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A Novel Machine Learning Model to Fast Predict Nonlinear Wave Forces on Monopile-Type Offshore Wind Turbine Foundations

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ABSTRACT: Offshore wind turbines encounter harsh environmental loads that critically influence their design, including complex wave-structure interactions with strongly nonlinear wave forces under storm conditions. To address this challenge, we present a novel, fast and accurate model for predicting nonlinear wave forces on offshore wind turbine foundations. Our approach uses a "Stokes-type" force formulation (Chen et al., 2018) that approximates the higher force harmonics ($2^{nd} – 5^{th}$) by correlating them to the linear force time series raised to an appropriate power, modified by amplitude and phase coefficients. A machine learning model, specifically the Gaussian Process (GP) model, expands the database of these coefficients established through our experimental tests to allow prediction across a wider range of wave regimes (Tang et al., 2024). Thus, we have developed a novel predictive framework, the Stokes-Gaussian Process (Stokes-GP) model. Figure 1(a) illustrates the flowchart of the Stokes-GP model, and Figure 1(b) demonstrates its precision in predicting experimental results. Notably, the linear force consistently underestimates both the peak force value and the higher frequency forcing components in severe wave conditions, highlighting the critical importance of accounting for nonlinearity. This comparison demonstrates the model's effectiveness in accurately forecasting the full force time-history.

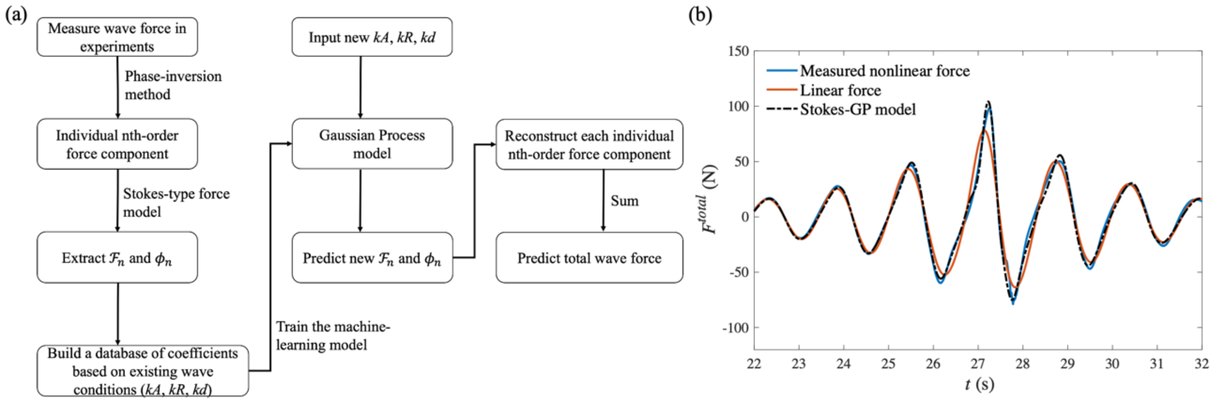

Figure 1: (a) Flowchart of the Stokes-GP model and (b) Predicted nonlinear force from the Stokes-GP model compared to the nonlinear force measured in experimental tests and its linear force with peak wave period (T_P = 1.64 s), peak wave amplitude (A = 0.11 m, is half the sum of the crest-focused wave crest and the trough-focused wave trough magnitude), water depth (d = 0.5 m) and cylinder radius (R = 0.125 m).

This model will be released as open access engineering tool. Predictions for a wave regime are completed within a few seconds, enabling comprehensive design evaluations during the planning phase, and supporting real-time monitoring. Comparative analyses with experimental data confirm the model's high fidelity in reproducing complex wave forces. Ultimately, the Stokes-GP model represents a transformative tool for optimising the design, safety, and sustainability of fixed offshore wind turbine foundations, directly contributing to the broader objectives of enhancing renewable energy infrastructure and supporting net-zero transition initiatives.

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REFERENCES:

Chen, L. F. et al. (2018). An experimental decomposition of nonlinear forces on a surface-piercing column: Stokes-type expansions of the force harmonics. Journal of Fluid Mechanics, 848, 42–77.

Tang, T. et al. (2024). A new Gaussian Process based model for non-linear wave loading on vertical cylinders. Coastal Engineering, 188(July 2023), 104427.