Nonlinear Wave Loads on a Vertical Cylinder

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Motivation

The wind industry is nowadays experiencing a technology transfer from onshore to offshore, making the offshore wind industry one of the fastest growing maritime sectors. Statistics presented by GWEC 2017 stats that the cumulative installed capacity in 2018 was of almost 19 GW, with a historical record of 4334 MW of new offshore wind power installed the past year.

Background

Experiments have shown that large diameter monopile support structures for offshore wind turbines are susceptible to transient structural deflections at frequencies substantially higher than the incident wave frequencies in severe seas. This phenomenon is often referred to as ringing and is characterized as a transient response vibration following a high, steep wave. Traditional wave load theories cannot explain this behavior. Great effort has thus been paid to explain the rationale behind since the phenomena were first observed in the late 1980s and early 1990s.

Analytically studies on ringing loads on a fixed, non-moving vertical, surface piercing cylinder, standing on the seafloor was reported by Faltinsen, Newmann and Vinje ([1]). They considered regular incident waves characterized by an amplitude ζ of the same order of magnitude as the diameter of the monopile, neglecting viscous effects such as flow separation. Kristiansen and Faltinsen ([2]) showed that the predicted forces and moments from the FNV model were in good agreement with experiments for small to medium steep waves, while markedly discrepancies were observed as the wave steepness excited a distinct limit. The local KC number along the cylinder axis indicated that flow separation occurred at the wave conditions where discrepancies were observed.

Method

The generalized FNV theory is modified to account for viscous effects. The linear forcing term is replaced with a viscous force term computed using a simplified numerical model assuming the cross-flow principle to be valid.

References

[1] O. Faltinsen, J. Newman and T. Vinje. Nonlinear wave loads on a slender vertical cylinder.

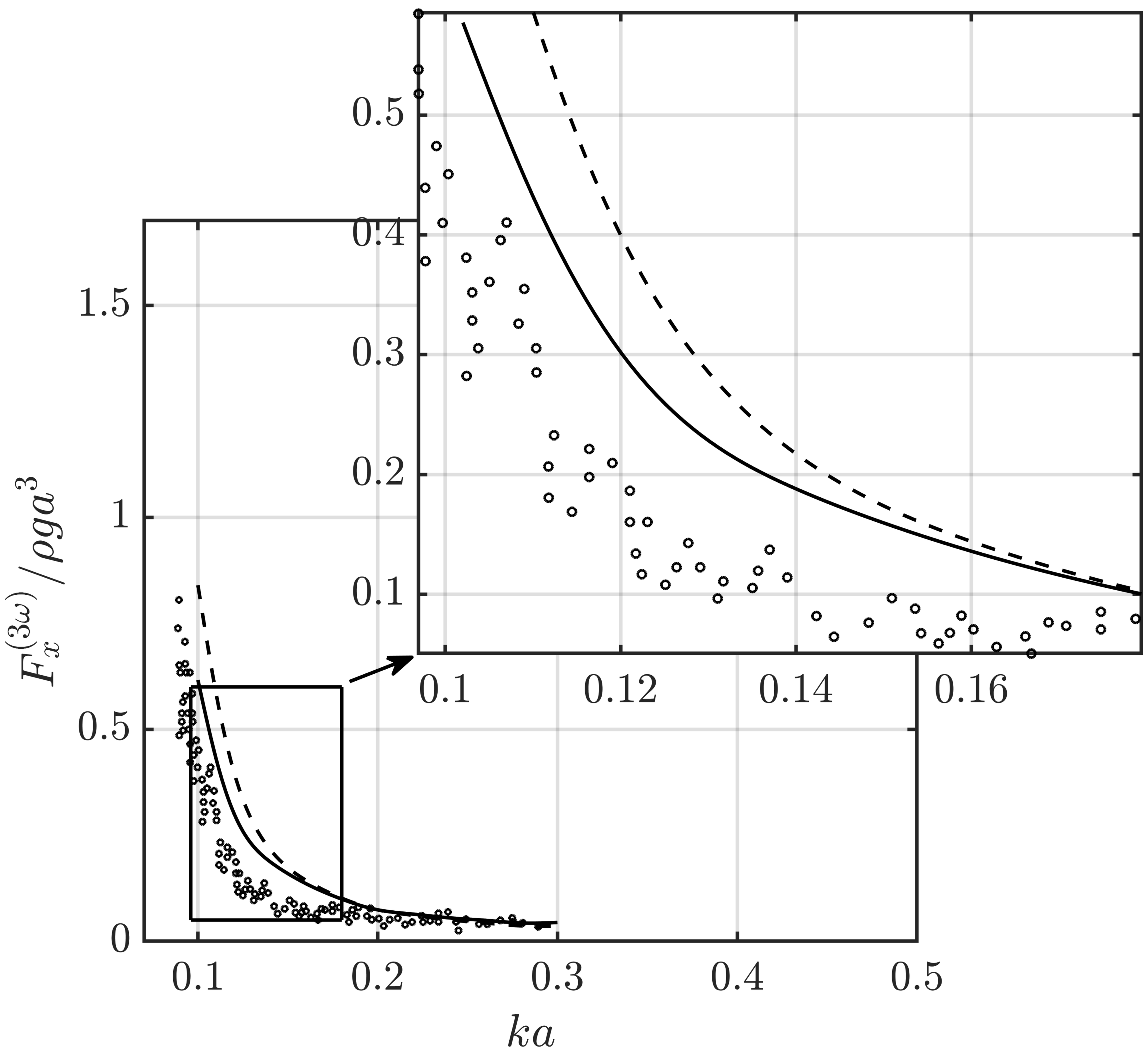
[2] T. Kristiansen and O. Faltinsen. Higher harmonic wave loads on a vertical cylinder in finite water depth.

Viscous model

At present, the most widely used CFD models are generally based on a direct resolution of the Navier-Stokes equations. The usual numerical scheme being the finite volume method. Although reliable, the Eulerian methods are computationally demanding. Other strategies were therefore developed in the early days of CFD. Among these is the mixed Eulerian-Lagrangian Vortex-In-Cell method. The main principle behind this method is to replace the continues vorticity field by a finite set of point vortices interacting through a stream function which satisfies the Poisson equation. The advantage of the Vortex-In-Cell methods is first of all the relatively low operational count. Moreover, the dynamics are computed on the Lagrangian particles, removing the Courant criterion traditionally limiting the time step in Eulerian methods. Thus the hybrid methods can tackle much greater time steps.

Results

The first three load harmonics obtained by the combined VIC-FNV method were indistinguishable from those obtained by the FNV method for short waves, independent of wave steepness. For lower values of ka, the combined VIC-FNV method gave, in general, lower estimates of all load harmonics. However, the modified FNV theory significantly overpredicted the third harmonic for the steepest waves.



Close-up view of the amplitude of the 3^{th} harmonic versus ka for wave steepness 1/25 and water depth h/a = 7.83. Solid curve, FNV theory; dashed curve, combined VIC-FNV method; Circles, experimental measurements ([2]).

Conclusion

The results indicate that viscous effects are important when evaluating higher order wave loads on circular cylinders. However, local flow separation along the cylinder axis do not entirely explain the discrepancies in the FNV model. The current model neglects three-dimensional flow effects. It is therefore believed that the discrepancies observed in the partly numerical model originate from such flow features.