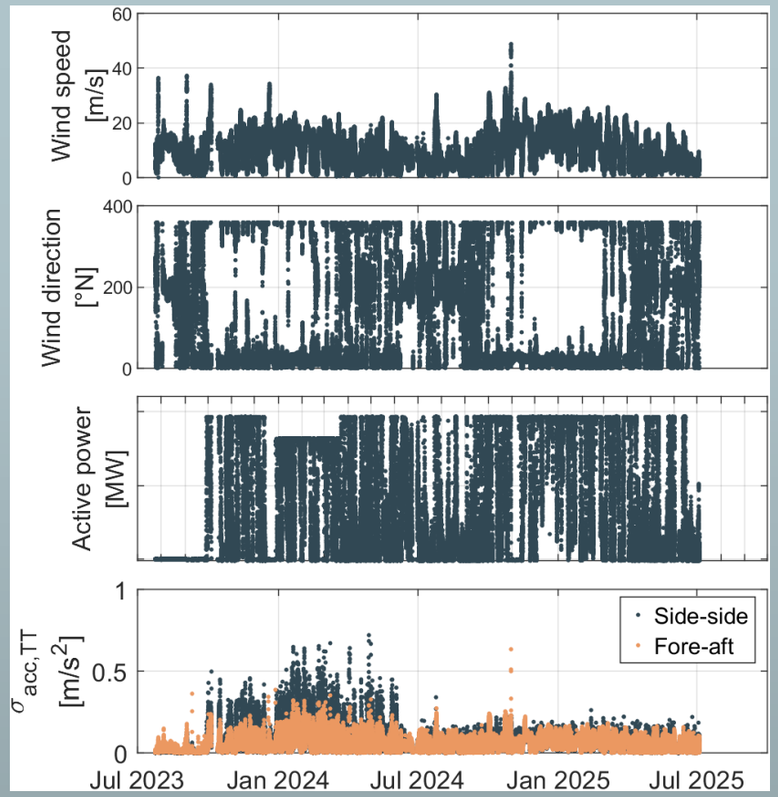
2. Tower acceleration statistics method

Method - Detailed

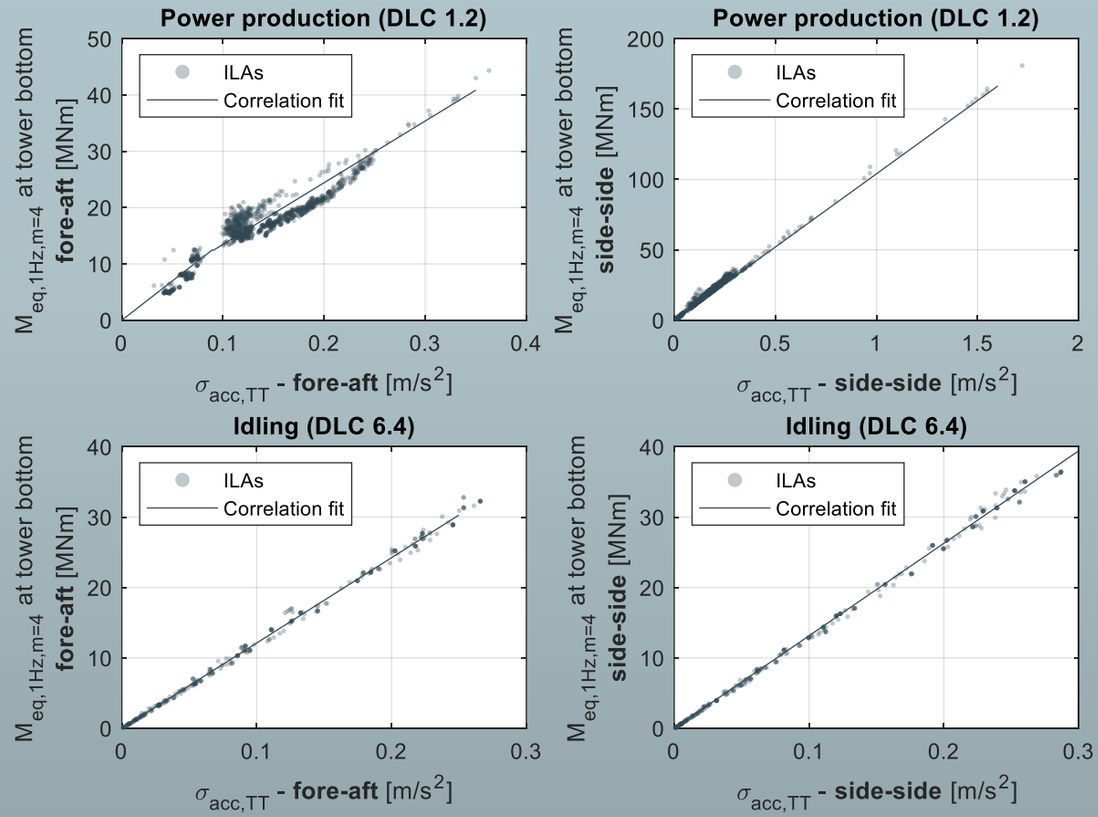
①

10-min SCADA statistics needed:



②

Correlation of tower top accelerations to tower bottom loads.



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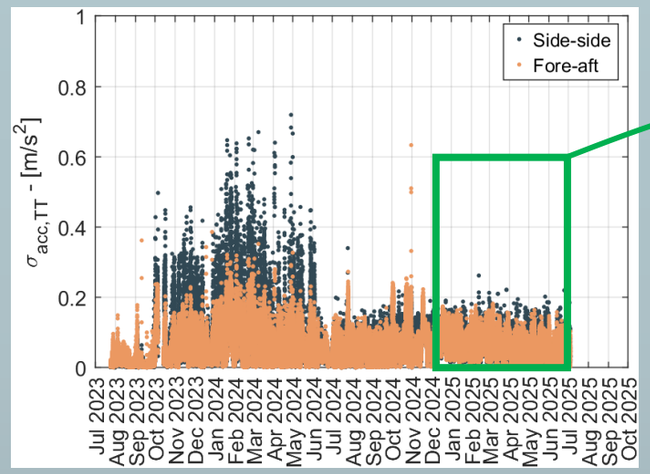
2. Tower acceleration statistics method

Method - Detailed

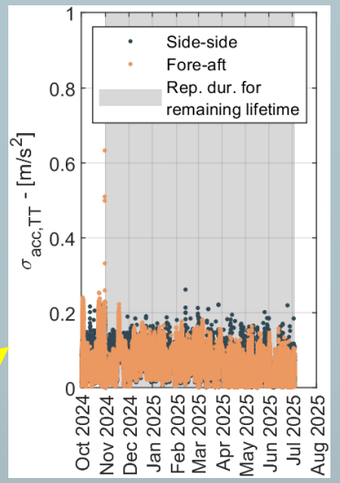
③ Assignment of durations

Past



+

Future



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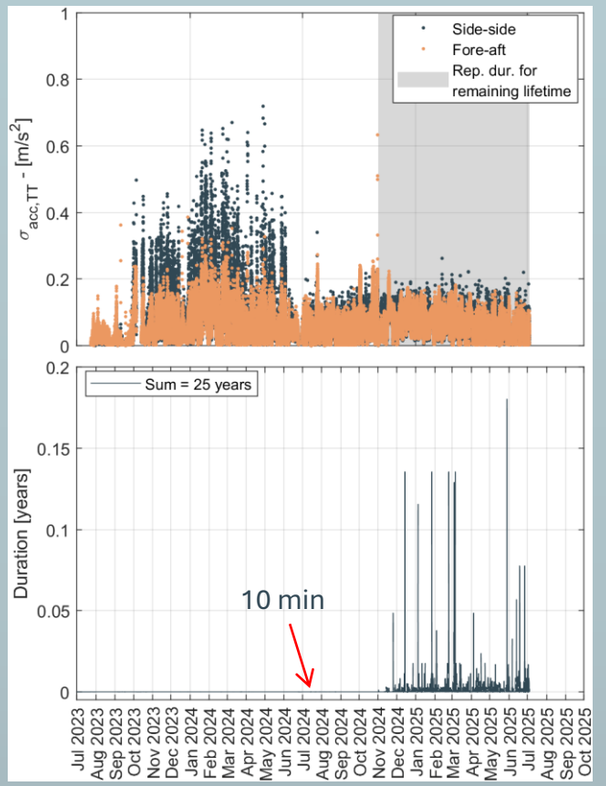
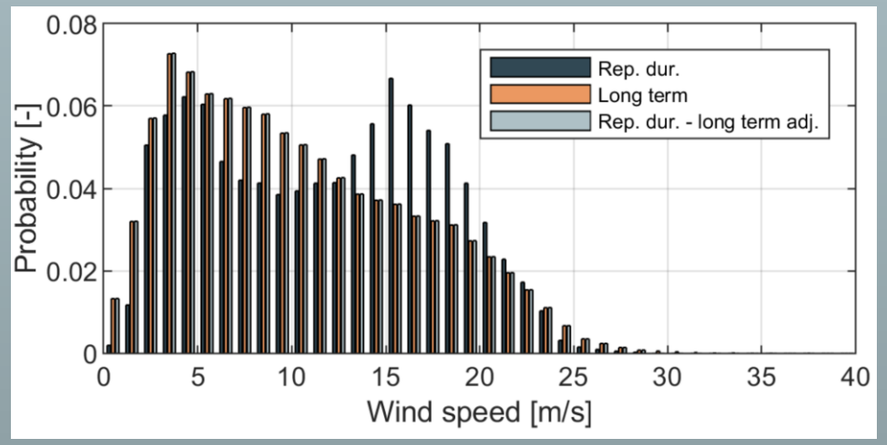
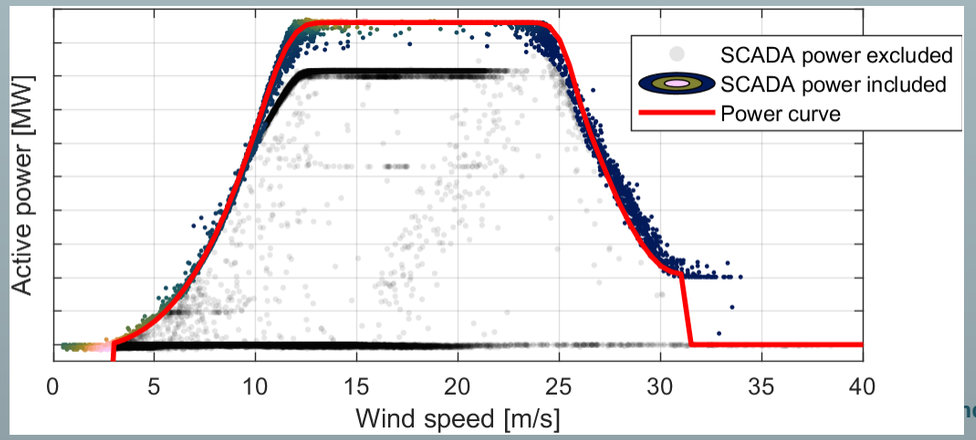


Adjust for long term wind distribution.



Excluding not normal operation.



2. Tower acceleration statistics method

Assumptions

	Impact on lifetime accuracy	Assumed by traditional SHM
Dominating mode shape – 1st mode	Minor	No
Standard deviation correlation with 1 Hz DEL	Minor	No
Load comparison ⇒ lifetime	"On paper" lifetime Actual lifetime	Yes

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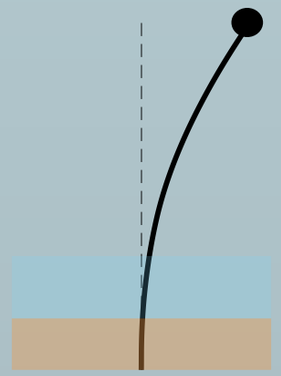
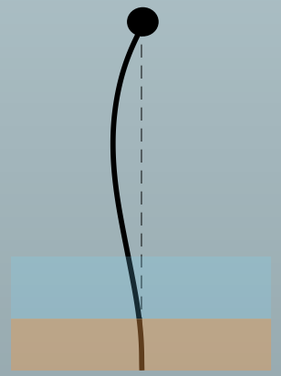
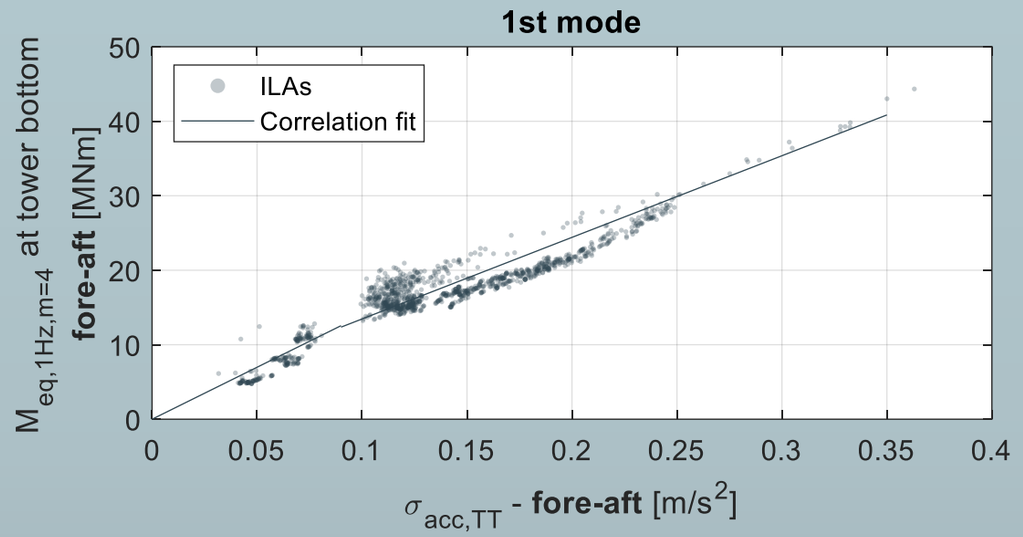
2. Tower acceleration statistics method

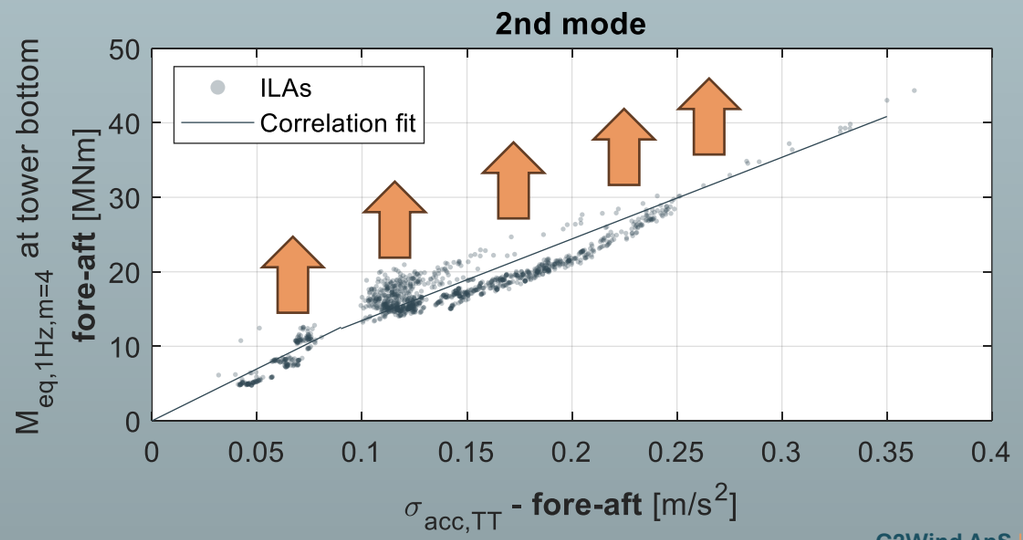
Assumptions – Dominating mode shape 1st mode

Why is this an assumption?









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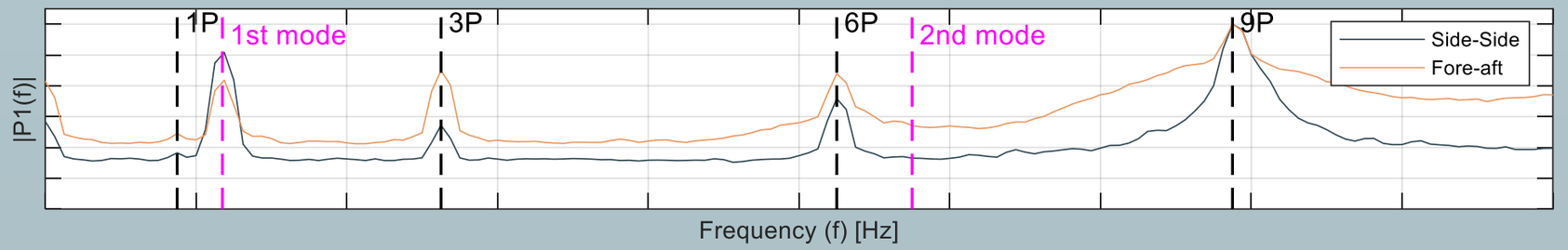
2. Tower acceleration statistics method

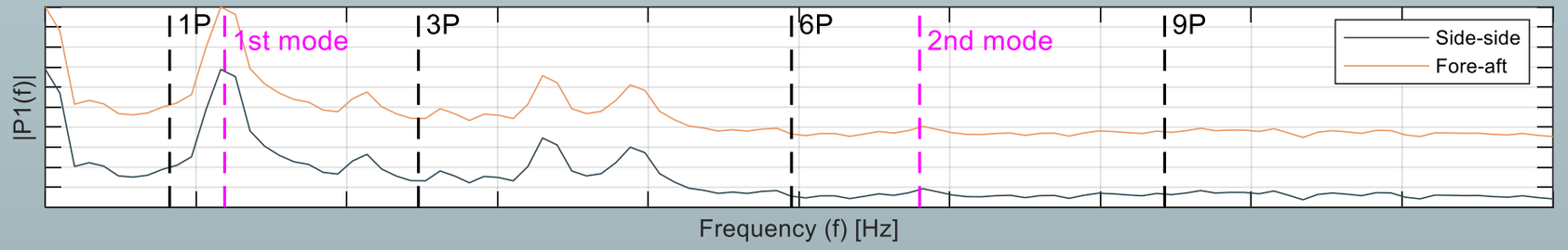
Assumptions – Dominating mode shape 1st mode

Example of an FFT plots from measurements – **no signs of 2nd mode oscillations:**

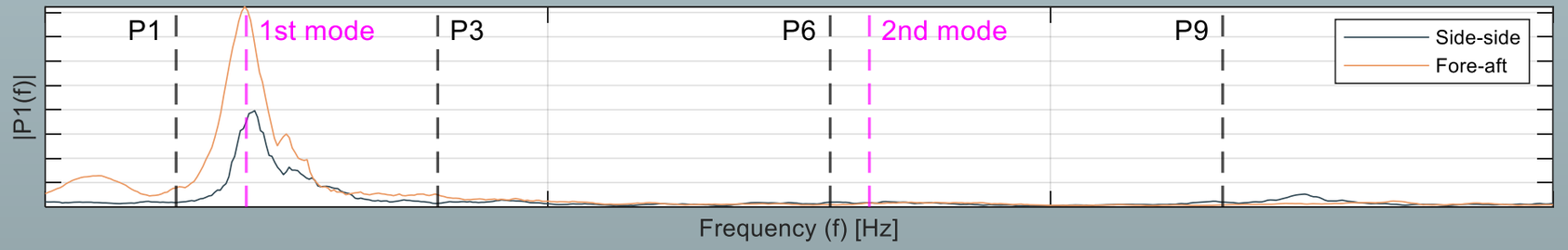
Jacket – tower bottom:



Jacket – tower top:



Monopile – tower top:



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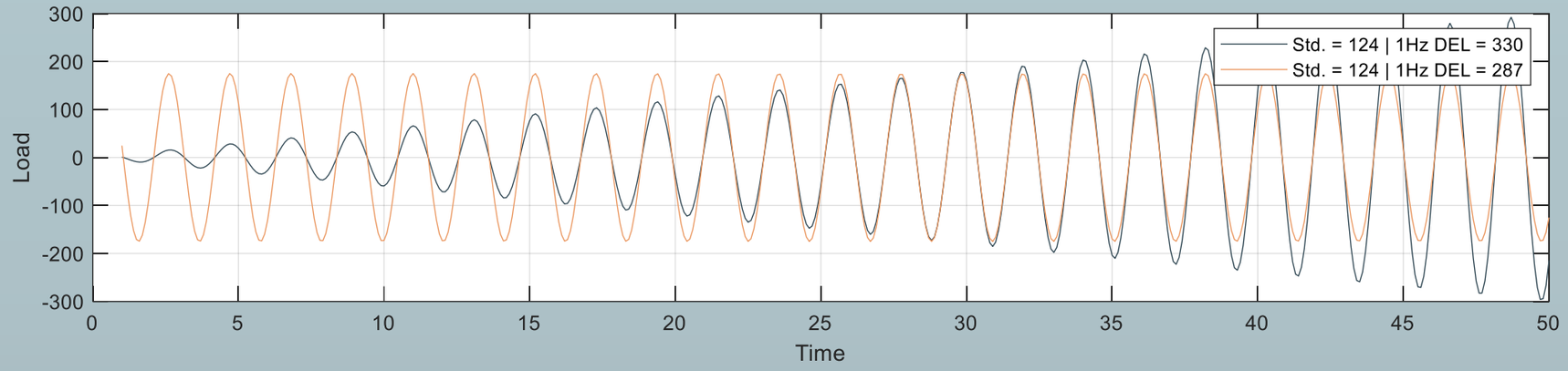
2. Tower acceleration statistics method

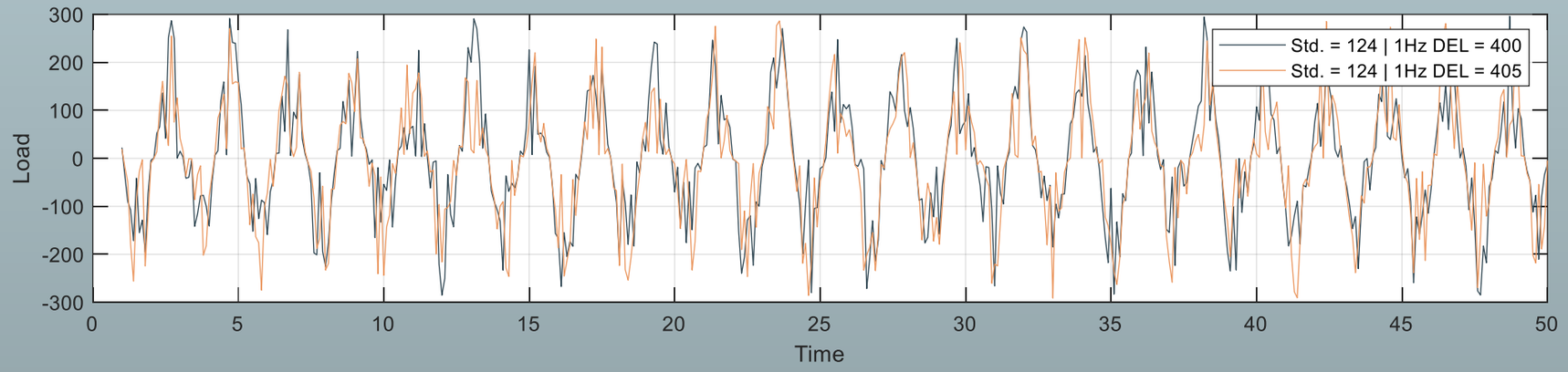
Assumptions – Standard deviation correlation with 1 Hz DEL

Examples of relation between std. and 1 Hz DEL:

Bad correlation-
Constant amplitude vs. increasing amplitude:



Good correlation -
Random signals comparison:



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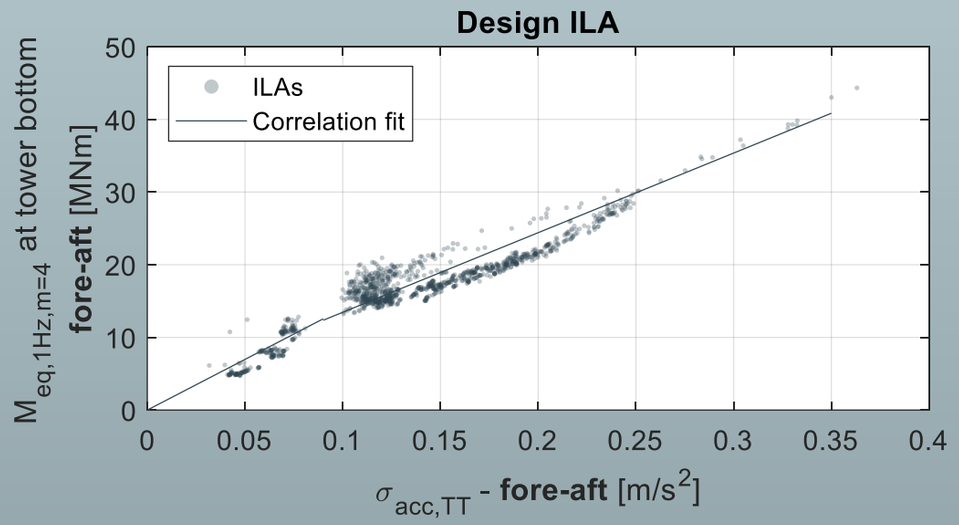
3. The ILA model

Standard approach:

Use design ILA model

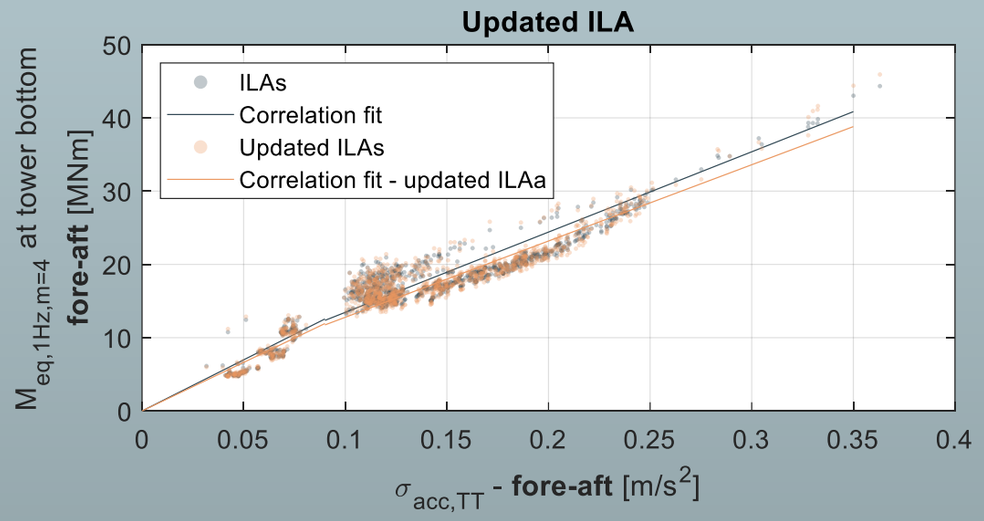
- Design interface loads
- Design damping
- Design position structure and soil



Updated approach:

Update of ILA model

- Measured damping
- Measured 1st natural frequency
- No update of environmental conditions



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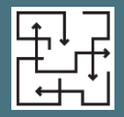
4. SHM method comparisons

	Traditional SHM method	Tower acceleration statistics method
Complexity and cost 	☹ Offshore operations required	☺ Existing SCADA sensors
Availability 	☹ After installed and calibrated	☺ Right after commissioning
Accuracy 	☺ Measuring loads at the tower bottom directly – but only for a few assets (😐)	🙂 Use ILA model to transfer tower top accelerations to tower bottom loads
Maintenance 	😐 Strain gauge calibration necessary – maybe continuously	☺ Tower top accelerometer must work for normal WTG operation – always maintained
Certifiable 	☺ Yes	☺ Yes

5. Implementation

Asset management software

➢Can be added to your asset management software with an API solution.

```
https://api.c2wind.com/C2SHM/v1/measurements?from=2026-05-01&to=2026-05-12
```

```
https://api.c2wind.com/C2SHM/v1/turbines/42/signals?type=lifetime
```

```
https://api.c2wind.com/C2SHM/v1/model/DEEP/acc1hzdemcor?type=foreaft
```

```
...
```

Thank you for your attention

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Backup slides

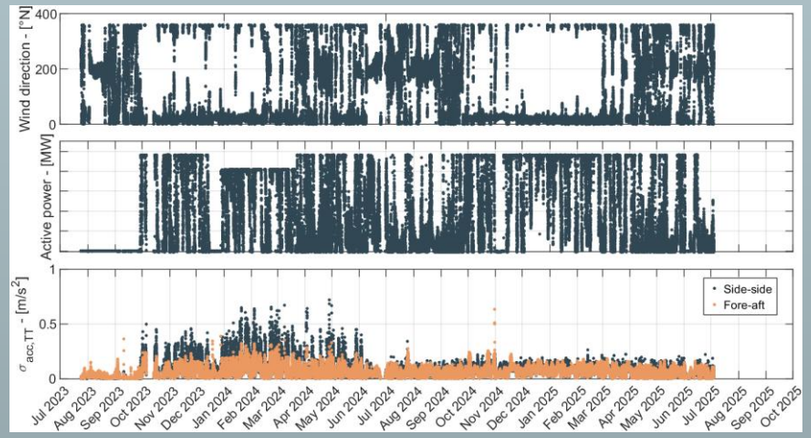
2. Tower acceleration statistics method

Method - Detailed

①

10-min SCADA statistics needed:

- **Mean wind direction:** For directional DEM
- **Mean wind speed**: For long-term correction (next slide)
- **Active power:** For choosing power production or standstill correlation
- **Std. of tower top acceleration:** For correlation to $M_{\mathrm{eq,1Hz}}$



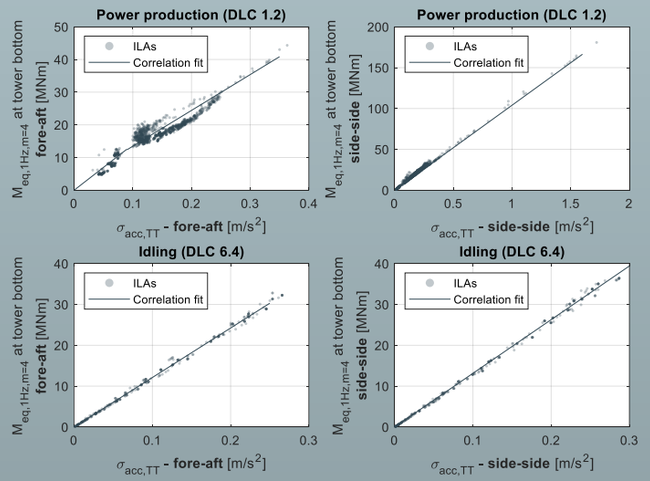
②

Correlation of tower top accelerations to tower bottom loads.

- Using the results from the **design ILA**
- Split the correlation in fore-aft and side-side, power production and standstill

$$M_{\mathrm{eq,1Hz}} = \left(\frac{\sum_i \Delta M_i^m n_i}{T_s} \right)^{1/m}$$

$M_{\mathrm{eq,1Hz}}$	1 Hz damage equivalent bending moment
ΔM_i	Bending moment range for bin i
n_i	Number of cycles for bin i
m	Wöhler exponent
T_s	Simulation time in seconds for the 10-minute ILA bin (600 s)



③

Calculate damage equivalent bending moment from the 1 Hz damage equivalent bending moment:

$$M_{\mathrm{eq}} = \left(\frac{\sum_j M_{\mathrm{eq,1Hz},j}^m n_j}{N_{\mathrm{ref}}} \right)^{1/m}$$

$M_{\mathrm{eq},\theta}$	Damage equivalent bending moment
$M_{\mathrm{eq,1Hz},j}$	1 Hz damage equivalent bending moment for timestamp j
n_j	Number of cycles for timestamp j
m	Wöhler exponent
N_{ref}	Reference number of cycles

④

Calculate the lifetime using the design lifetime and the design damage equivalent bending moment:

$$\frac{\mathrm{Lifetime}}{\mathrm{Lifetime}_{\mathrm{design}}} = \left(\frac{M_{\mathrm{eq,design}}}{L_{\mathrm{eq}}} \right)^m$$

$\mathrm{Lifetime}$	New lifetime corresponding to M_{eq}
$\mathrm{Lifetime}_{\mathrm{design}}$	Lifetime used in the detailed design
$M_{\mathrm{eq,design}}$	Damage equivalent bending moment used in the design
M_{eq}	New damage equivalent bending moment
m	Wöhler exponent