

Breaking wave loads on FOWTs

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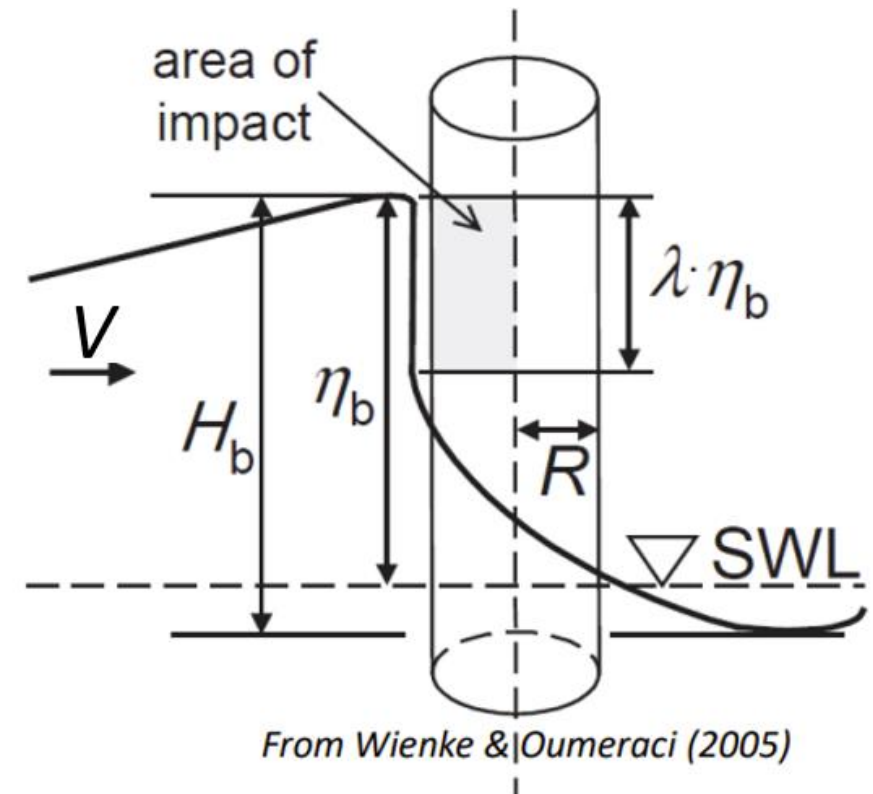


Summary

Objectives:

- Better characterize and estimate slamming loads acting on FOWTs
- Provide a methodology for incorporating breaking waves loads in coupled models

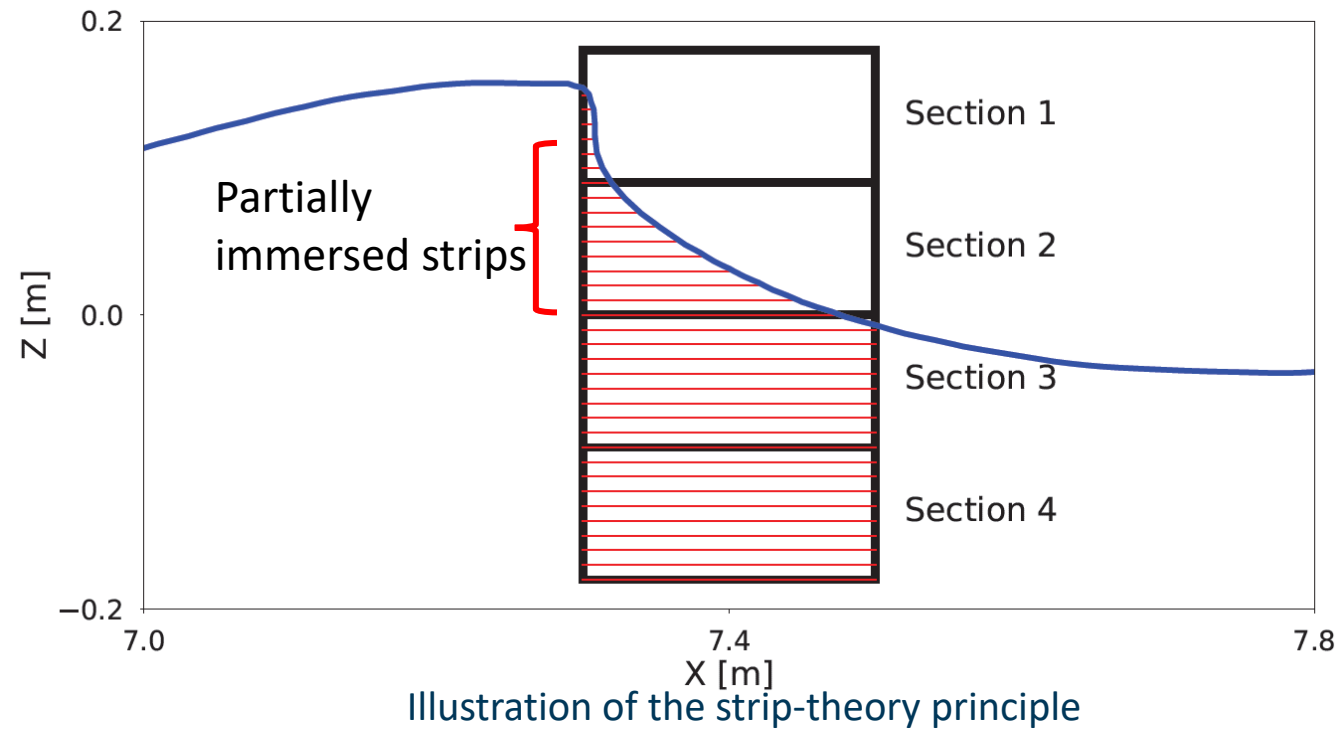
- 1) Strip-theory models **High Fidelity Level**
 - Fed with the kinematics and free surface shape of numerical breaking waves
 - Variable hydrodynamic coefficients
- 2) Simplified formulation **Medium Fidelity Level**
 - Accounting for floater dynamics
 - Slamming coefficient from Wagner theory
 - Nonlinear wave parameters derived from the wave database
- 3) Breaking wave loads from linear wave properties **Low Fidelity Level**
 - Nonbreaking wave load from an equivalent nonlinear regular wave
 - Slamming load from the simplified formulation



1) Strip-theory models

High fidelity level

- Objective: Model hydrodynamic forces based on the geometry and kinematics of a breaking wave
- Focused waves generated from CFD or FNPF solver
- Froude-Krylov hypothesis (= undisturbed wave)
- 2D load model



- FOWTs = Truncated cylinders
 - Contribution of the partially immersed strips can be significant
 - Dynamics of the floater

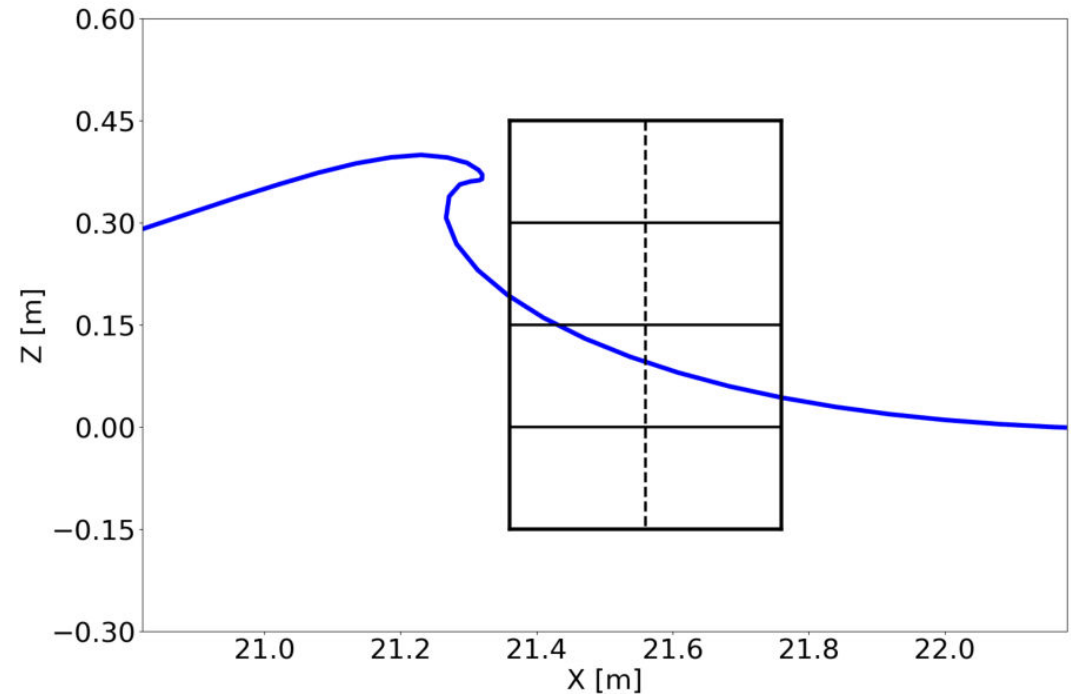
1) Strip-theory models

High fidelity level

$$dF_{tot}(h) = \left(\underbrace{\rho A(h) \frac{dU}{dt}}_{\text{Froude-Krylov term}} + \underbrace{F_a(h) \left(\frac{dU}{dt} - \frac{dU_b}{dt} \right)}_{\text{Added mass term}} + \underbrace{F_v(h)(U - U_b)^2}_{\text{Slamming term}} + \underbrace{F_a(h)(U - U_b) \frac{\partial W}{\partial z}}_{\text{Axial divergence term}} + \underbrace{\frac{1}{2} \rho C_D(h) D(U - U_b) |U - U_b|}_{\text{Drag load}} \right) dl$$

Main conclusions:

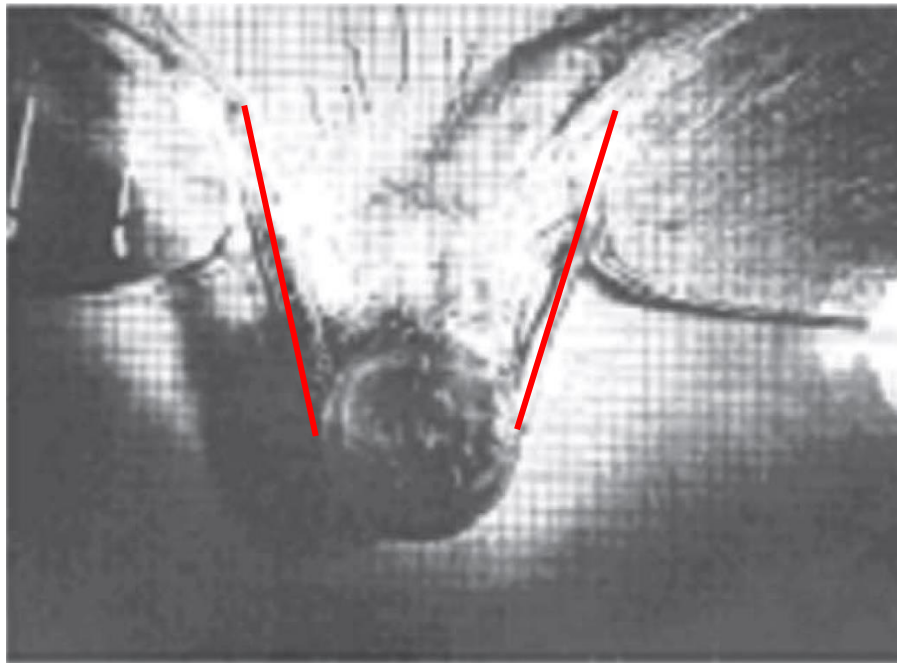
- Good overall agreement with the experimental data
- Load in the partially immersed strips well estimated
- Ability of the models to account for the horizontal motion and tilt of the structure
- Modelling flow separation gives a better estimate during load decay
- Slamming load well estimated by accounting for the vertical variation of the horizontal fluid velocity
- Effect of the cylinder on the flow



2) A new slamming load formula

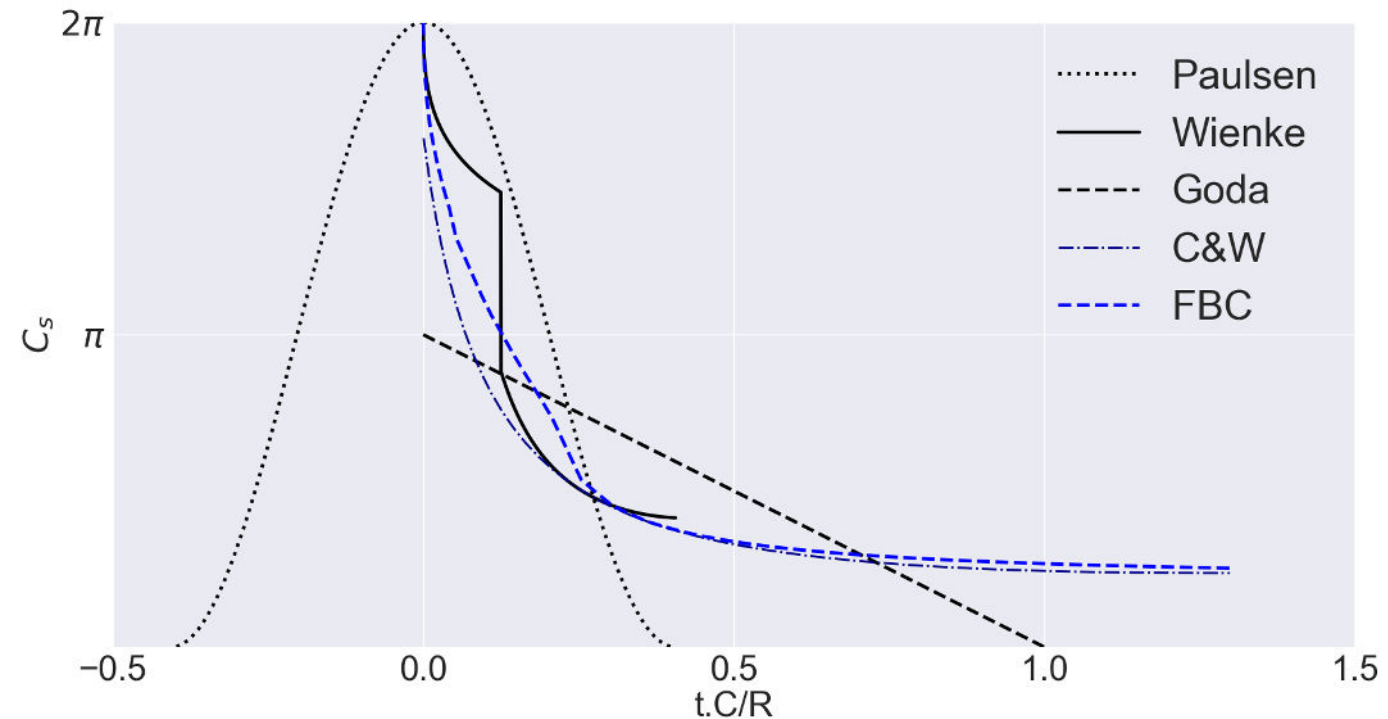
Medium fidelity level

- Engineering formula based on the vertical variation of the horizontal fluid velocity and accounts for flow separation (Fictitious Body Continuation (FBC) slamming coefficient, Tassin et al., 2014)



Greenhow & Lin, 1983 ; Zhu et al., 2005

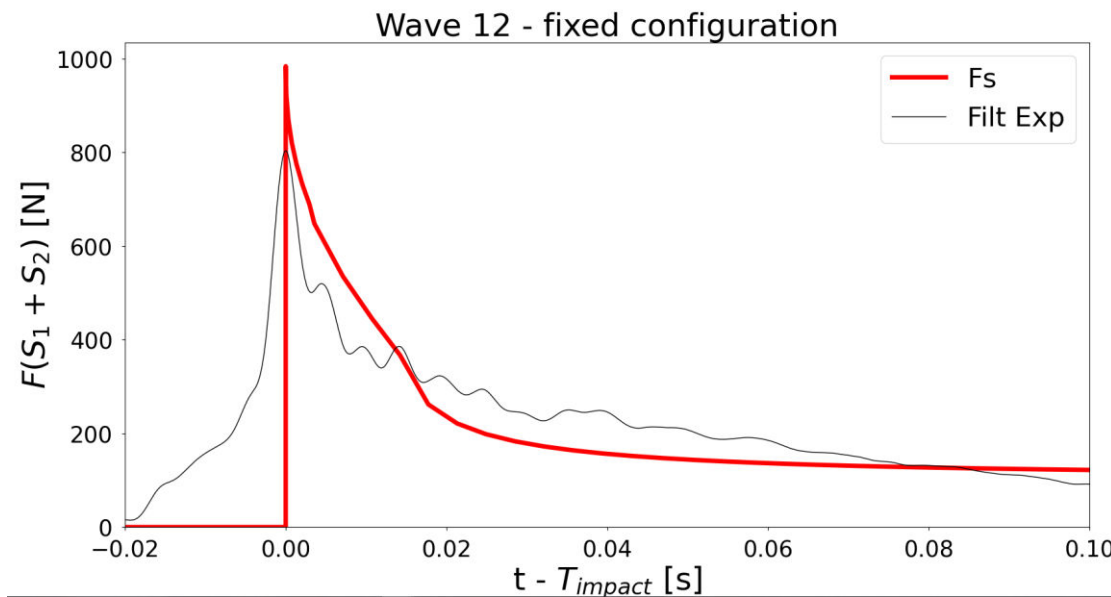
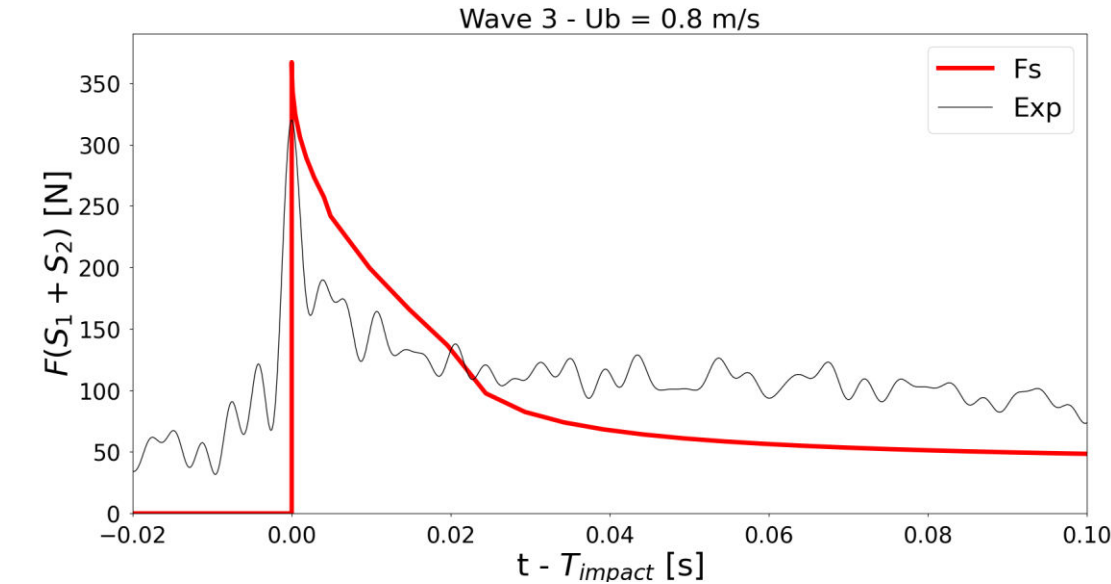
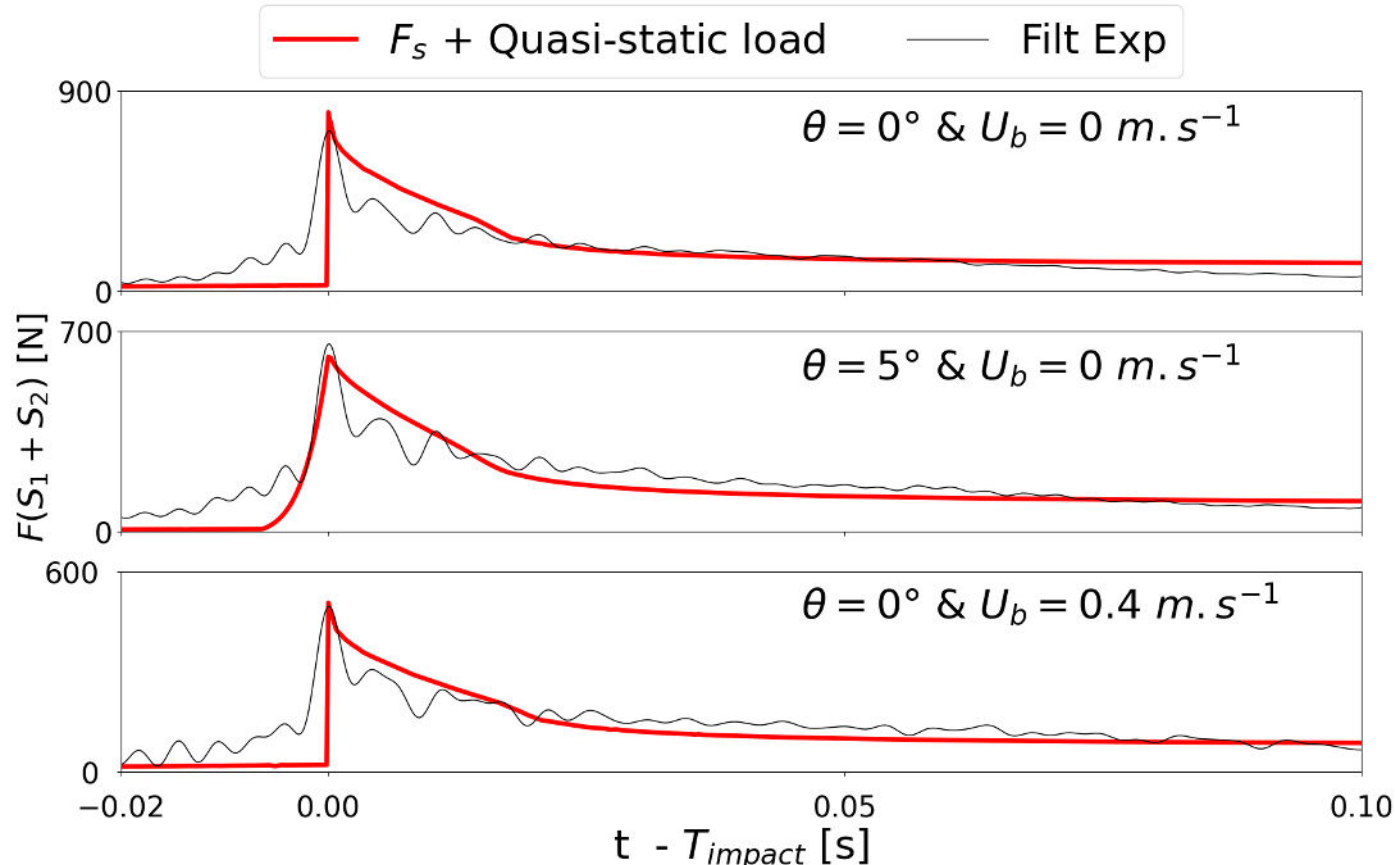
$$F_s(t) = \rho R \int_{(1-\lambda)\eta_v}^{\eta_e(t) \leq \eta_v} C_s(h(z,t)) (U(z) - U_b)^2 \cos^2 \theta dz$$



Comparison of slamming coefficients

2) A new slamming load formula

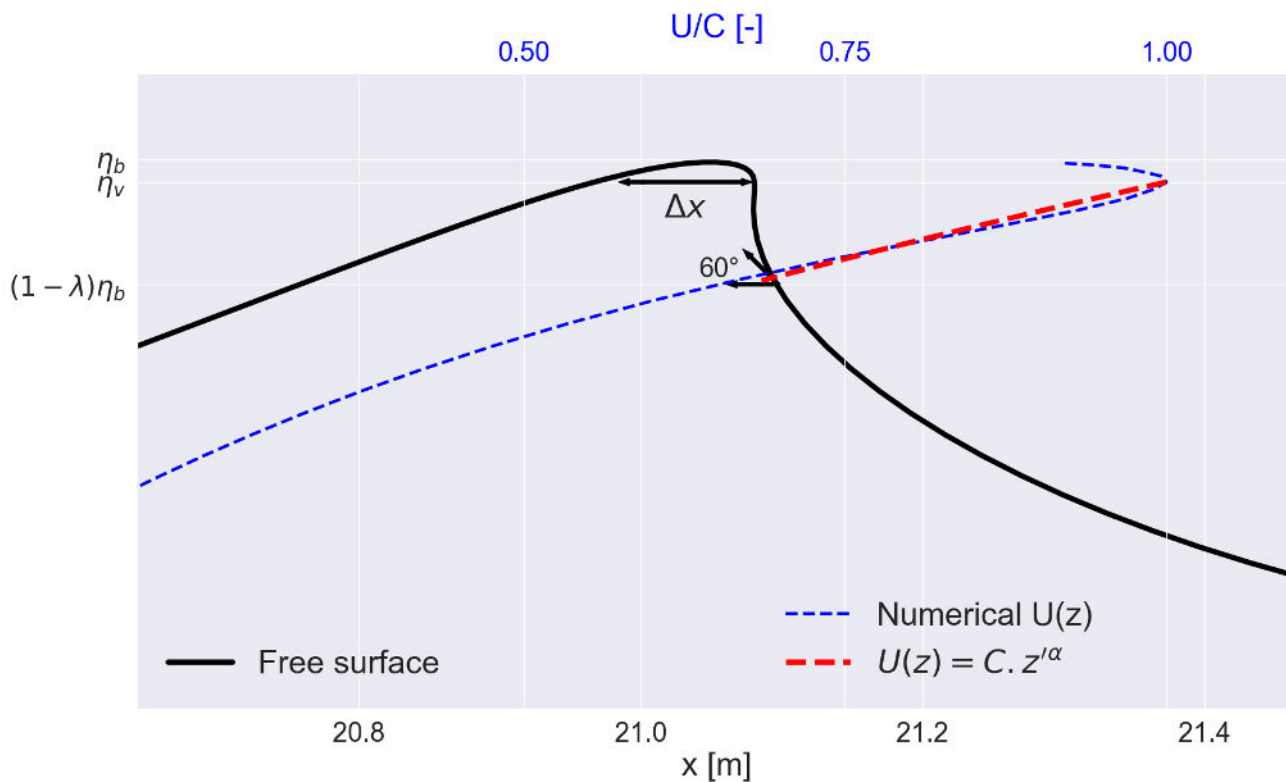
Application on wave 3 – configuration: fixed, inclined, surging cylinder



Renaud et al., Semi-Analytical Load Models Accounting for the Tilt and Motion of a Cylinder Impacted by a Plunging Breaking Wave. *Proceedings of the ASME 2023 42nd International Conference on Ocean, Offshore and Arctic Engineering*. Melbourne, Australia. June 11–16, 2023. ASME. <https://doi.org/10.1115/OMAE2023-107740>

2) A new slamming load formula – Nonlinear wave parameters

Parameterization of the nonlinear wave parameters as a function of $\Gamma^{nl} = T_b \frac{dU/C}{dt} \Big|_B = 0.85$



Curling factor
 Geometric criterion
 Free surface slope $> 60^\circ$

Free surface elevation of max fluid velocity

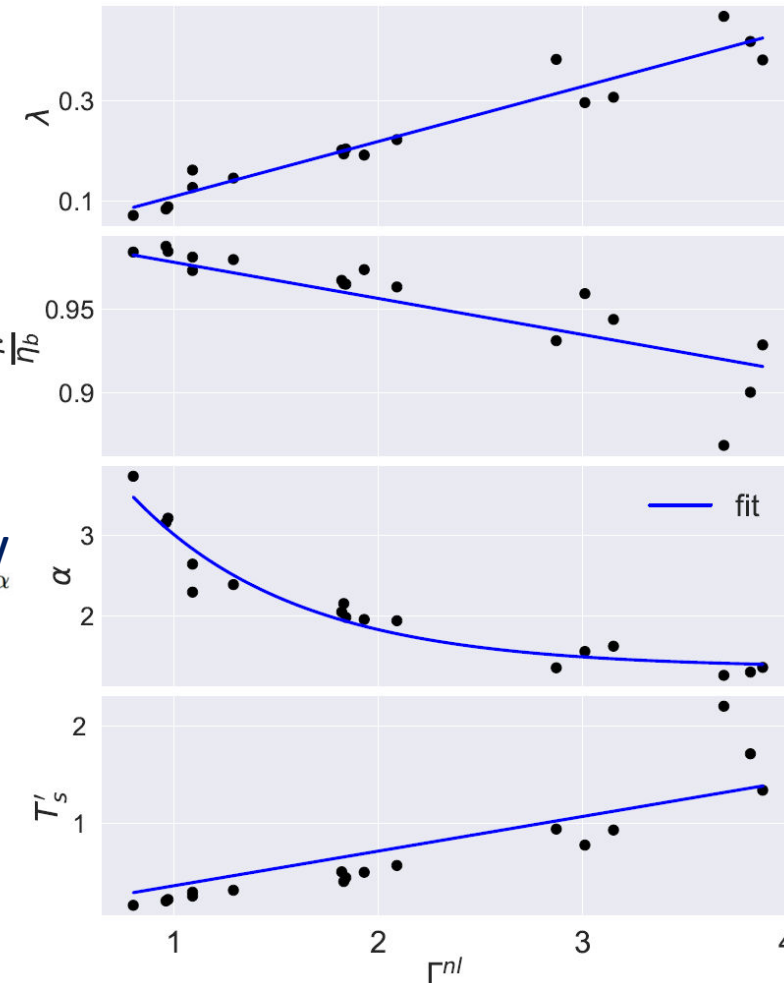
Variation of fluid velocity

$$U(z) = C \cdot z'^\alpha = C \cdot \left(\frac{z}{\eta_v} \right)^\alpha$$

Slamming duration

$$T_s = \frac{\Delta x}{C} = T'_s \frac{R}{C}$$

Parametric models

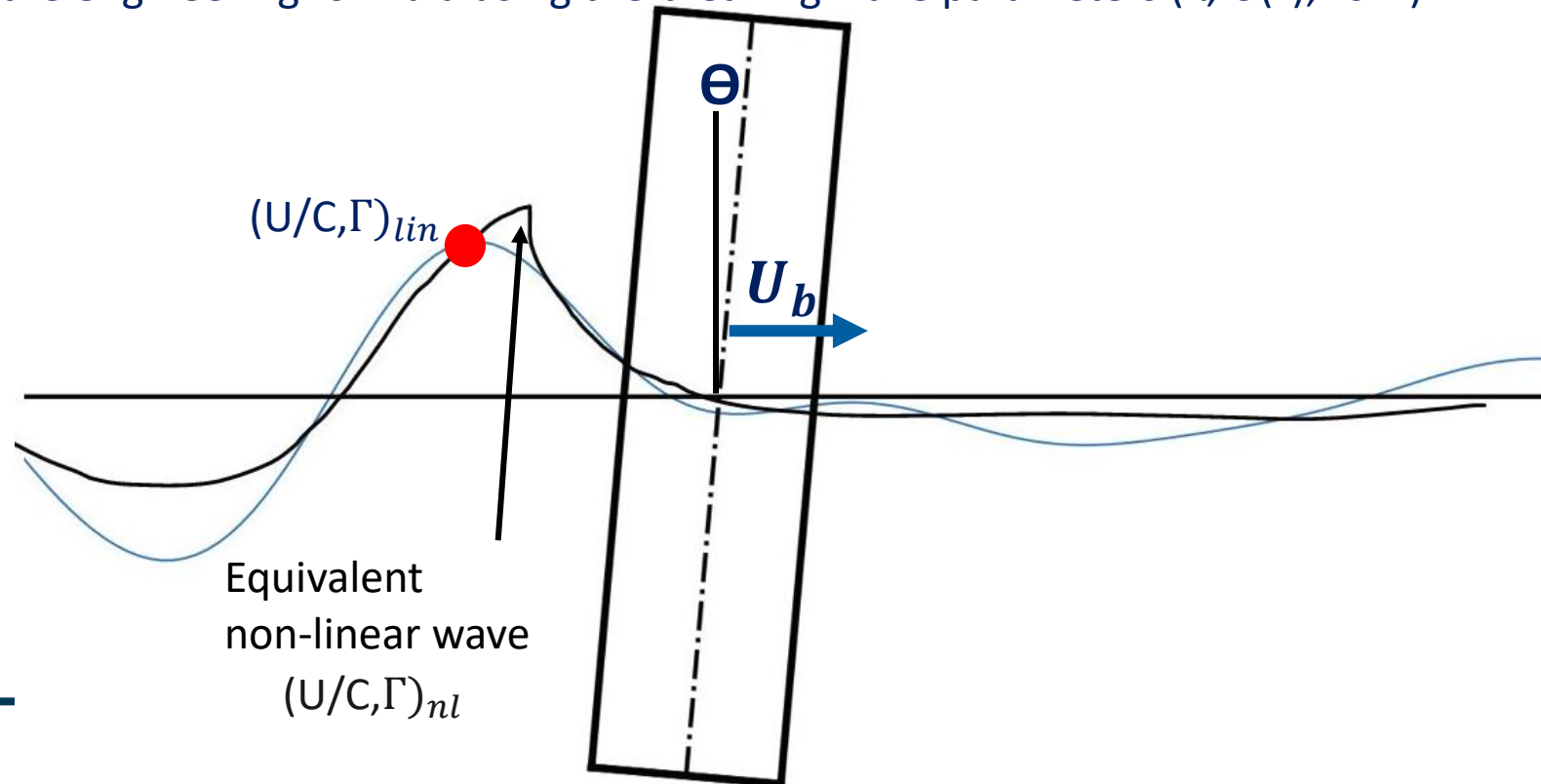


3) Breaking wave loads from linear wave properties

Low fidelity level

Reproduce the loads measured in the wave tank using only the linear properties of the experimental wave packets

- How to compute a realistic nonbreaking load? → **Nonlinear regular wave (Stream function, Clamond & Dutykh, Cokelet ...)**
- Slamming load computed with the engineering formula using the breaking wave parameters (λ , $U(z)$, T_s ...)



3) Breaking wave loads from linear wave properties

Methodology:

1) Detect breaking in the linear framework

$$(U/C)_{lin} > B(kd)$$

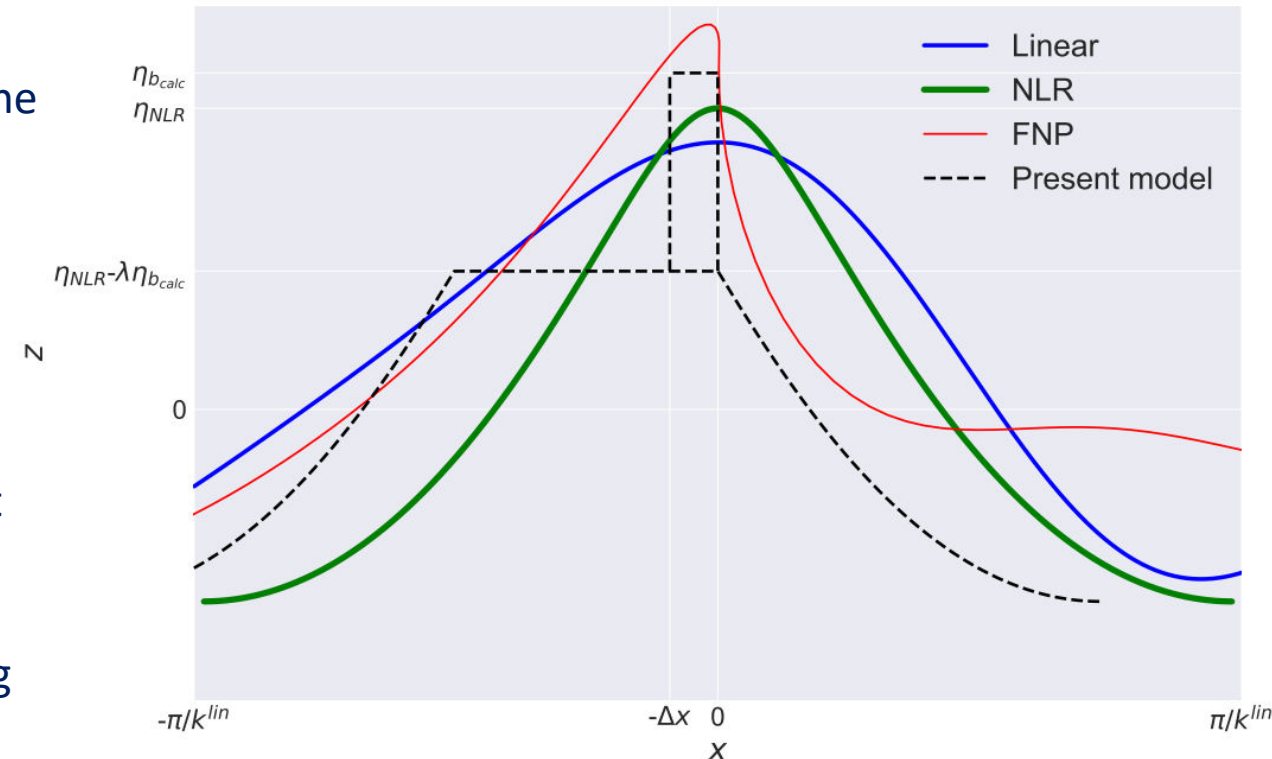
2) Compute the total energy, impulse and breaking severity of the linear wave

$$T, I, \Gamma_{lin}$$

3) Derive an equivalent steady surface gravity wave of same energy and impulse (Algorithm from Clamond & Dutykh, 2018)

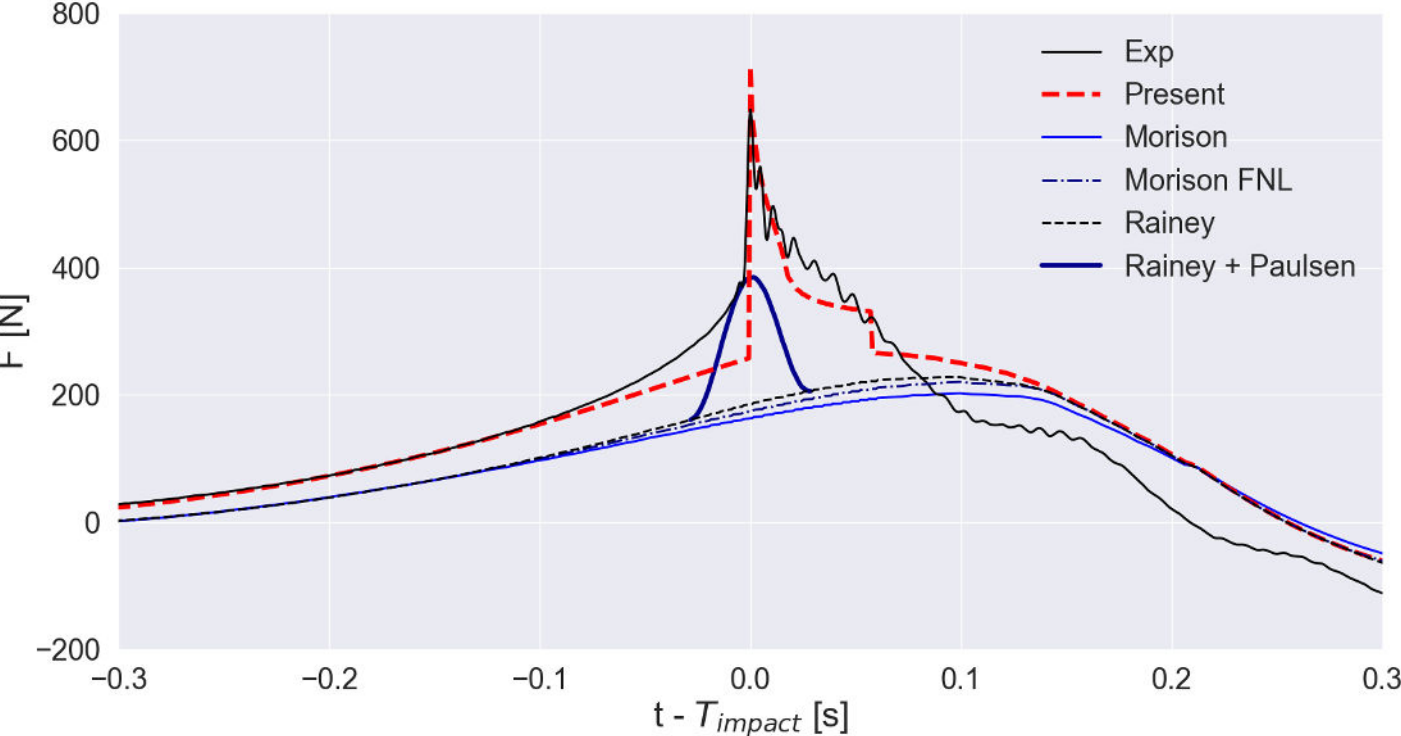
4) Nonbreaking wave load computed with the GvKM (Renaud et al., 2023) up to the portion involved in slamming $(1-\lambda)\eta_b$

5) A fictitious vertical front induces the impact load (engineering formula & nonlinear parameters using $\Gamma_{nl} = 3.89 \Gamma_{lin}$)

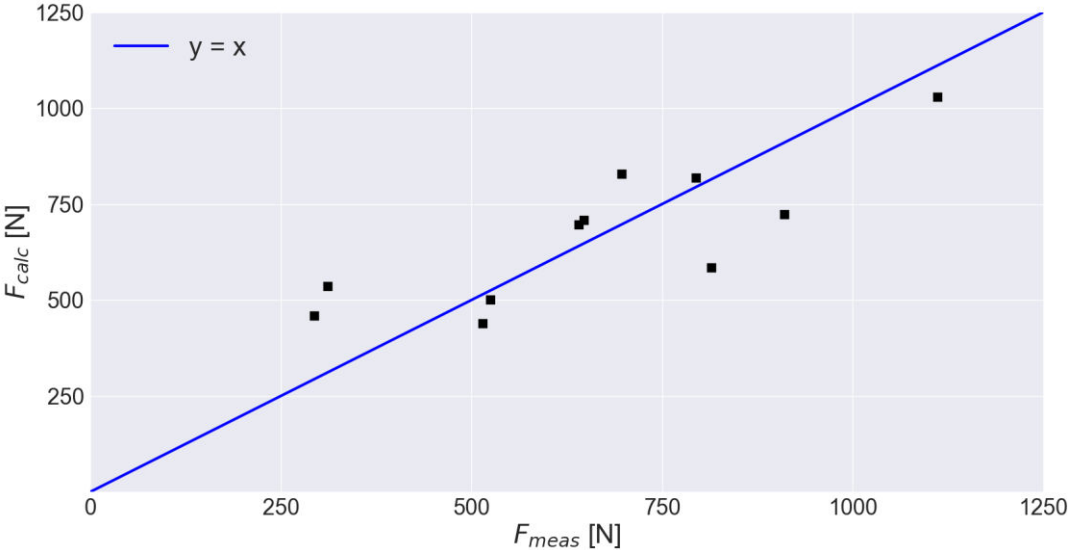


3) Breaking wave loads from linear wave properties

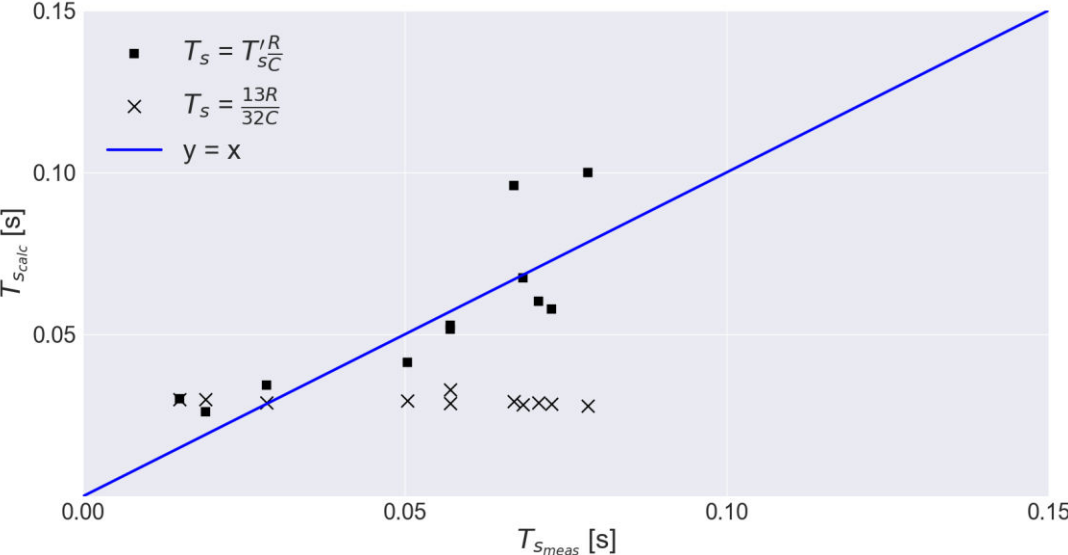
Application to a fixed cylinder



Comparison of the load induced by wave 7



Modeled vs measured forces



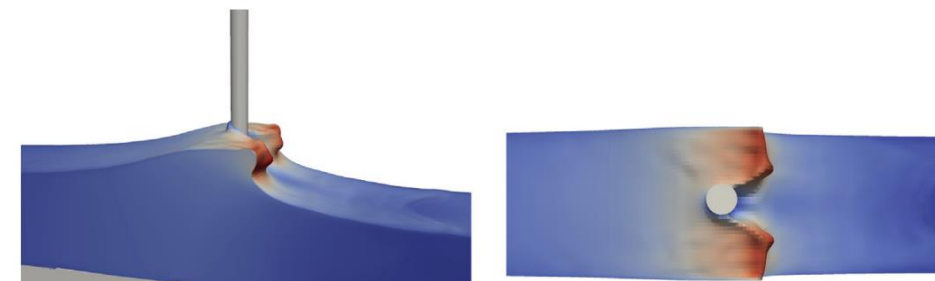
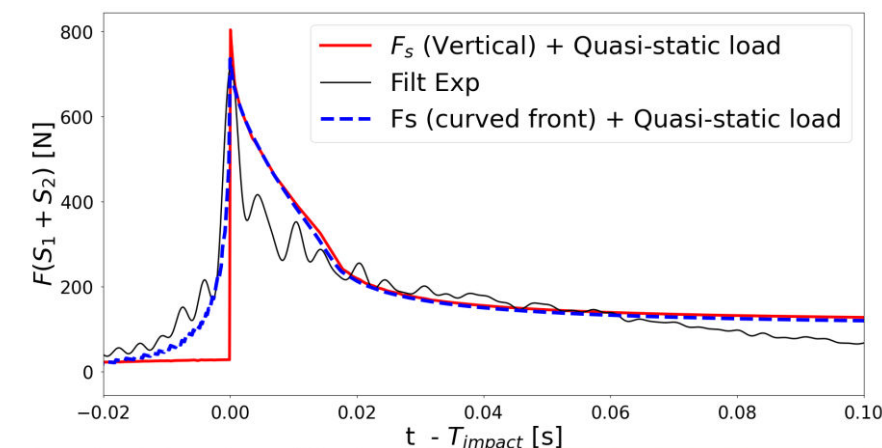
Modeled vs measured periods

Conclusion & Perspectives

- Load models (strip-theory, engineering formula) accounting for the cylinder dynamics
- Good overall agreement with the experimental data
- Engineering formula and parameterization of non-linear wave parameters easily usable in a pre-design phase
- Main limitation: spilling breakers (wavefront highly distorted by the structure = conservative slamming load)

Perspectives:

- Improvement of the slamming formula (curved front, breaking location ...)
- Measurement of λ - flow separation height)
- Implementation in global FOWT simulations



From Chella et al. (2019)

Thank you for your attention

