Convergence of Extreme Loads for Offshore Wind Turbine Support Structures

NAWEA 2015 Presentation

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Motivation

- International Electrotechnical Commission (IEC) offshore design standards recommend the average of the maximums of 6 one hour simulations for the 50-year extreme event load cases (DLC 6.X)
- Research has shown that this amount of simulation time may not enough for convergence for fixed-bottom support structures, but little research has been done concerning convergence of extreme loads for floating platforms
- This presentation will discuss the convergence of extreme loads for a fixed bottom monopile support structure as well as two floating platforms.

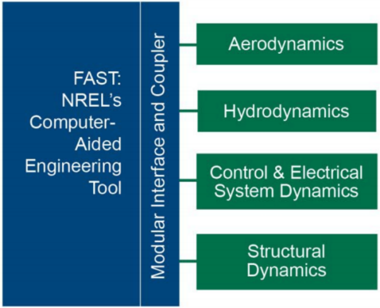
Research Questions

How does the convergence of extreme loads of different support structures differ?

Can we create an analytical method of predicting how many simulations any given combination of support structure and set of input conditions requires for convergence?

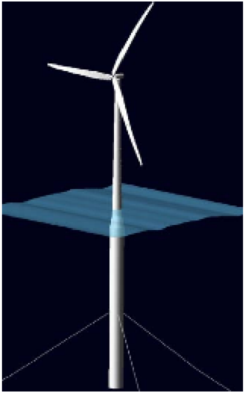
Simulation Tools

- To run the simulations, we use FAST; NREL's computer-aided wind turbine design tool
- FAST version 8 is used, which can implement 2nd order waves
- TurbSim is used to create the turbulent wind fields

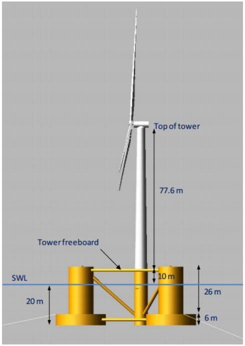


Support Structures

OC3 Monopile



OC3 Hywind Spar Buoy

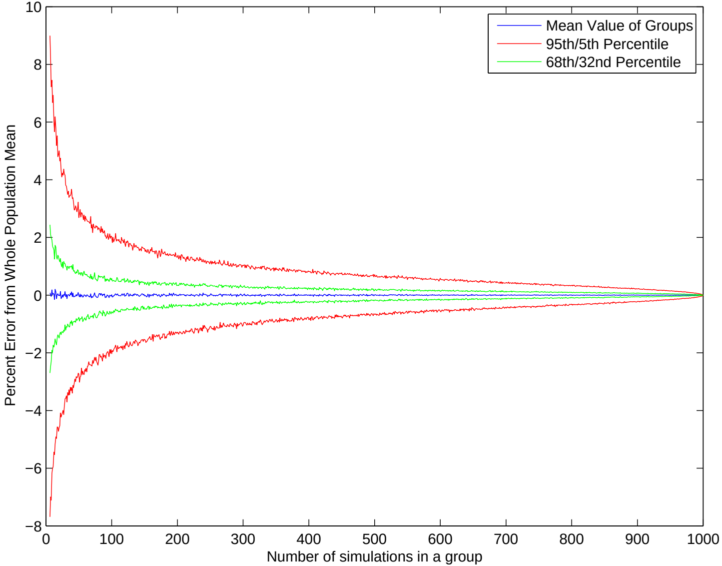


OC4 DeepCWind Semi-submersible

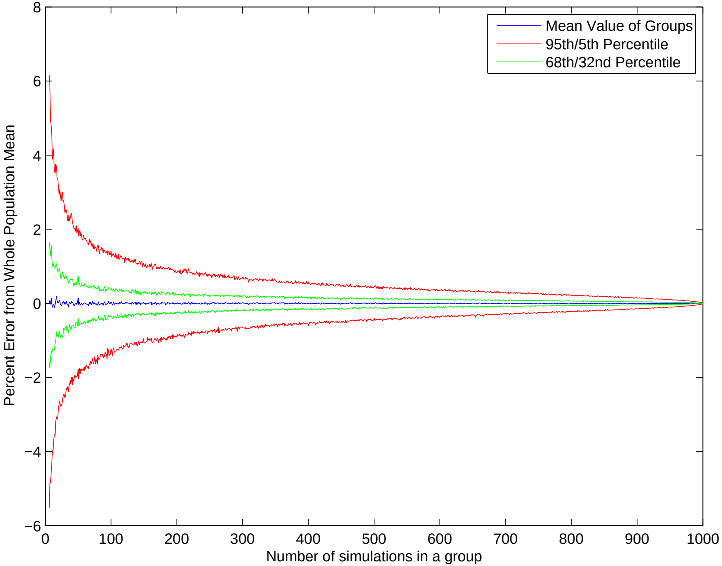
Simulation Overview

- Floating simulations used 35 m/s wind speeds, significant wave heights of 15 m, and a wave peak spectral period of 14 s, while monopile simulations used 54 m/s wind and 10 m significant wave heights.
- Each support structure was simulated for 1000 one-hour simulations for each of the following conditions: wind and second order waves, wind and first order waves, no wind with second order waves, no wind with first order waves, and wind but no waves.
- For brevity, we will show results from only the wind and second order waves simulations and the wind and first order waves simulations.
- The results use the resultant tower bending moment, calculated using a root sum square value of the fore-aft and side-side bending moments.

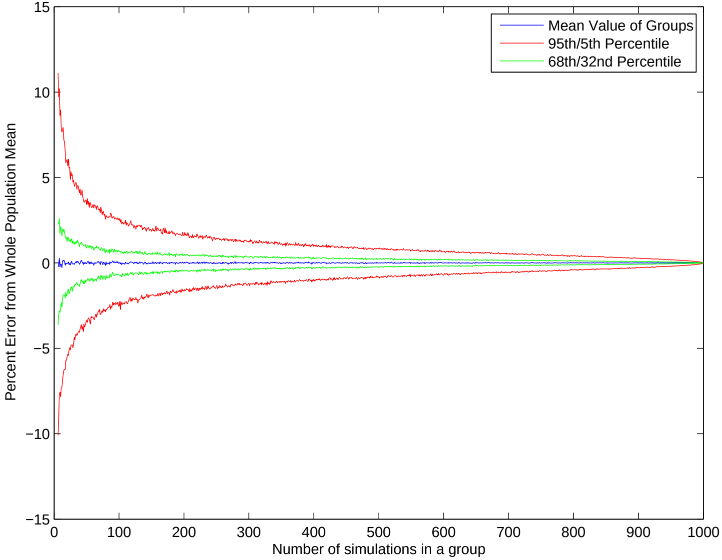
Extreme Load Convergence for Semi-Submersible



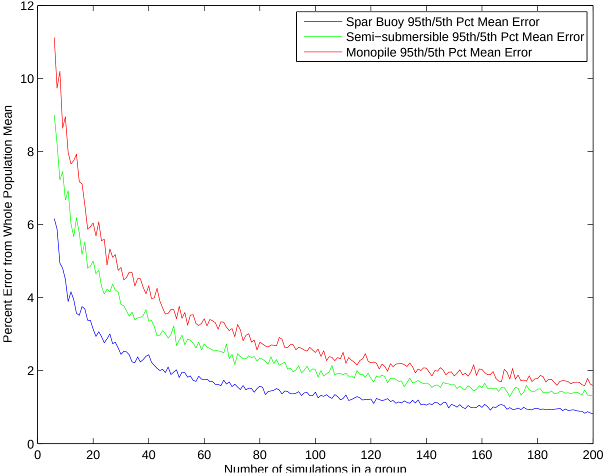
Extreme Load Convergence for Spar Buoy



Extreme Load Convergence for Monopile

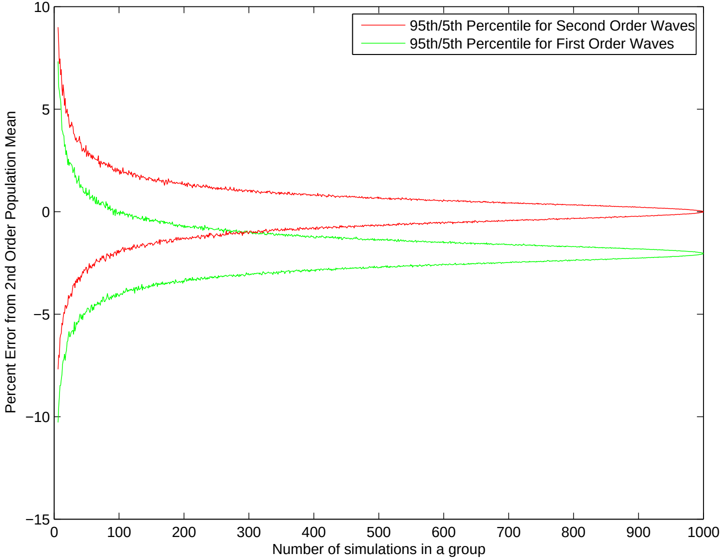


Support Structure Comparison

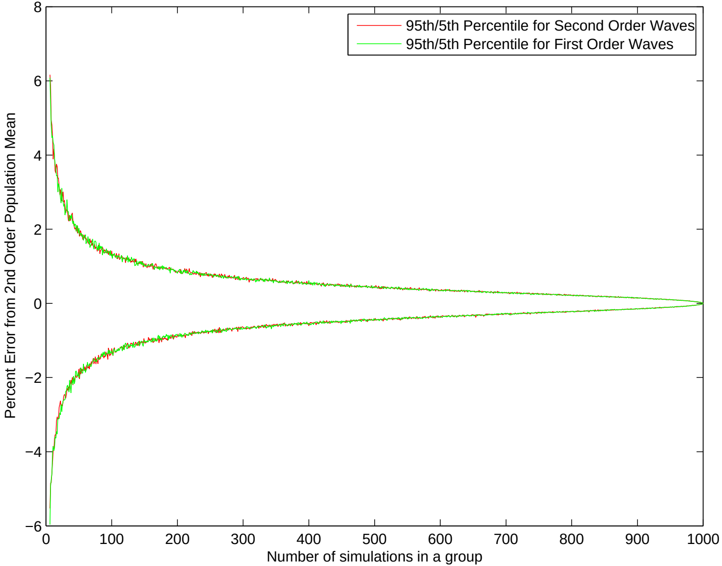


Note that the mean maximum value for each support structure is different; $1.67x10^5 kNm$ for the monopile, $1.78x10^5 kNm$ for the semi-submersible, and $2.79x10^5 kNm$ for the spar buoy.

Second Order Waves- Semi-submersible



Second Order Waves- Spar Buoy



Probabilistic Problem Formulation

Consider a stochastic process (e.g. tower base bending moment)

$$X(t)$$

and a time interval [0, tf) during which the process is observed. The maximum value of the process:

$$X_{max,t_f} = \max(X(t) : t \in [0, t_f))$$

is a random variable that depends on the properties of X(t) and tf and has distribution and second moment properties:

$$F_{x_{max},t_f}(x),\ \mu_{x_{max},t_f},\ \sigma_{x_{max},t_f}$$

If n observations $x(t)$ of $X(t)$ in $[0, t_f)$ are available and have maxima:

$$x_{max,t_f}$$

one can employ the estimator:

$$\bar{X}_{max,t_f} = \frac{1}{n}\sum_{i=1}^{n} x_{max,t_f,i}$$

Probabilistic Problem Formulation, Continued

The estimator is itself a random variable with distribution and properties:

$$F_{\bar{x}_{max},t_f}(x),\ \mu_{\bar{x}_{max},t_f},\ \sigma_{\bar{x}_{max},t_f}$$

Assuming independence of the observations, the estimator:

$$\bar{X}_{max,t_f}$$

is unbiased with

$$\sigma^2_{\bar{x}_{max},t_f} = \frac{\sigma^2_{x_{max},t_f}}{n} \qquad \mathrm{COV}_{\bar{x}_{max},t_f} = \frac{\sigma_{x_{max},t_f}}{\mu_{x_{max},t_f}\sqrt{n}}$$

implying a $1/n$ convergence rate for the variance

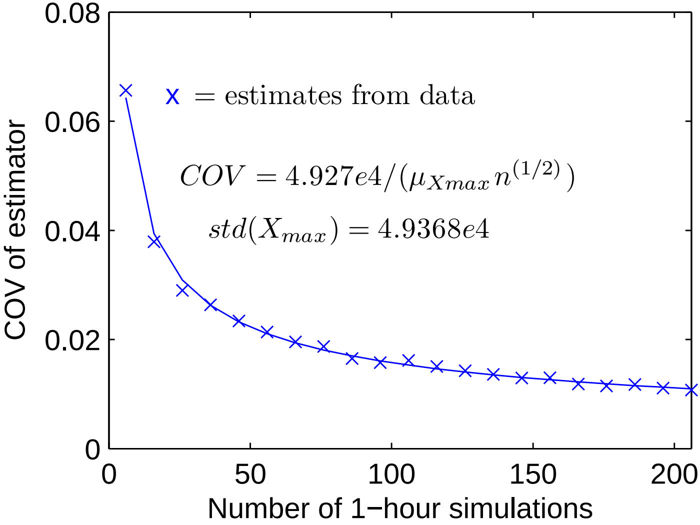
Conclusion: One needs only accurately estimate:

$$\sigma^2_{x_{max},t_f}$$

to understand the convergence of:

$$\bar{X}_{max,t_f}$$

Probabilistic Model Validation for the Monopile



Summary

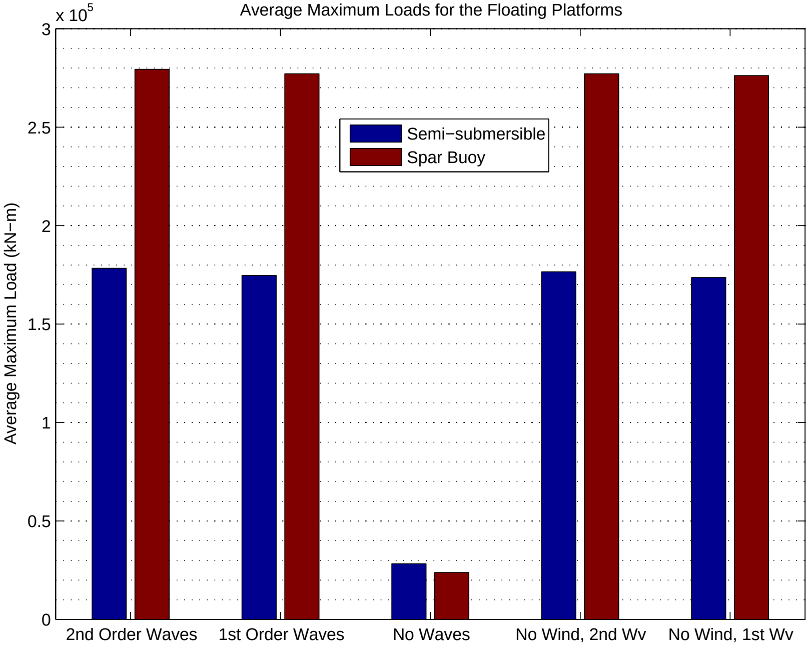
- Current IEC guidelines for 50 year extreme condition cases require too few simulations for proper convergence of extreme loads

- The convergence of extremes under these conditions is highly dependent on support platform

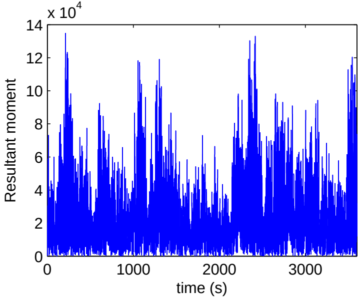
- Second-order waves were important for semi-submersible extremes, but not for the spar buoy

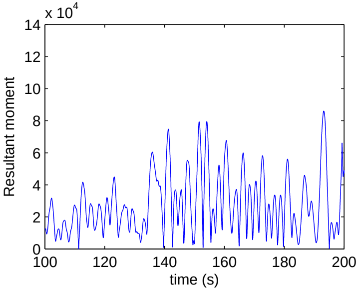
- Using probabilistic methods, the convergence of the variance of extreme loads can be defined

Thanks and any questions?


Average Maximum Loads for the Floating Platforms
x 10^5
3
2.5
2
1.5
1
0.5
0
Average Maximum Load (kN−m)
Semi−submersible
Spar Buoy
2nd Order Waves
1st Order Waves
No Waves
No Wind, 2nd Wv
No Wind, 1st Wv

Probabilistic Model Validation- Sample Characteristics

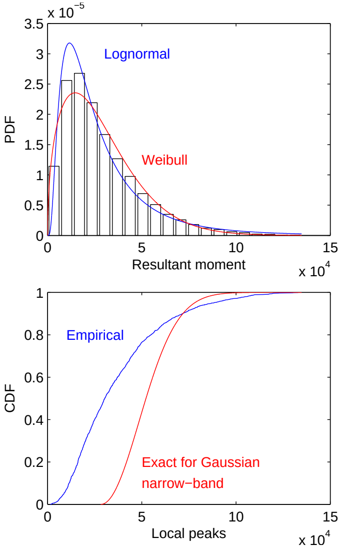




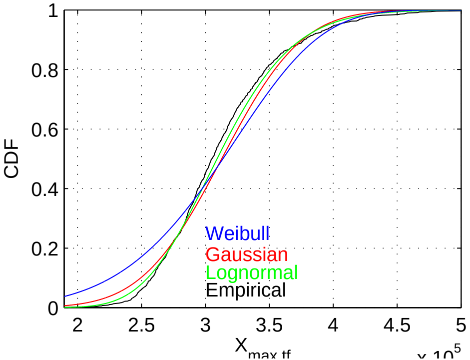
- Non-Gaussian
- $X(t) > 0$
- Multiple frequencies present
  - First natural freq.
  - Wave freq.

Probabilistic Model Validation- Distribution Characteristics of X(t)

- Marginal
  - Non-Gaussian
  - Weibull and Lognormal poor fits
  - Weibull potentially better at upper tail
- Local peaks
  - Non-Gaussian
  - Non-narrow band



Probabilistic Model Validation- Extreme Value Characteristics of X(t)



- Extreme values $X_{max,tf}$
  - Non-Gaussian
  - No good overall fits
  - Weibull best at upper tail