The structure of the Sea Swallows modelling

Beyond Morison loading - Stokes expansions, symmetry and wave groups

Paul H. Taylor

School of Earth and Oceans

THE UNIVERSITY OF WESTERN AUSTRALIA

Sea-Swallows

https://www.rspb.org.uk/birds-and-wildlife/arctic-tern

Contents

What do we ***know***?	Morison, Stokes expansions
What can we ***infer***?	Full harmonic structure, amplitude and phase coeffs.
What can we ***check***?	Reconstructed forces, components scaling as Stokes terms
What do we ***get***?	A simple model for exciting force or moment on a monopile defined for wave groups, - should work for regular waves, in random waves

For the wave load on a Fixed Offshore Wind monopile,

*why not simply use the well-known **Morison Equation** (1950) ?*

https://commons.wikimedia.org/wiki/File:Alpha_Ventus_Windmills.JPG

Force on a cylinder in an oscillatory flow

Inertia   Drag

$$F(t) = C_m \, \rho \, \frac{\pi}{4} D^2 \, \dot{u} \; + \; C_d \, \frac{1}{2} \, \rho \, D \, u \, |u|$$

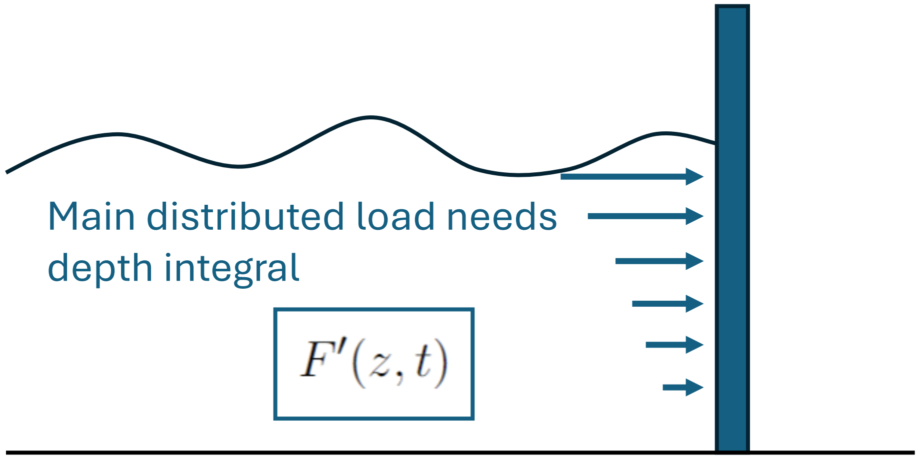
Answer: *because it doesn't accurately estimate the force*

particularly not the higher harmonics of force driving tower structural resonance, at least not without kinematics to at least 5th order / harmonic

Extended Morison Force model :
Faltinsen, Newman, Vinje JFM 1995
see also Rainey 1995, Kristiansen & Faltinsen 2017

$$F = \int_{-d}^{\eta(t)} \boxed{F'(z,t)\mathrm{d}z} + F^{\psi},$$

FNV point load



Morison inertia + convective deriv + ..

$$\underline{F'(z,t)} = \rho\pi R^2 \left(2\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + 2w\frac{\partial u}{\partial z}\right),$$

Valid for a **sufficiently compact body**
- in fully nonlinear potential flow

Dominant contribution to the potential flow force is proportional to local fluid **acceleration**

BUT **acceleration is nonlinear in wave amplitude**, so much of the nonlinear forcing arises here.

Note the necessity for **accurate high order/harmonics** in the wave field

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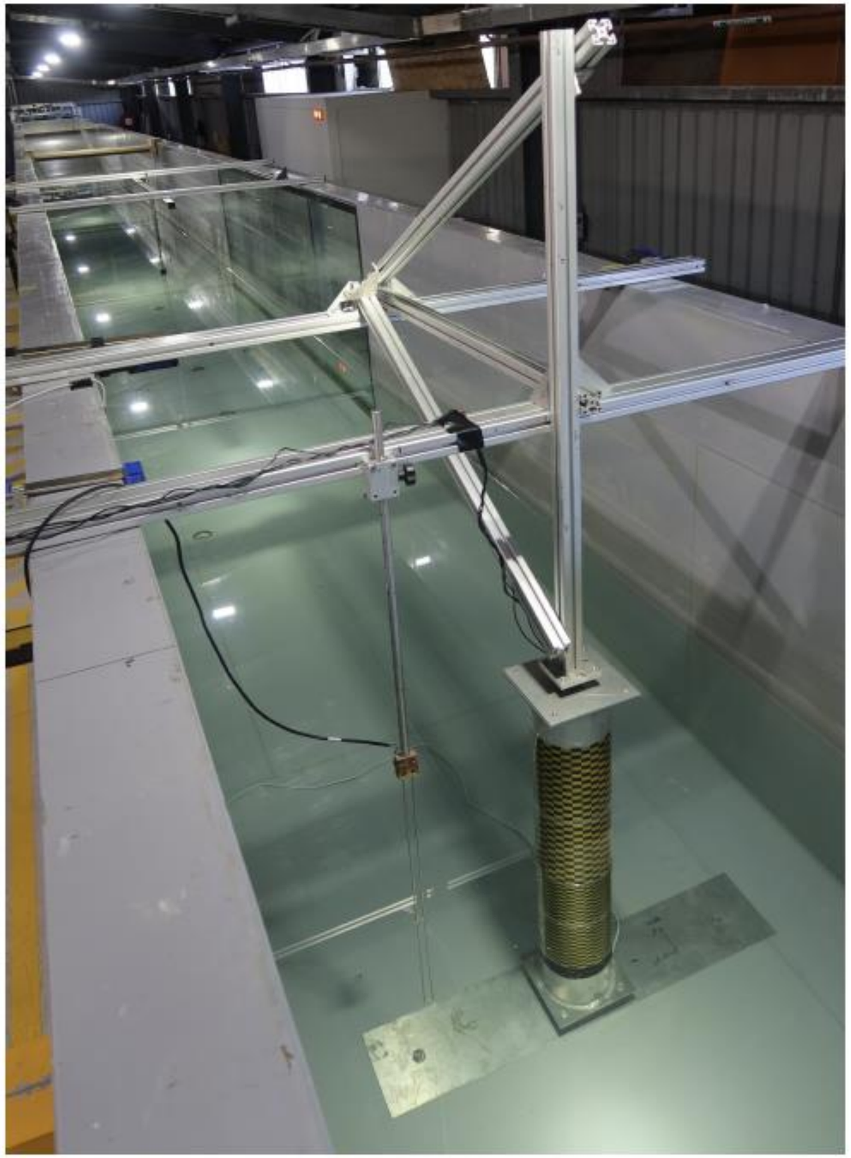


Tests performed by Jana Orszaghova at UWA entirely independently of Sea Swallows

Experimental set-up in the UWA flume, looking down the tank.

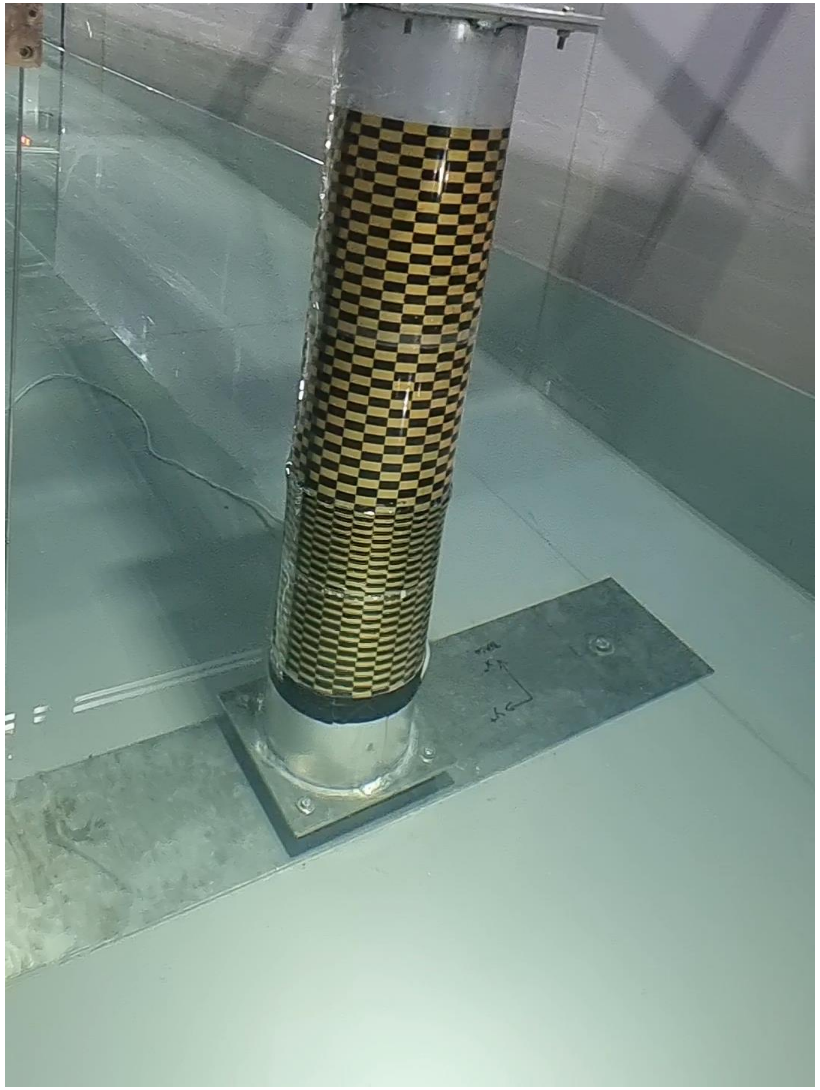
Bottom mounted surface piercing cylinder

Force transducers at top and bottom,
giving total horizontal load and moment

Why test with localized (compact) wave groups
and NOT with regular waves or long random runs?

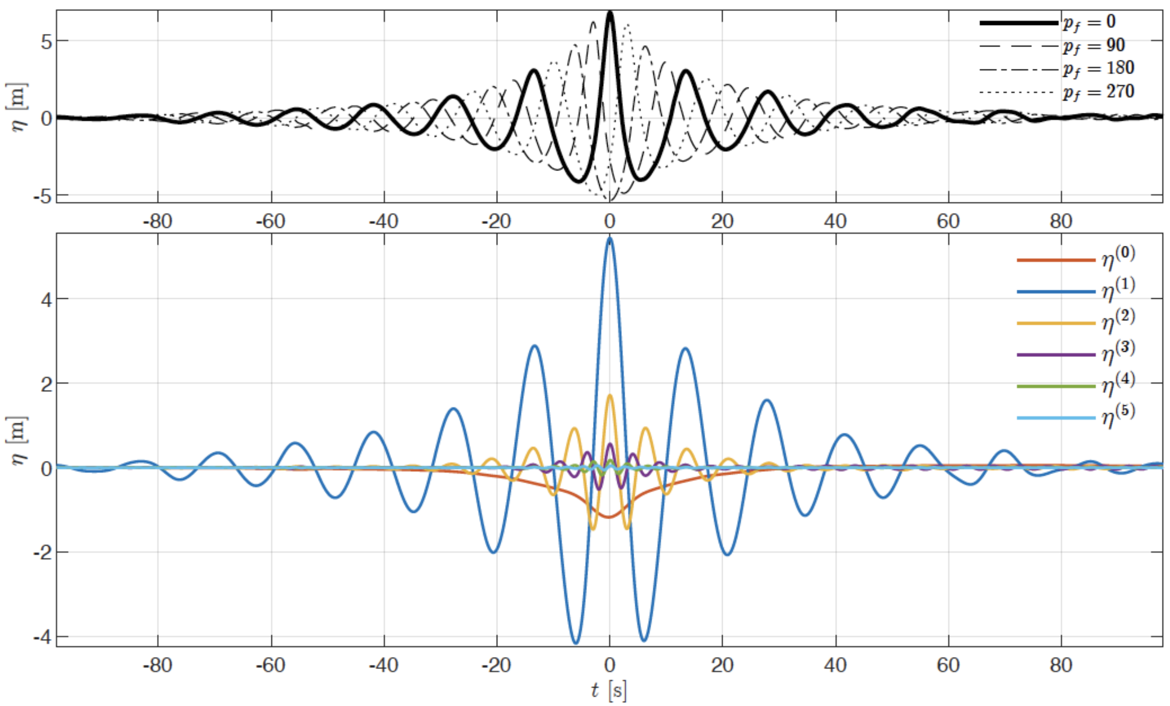
- wall reflections provide severe contamination
  BUT compact wave groups behave as in infinite ocean - the results are clean

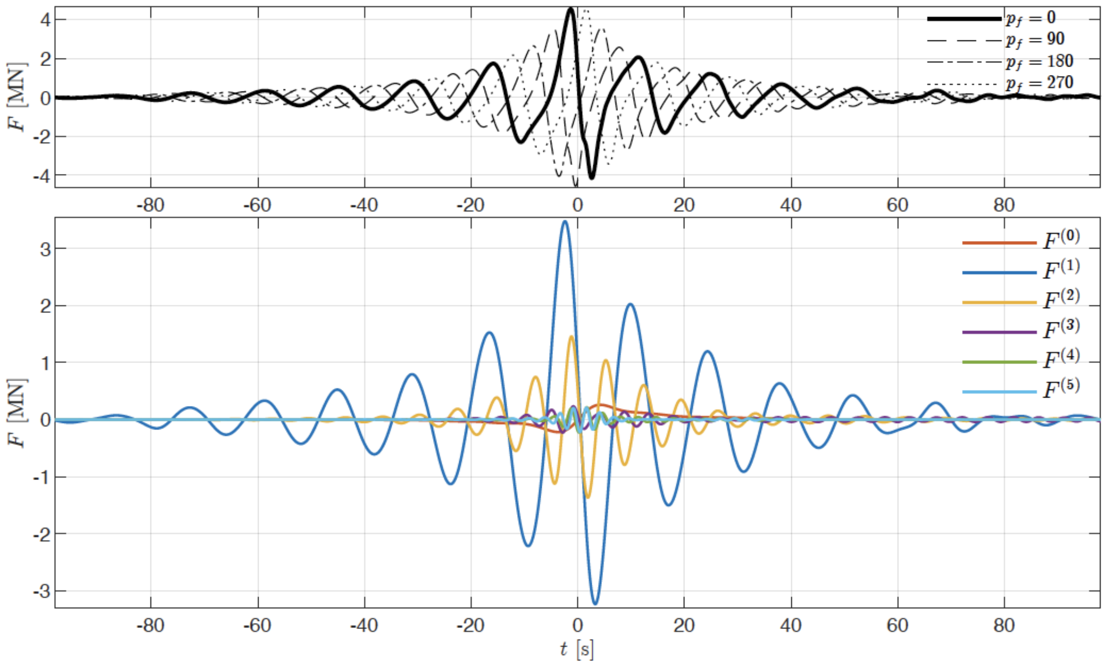
  Much of the historical available data is hard to interpret



Scattering and run-up around a monopile

- our aim is to separate what matters from what doesn't (even if it looks as though it might)





4-phase decomposition of wave group **surface elevation**

Using linear combinations of signals for 4 wave groups, this allows clean separation of the wave harmonics

- all the harmonics are ***symmetric*** in time

4-phase decomposition of **monopile horizontal load**

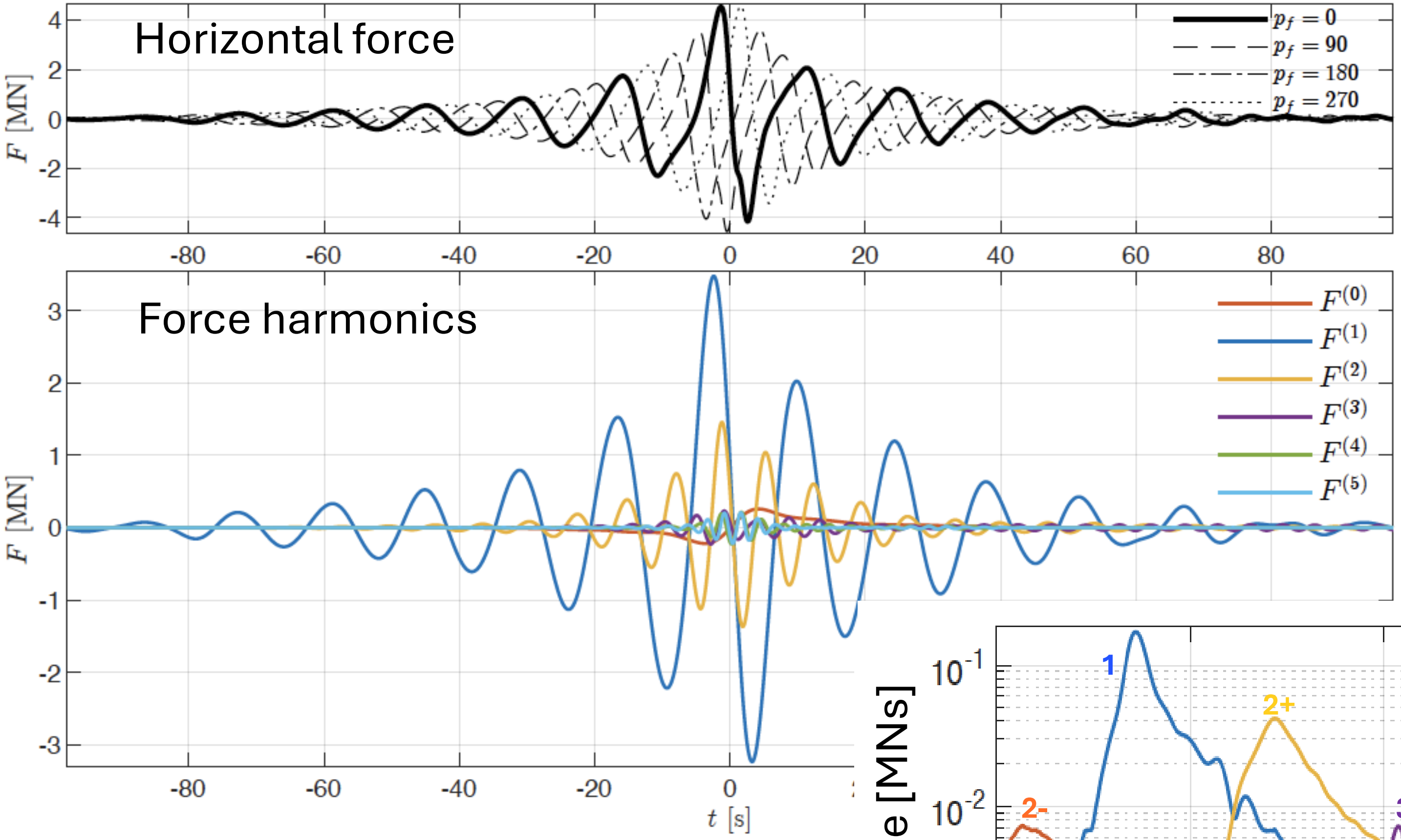
force harmonics are ***skew*** for focussed wave crest

Implies drag is negligible

- harmonics are increasingly localised – simple form ?

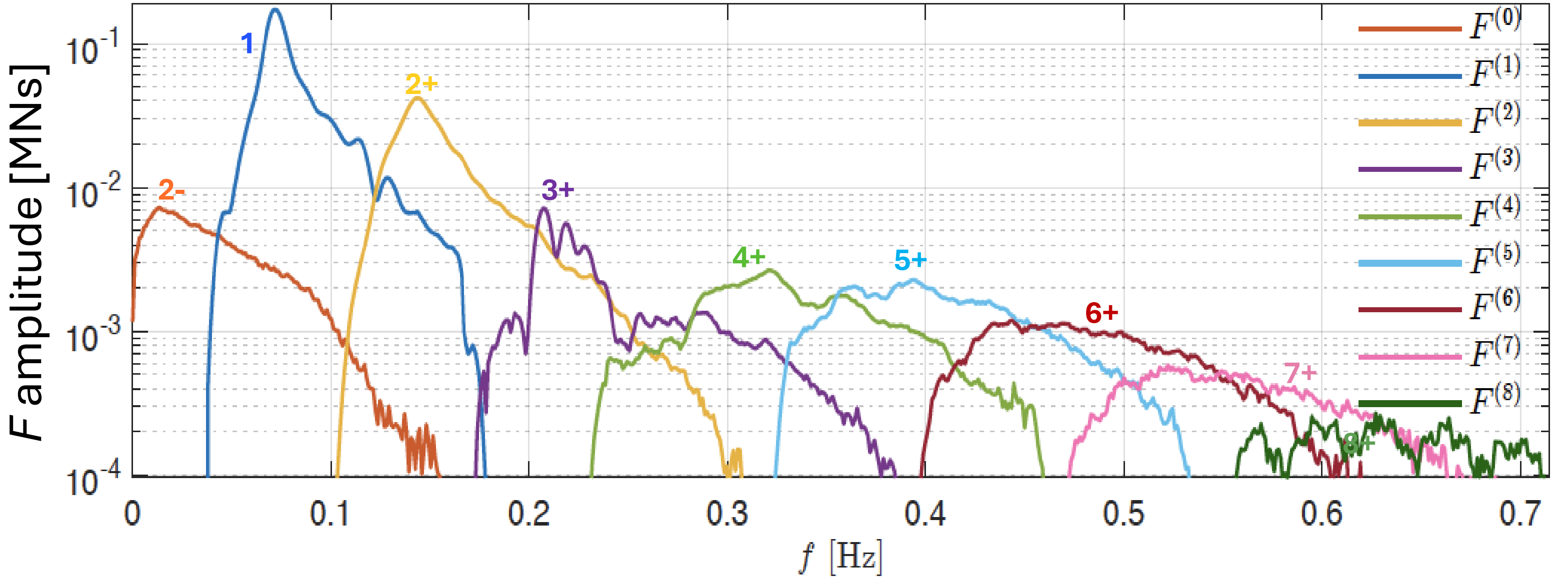
envelope of n-th harmonic ~ (envelope of linear)^n

phase of n-th harmonic ~ (n x phase of linear + shift)



Force spectrum flatter than surface elevation,
force ~ surface slope

Higher harmonics of force are more important than for elevation



Amplitude spectra of harmonics of horizontal force

1st harmonic (linear) diffraction - easy (McCamy Fuchs)
2nd harmonic possible (but slow for irregular waves)
3rd harmonic partially calculable, for a regular wave only
4th+ harmonics impossible

CFD works but much too slow as a design tool

But we need force & moment to ~ 5 f_p, so should include up to 5th order/harmonic

Aim to build a suitable approximation

- mathematical structure informed by form of Stokes waves
- calibrated by extensive lab testing & CFD + smart interpolation (assumes Froude scaling into the field)
- valid for wave groups, regular and irregular waves
- should be simple, so fast to compute

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Aim to build a suitable approximation

- mathematical structure informed by form of Stokes expansions for waves

Attempt a Stokes expansion FOR TOTAL FORCE in terms of

LINEAR COMPONENT OF FORCE (F_1) in time (and its Hilbert transform F_{1H})

$$\mathbf{F}_{\mathbf{TOTAL}} = F_1 + (..)(F_1^2 - F_{1H}^2) + (..)(2 F_1 F_{1H}) + (..) F_1 (F_1^2 - 3 F_{1H}^2) + (..) F_{1H} (3 F_1^2 - F_{1H}^2) + \ldots\ldots$$

cf. for wave A cos | A^2 cos 2 | A^2 sin 2 | A^3 cos 3 | A^3 sin 3

For each harmonic 2-5,

we build a similar approx., with amplitude and phase coefficient

4-phase analysis of expts & CFD provides form of each harmonic

Build a library of coefficients and use smart interpolation across ($k_p R$, $k_p d$)

How well does this approx. work?

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Philosophy and output

What do we know?	Morison, Stokes expansions for waves
What do we infer?	Full harmonic structure for force, smart library of phase and amplitude coeffs
What do we check?	Reconstructed forces, components scaling as Stokes terms
What do we get?	**A simple model** for exciting force or moment on a monopile - in wave groups, in regular waves, in random waves - simply starting with linear force in time **Very fast to compute, and very robust** **Captures what matters for extreme loading and fatigue**