Fully integrated load analysis included in the structural reliability assessment of a monopile supported offshore wind turbine

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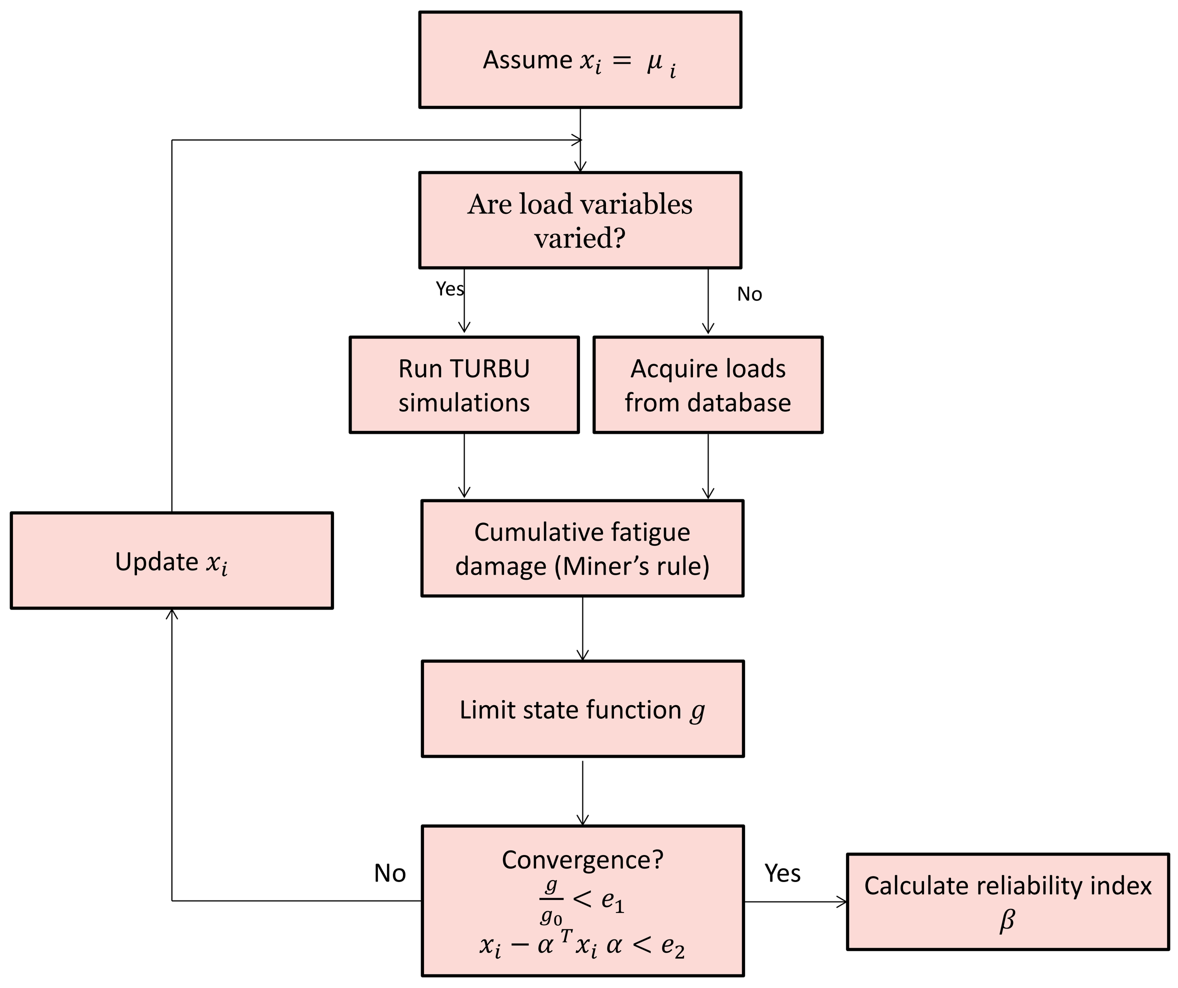
Objective

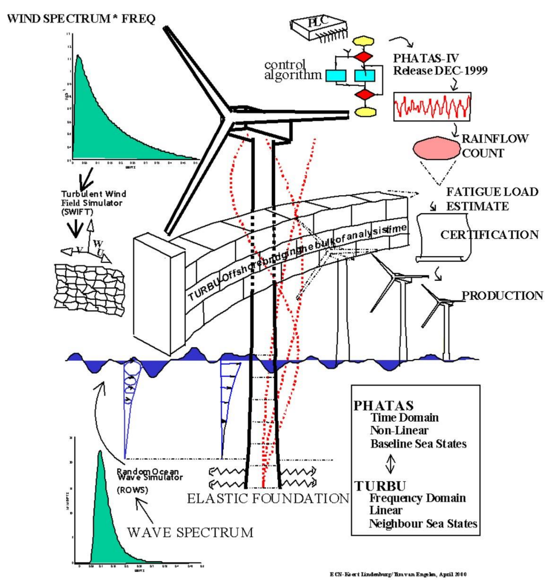
To investigate where cost reduction are possible in the support structure while keeping a sound and safe design:

- Probabilistic design methods are used.
- For time efficient load computations TURBU, a fast fully integrated wind turbine design and analysis tool in the frequency domain, is integrated in the probabilistic approach.



TURBU

- Full non-linear steady state model (multi-body average deformation)
- Time-invariant linear dynamic model (multi-body, Newton, Coleman)
- Linear frequency and time domain analysis of 3-bladed Horizontal Axis Wind turbines



Fatigue limit state:

$$g = \Delta - D = 0$$

Nmax = f(logC1,logC2) of SN- curve (DNV RP-C203)

$$D = \sum_i \frac{n_i}{N_{max,i}}$$

FERUM

- Open source structural reliability code in MATLAB.
- First Order Reliability Method (FORM) selected.
- Advantage FORM is information on contribution of selected stochastic variables to the variance of the limit state function g.

Variable	Distribution	Mean	Standard deviation
logC1	Normal	12.164	0.20
logC2	Normal	16.106	0.25
Δ (Miner)	Lognormal	1.00	0.30
Young modulus	Lognormal	210e9	42e9
CD	Normal	0.70	0.10
CM	Normal	2.00	0.10
Soil stiffness	Lognormal	6.603e10	1.321e10

Case study

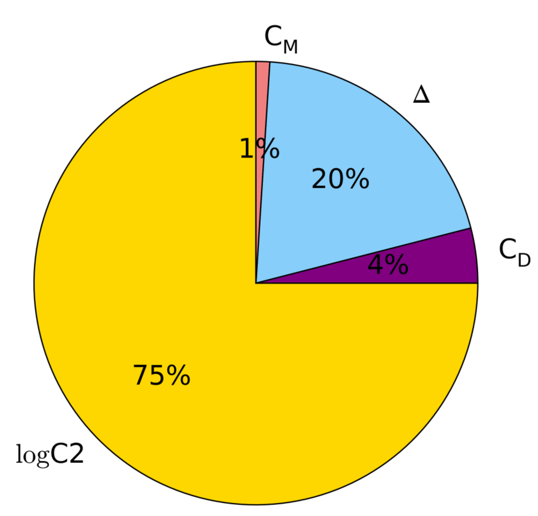
- Modern 4MW wind turbine with monopile support structure, rotor diameter 130m, in 30m water depth.
- Twelve wind bins with for every wind bin six time series of one hour.
- Windspeed Weibull distribution k = 2.15 and u = 9.36m/s.

Bin	Wind velocity [m/s]	Significant wave height [m]	Spectra Peak Period [s]	peak shape parameter (gamma)
1	3	0.375	4.5	1.00
2	5	0.625	4.5	1.00
3	7	0.875	4.5	1.24
4	9	1.125	5.5	1.00
5	11	1.375	5.5	1.43
6	13	1.875	6.5	1.34
7	15	2.375	7.5	1.17
8	17	3.125	7.5	2.39
9	19	3.875	8.5	2.19
10	21	4.375	9.5	1.69
11	23	5.125	9.5	2.52
12	25	6.375	10.5	2.63

Results

- Rainflow count of fore-aft bending moment at mudline only.
- Design reliability index β > 3.7 (DNV OS-J101)
- Reliability index β = 6.35 (Failure probability = 1E-10) in case study.

Variable	Design point	Contribution to variance limit state function
logC1	12.164	0%
logC2	14.72	75%
Δ (Miner)	0.42	20%
Young modulus	210e9	0%
C_D	0.81	4%
C_M	2.13	1%
Soil stiffness	5.956e10	0%



Contribution to variance

Conclusions and recommendations

- Integration of full load calculations in probabilistic design method (FORM) is successful for fatigue limit state at mudline.
- The contribution of the Miner rule (Delta) and SN-curve (logC2) variables to the variance of the limit state function is largest.
- Calculated reliability index β = 6.35 shows there is room for design optimisation.
- Ultimate limit state and additional locations still need to be included.

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