Parameter Estimation of a Breaking Wave Slamming Load Model using Monte Carlo Simulation

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Introduction

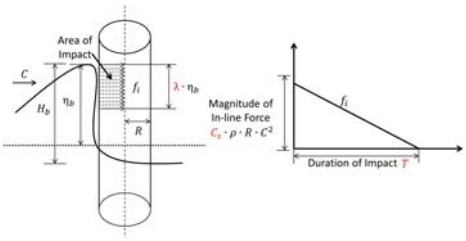


Fig 1. Breaking wave induced slamming load

- Offshore wind turbines (OWTs) are installed in intermediate and shallow water with occurrence of breaking waves.
- OWTs subjected to the breaking wave, especially plunging breakers, are excited by an impulsive impact force referred to as the slamming load influencing the design loads significantly.
- Engineering model of the slamming load with significant parameter variabilities [1, 2]:

$$F(t) = \lambda \cdot \eta_b \cdot C_s \cdot \rho \cdot R \cdot C^2 \cdot (1 - \frac{t}{T})$$

- Objective: Estimate the governing parameters: Slamming Coefficient C_s, Curling Factor λ and Impact Duration T by a combination of large-scale experimental data and numerical simulations performed with the Monte Carlo method.
- Methodology : Estimate the parameters from 5000 random MC combinations of the three parameters by comparing simulated response in HAWC2 against the measured response from a large-scale experiment.
- Monte Carlo Simulations: 5000 simulations with an independent, uniform distributed input parameters of C_s $(0.5\pi - 2.5\pi)$, λ $(0.3 - 0.5)$ and T $(0.02 - 0.26)$.

Large-Scale Experiment

- Experiment setting: regular wave (H 1.3m, T 4s, D 1.5m), sloped wave tank.

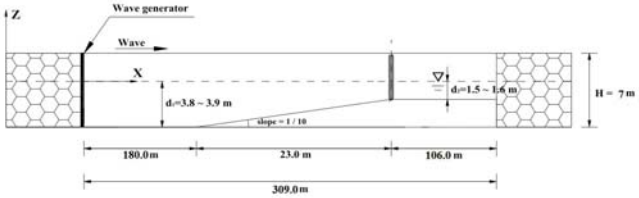


Fig 2. Experimental set up in GWK [3]

- Experiment data: wave elevation at pile, measured force at pile top and bottom. Repeated wave packets include nonbreaking wave and breaking wave.

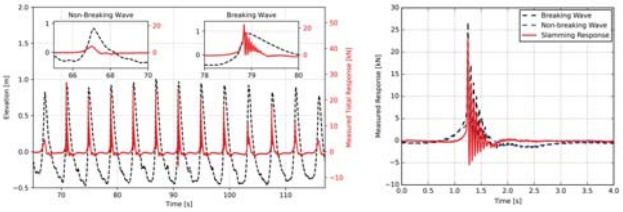


Fig 4. Measured wave elevation and total response force (left). Decomposition of slamming load response from total force measurement for a breaking wave (right)

Numerical Simulation

- OceanWave3D: fully nonlinear potential flow solver at DTU Mechanical. The wave surface elevation and wave particle kinematics are obtained.

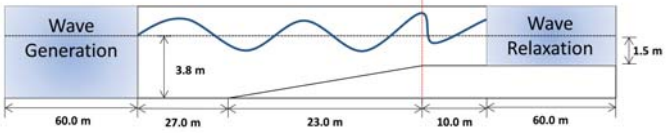
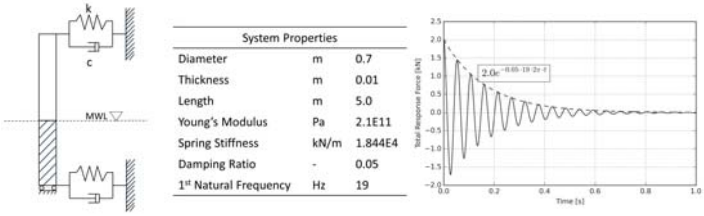


Fig 3. Numerical set up in OceanWave3D

- HAWC2: Aero-Elastic-Hydro Code at DTU Wind Energy. The quasi-static force is calculated using Morison equation associated with wave kinematics from OceanWave3D. The responses simulated from 5000 Monte Carlo simulations are quantified against experimental responses using RMSE.



System Properties		
Diameter	m	0.7
Thickness	m	0.01
Length	m	5.0
Young's Modulus	Pa	2.1E11
Spring Stiffness	kN/m	1.844E4
Damping Ratio	-	0.05
1st Natural Frequency	Hz	19

Fig 5. Verified pile model set up in HAWC2 with first NF around 19Hz

Results

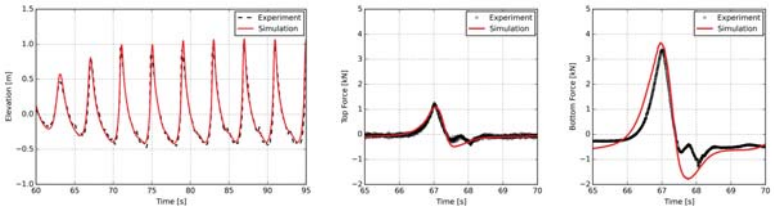


Fig 6. Wave surface elevations simulated in OceanWave3D agree well with experimental data. Response force for a non-breaking wave are simulated in HAWC2 with the wave kinematics from OceanWave3D showing good agreement with measurements

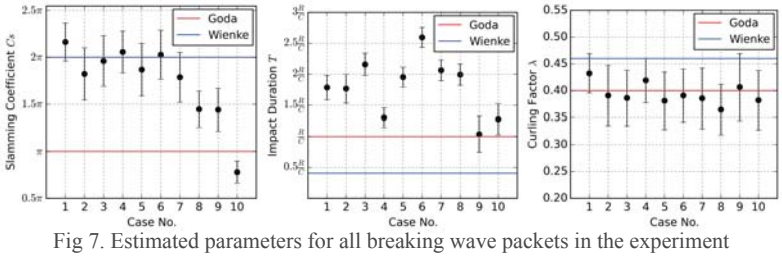


Fig 7. Estimated parameters for all breaking wave packets in the experiment

Parameter	Slamming Coefficient C_s	Impact Duration T	Curling Factor λ
Mean	1.89π	$1.95\,R/C$	0.39
Standard deviation	0.21π	$0.35\,R/C$	0.02
Goda	π	R/C	0.40
Wienke-Oumeraci	2π	$13\,R/32C$	0.46

Table 1. Statistics of the estimated parameters (case 1-8)

Conclusions

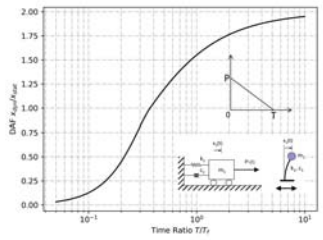


Fig 8. DAF is dependent on time ratio

- OceanWave3D reproduces highly nonlinear wave elevation with good agreement.
- The Morison's equation is able to calculate steep non-breaking wave force with wave kinematics from OceanWave3D.
- The slamming coefficient C_s and curling factor λ are close to values in Winek-Oumeraci model.
- Slamming load impact duration T is significantly larger than the values found by the Goda and Wienke-Oumeraci model, which decides the dynamic amplification for OWTs.
- For OWTs located in areas where breaking waves are present, a flexible structure is recommended to eliminate its dynamic amplifications.

References

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Acknowledgement

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