Recent hydrodynamic investigations – Floating solar islands and Ringing of offshore wind turbines

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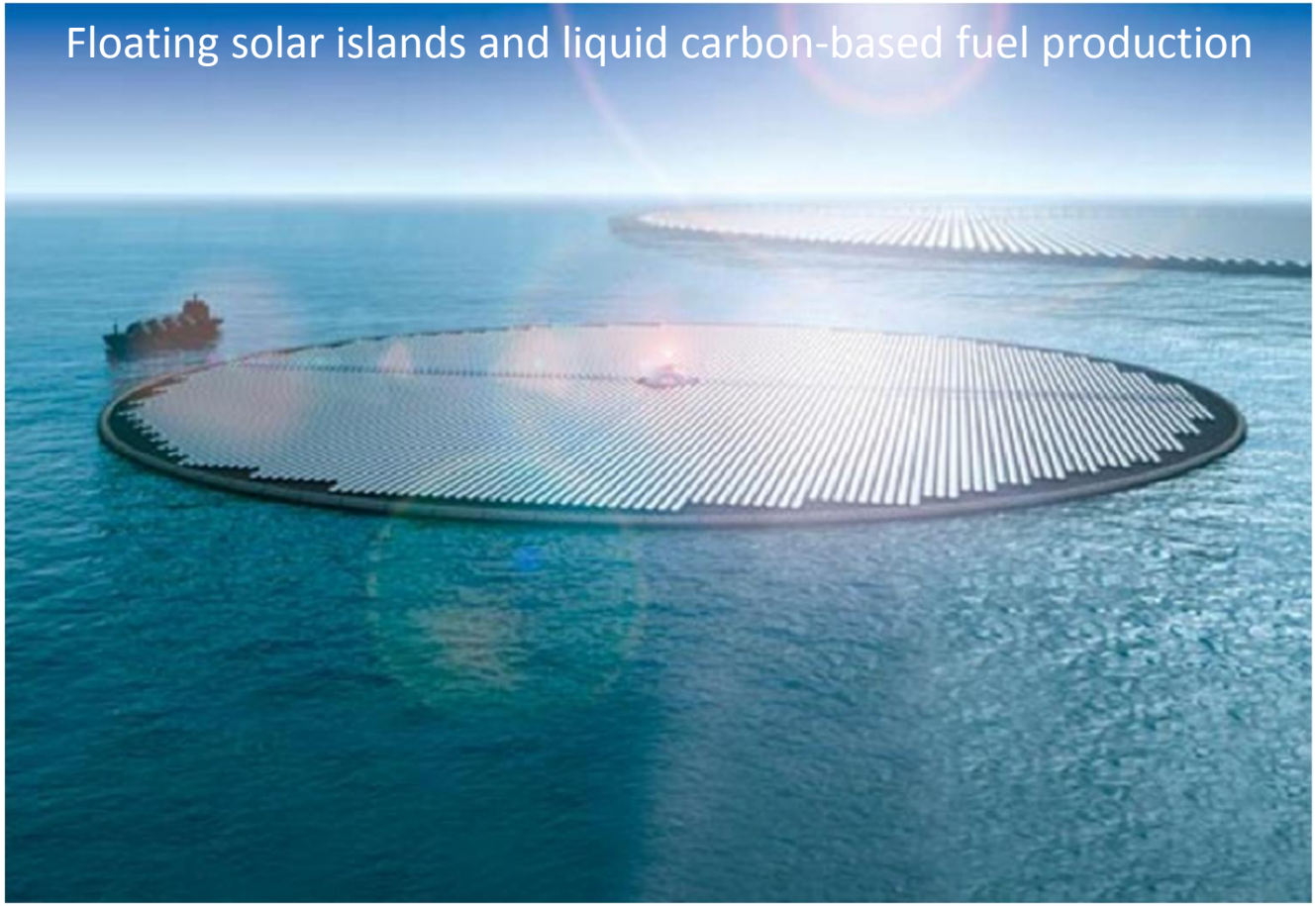
SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

7
AFFORDABLE AND
CLEAN ENERGY

Offshore wind

Floating solar islands and liquid carbon-based fuel production



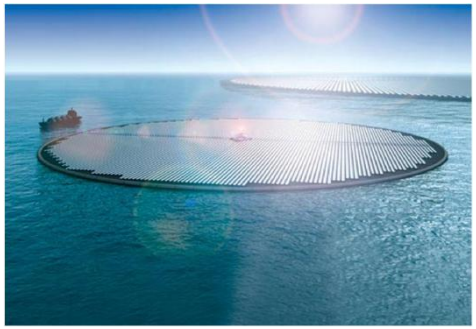
Global perspectives in energy

2006

17 TW

2050*

27 TW



*

Population growth 2016 → 2050: 2.3 billion (mean ~ 0.8 %/yr)

Lewis & Nocera, PNAS (2006)

Economic growth per capita: GDP/N ~ + 2.2 %/yr

Energy intensity decrease: E/GDP ~ - 0.8 %/yr

Energy consumption rate: E ~ + 1.4 %/yr → + 10 TW power by 2050

Options:

Lewis & Nocera, PNAS (2006)

Nuclear fission

Need to build 1 GW plant per 1.25 days, ^{235}U exhausted in 10 yrs

Fossil fuels + CO_2 capture / storage

store 1.4 x Lake Superior/yr (at NTP) or 10% of LS/yr (at P ~ 14.5 atm);
leakage < 1%/century

Offshore Wind

Significant global potential (need 20 million 10MW turbines)

Wave power

No global potential

Solar

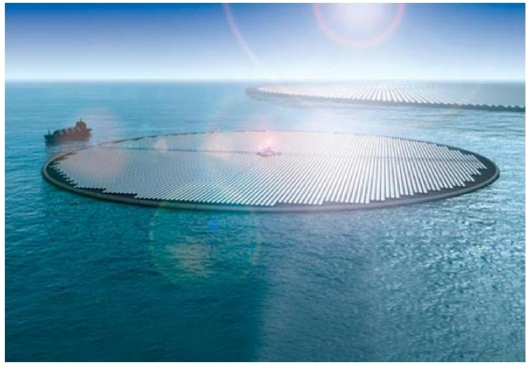
Average daily insolation 200 W/m^2 (Southern Spain)
10 TW @ 20% PV panel efficiency → need $500 \times 500\ km^2$

PV = Photo Voltaic

Energy storage:

- Batteries: too expensive, insufficient capacity
- Bio fuel: efficiency $< 0.5\%$
- Solar thermal: maybe
- Hydrogen: new infrastructure needed, dangerous
- **Chemical bonds: liquid C-based solar fuel** **Ocean and atmosphere in CO_2 equilibrum**

IPCC: We need additional 10 TW C-free energy by 2050



Floating C-based fuel factories at sea ***Powered by floating solar islands***

Idea: Frode Mo and Bruce Patterson

Multi-disciplinary

New technology

Marine structures

Fuel factories

Solar islands

(Cost-efficient!)

Operations

Liquid fuel transport

Installation

Maintenance

Robots

Autonomy

Physics (PV-panels)

Robust

Sea spray, heat

Chemical processing

Robust

Efficiency rate

Electrical engineering

New materials

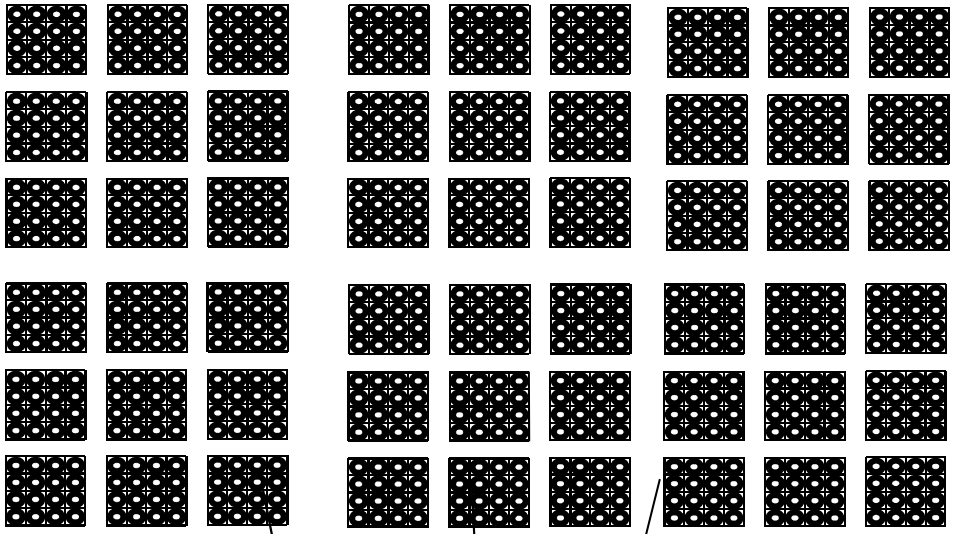
Political and social aspects

Safety

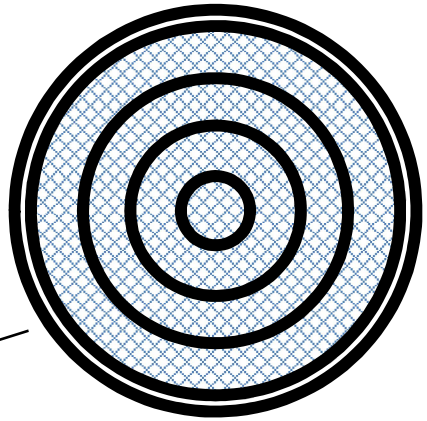
$500 \times 500\ \mathrm{km}^2$

0.07% of World oceans

Solar island park producing power

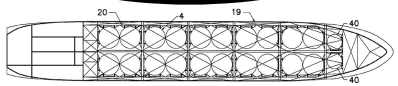


Solar island

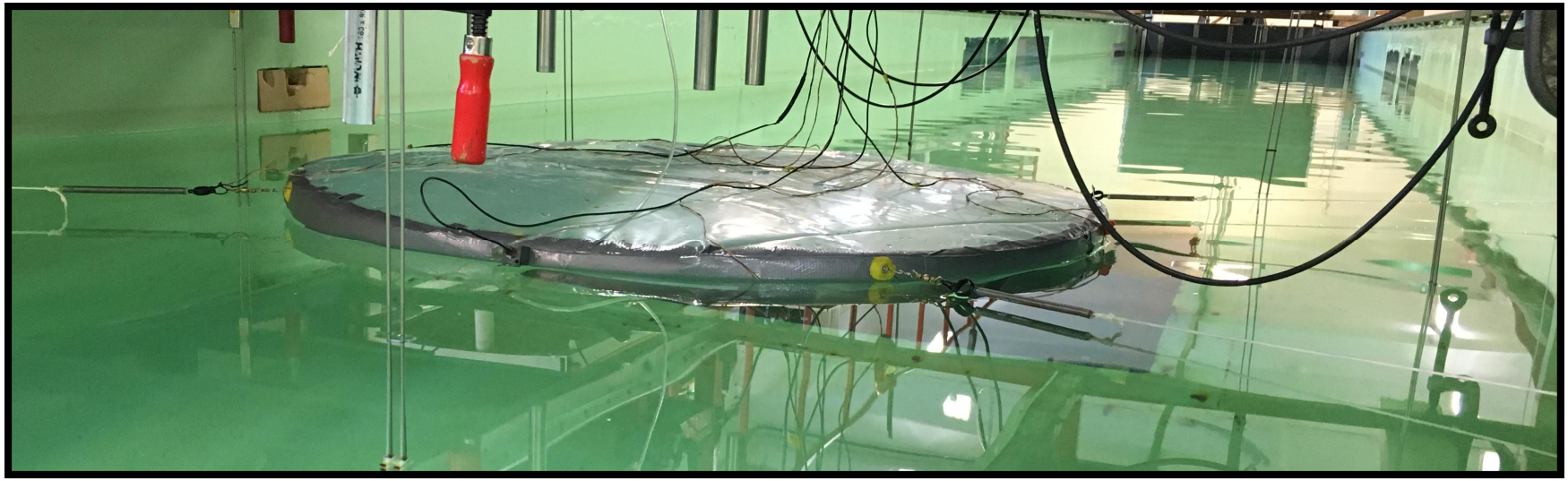


Inspired by fish farms

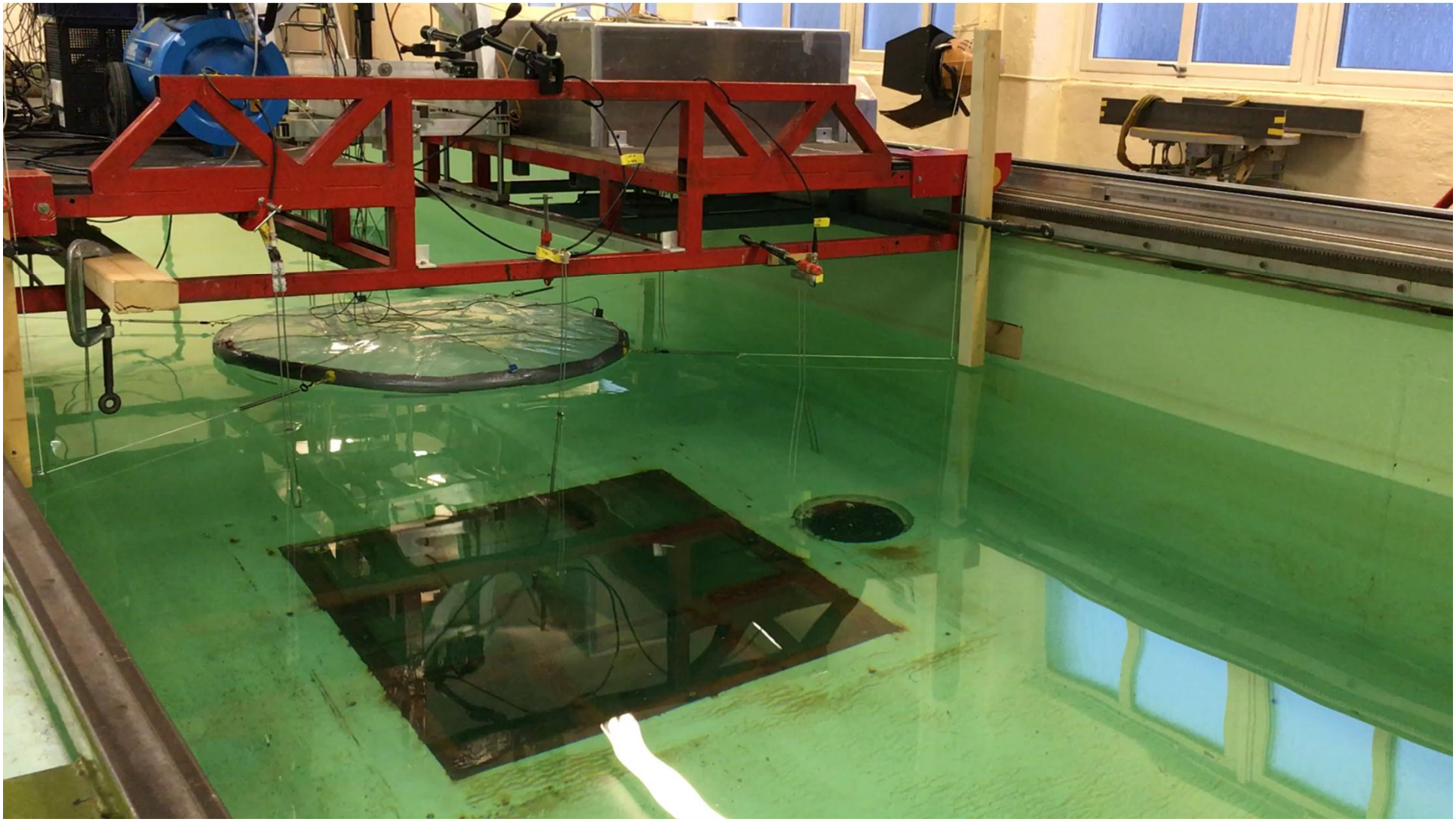
Carbon-based fuel factory and storage

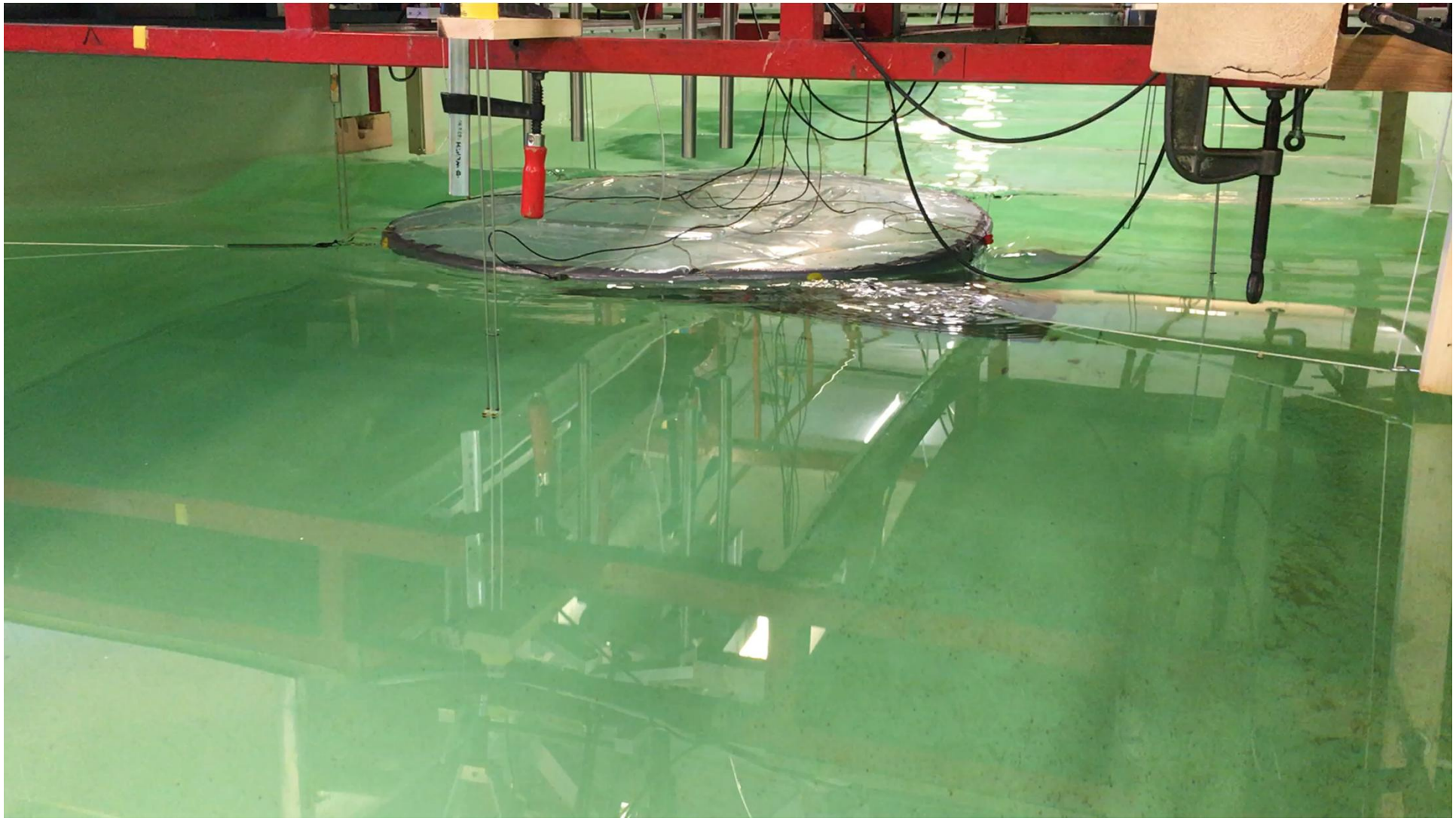


Example: Air-supported solar island



Petter Borvik, master thesis (2017)





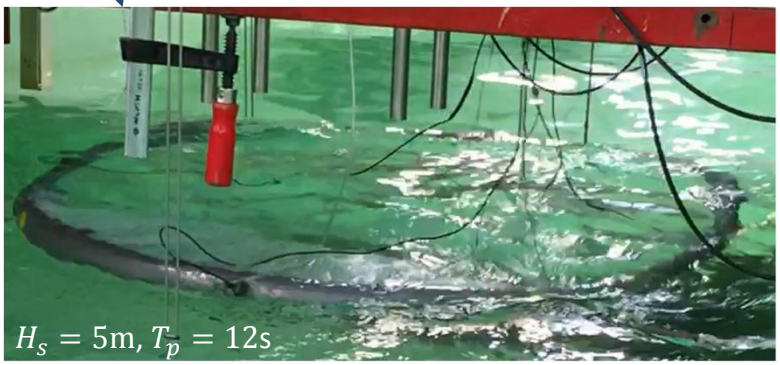
Example: Air-supported solar island

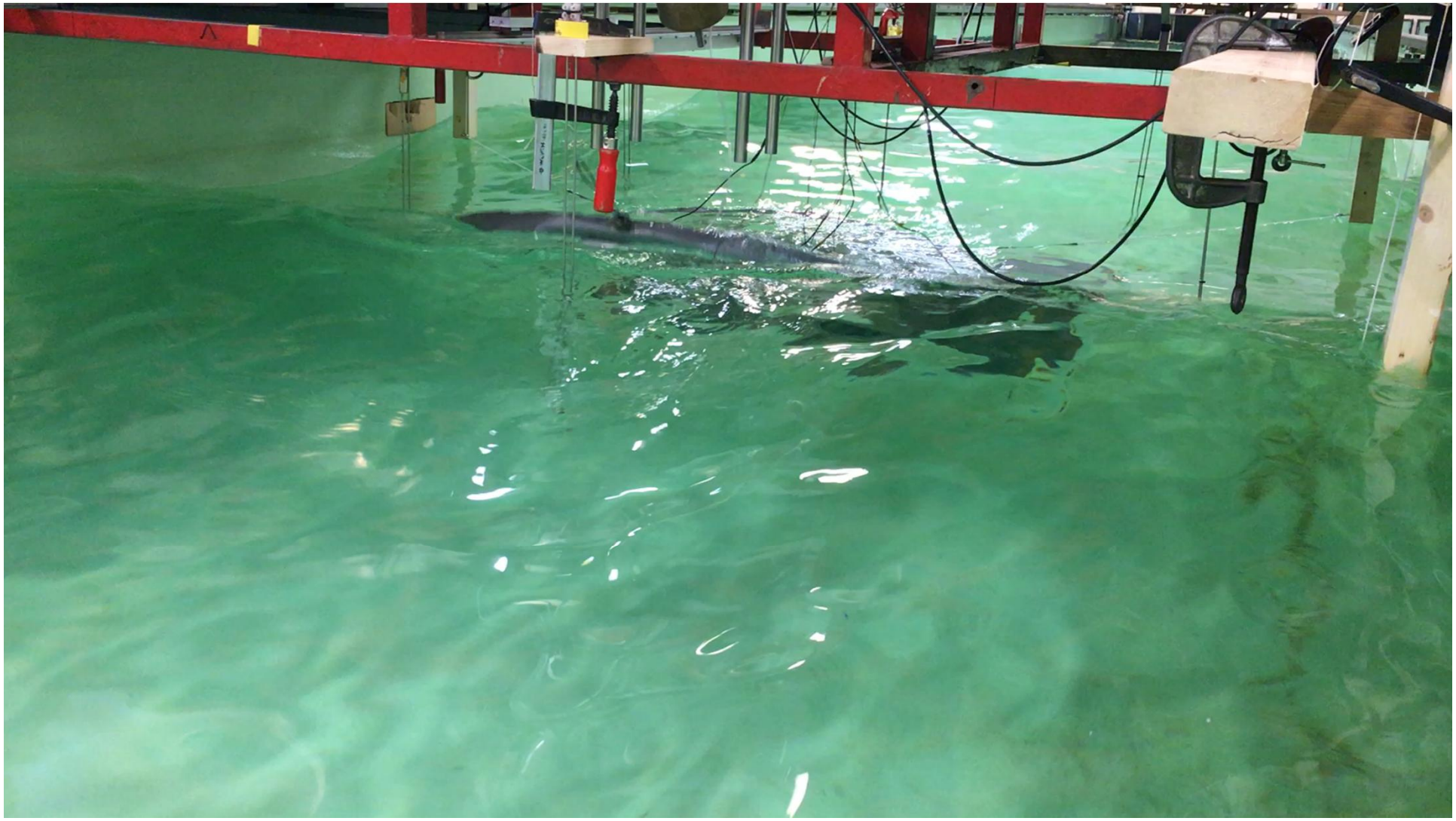
Operation:

- Limitations on angles and accelerations
- Slamming on PV panels

Failure modes:

- **Air escape**
  - Out of water
  - Wear and tear
- **Flooding -** Wave over-topping





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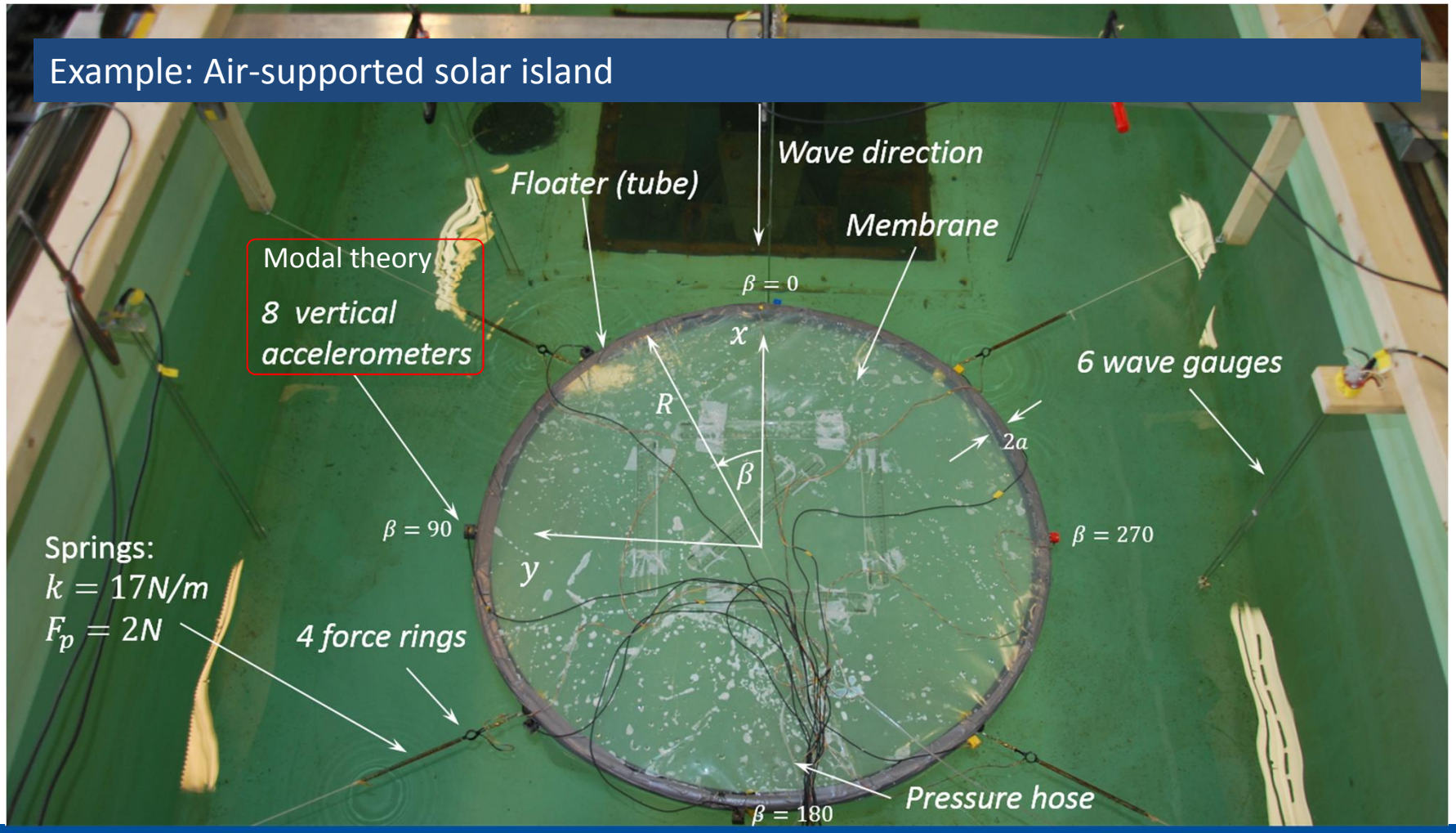

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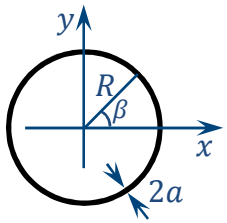


Modal theory:

Vertical motion

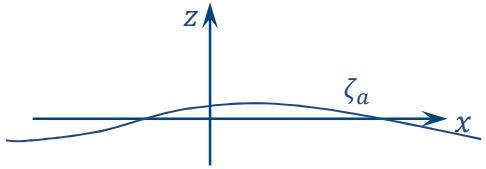
$$w(\beta,t)=\sum_{n=0}^{\infty}a_n(t)\cos n\beta$$

a_0: heave
a_1: pitch
a_2: first flexible mode
...
a_n: higher flexible modes

Euler beam equation for floater:

$$m\frac{\partial^2 w}{\partial t^2}+EI\frac{\partial^4 w}{\partial s^4}+\frac{EI}{R^2}\frac{\partial^2 w}{\partial s^2}=f_z(s,t)$$

Peng Li and Odd Faltinsen 2017



Simplified heave equation, including air cushion:

$$(2\pi R(m+a_{33})+M_s)\frac{\partial^2\eta_3}{\partial t^2}+\left(2\pi R\rho g b_w+\frac{A_b\gamma p_0}{h_b}\right)\eta_3=\left(\frac{\gamma p_0}{h_b}i\zeta_a q+2\pi R(\rho g b_w-\omega^2 a_{33})\zeta_a J_0(\nu R)\right)e^{-i\omega t}$$

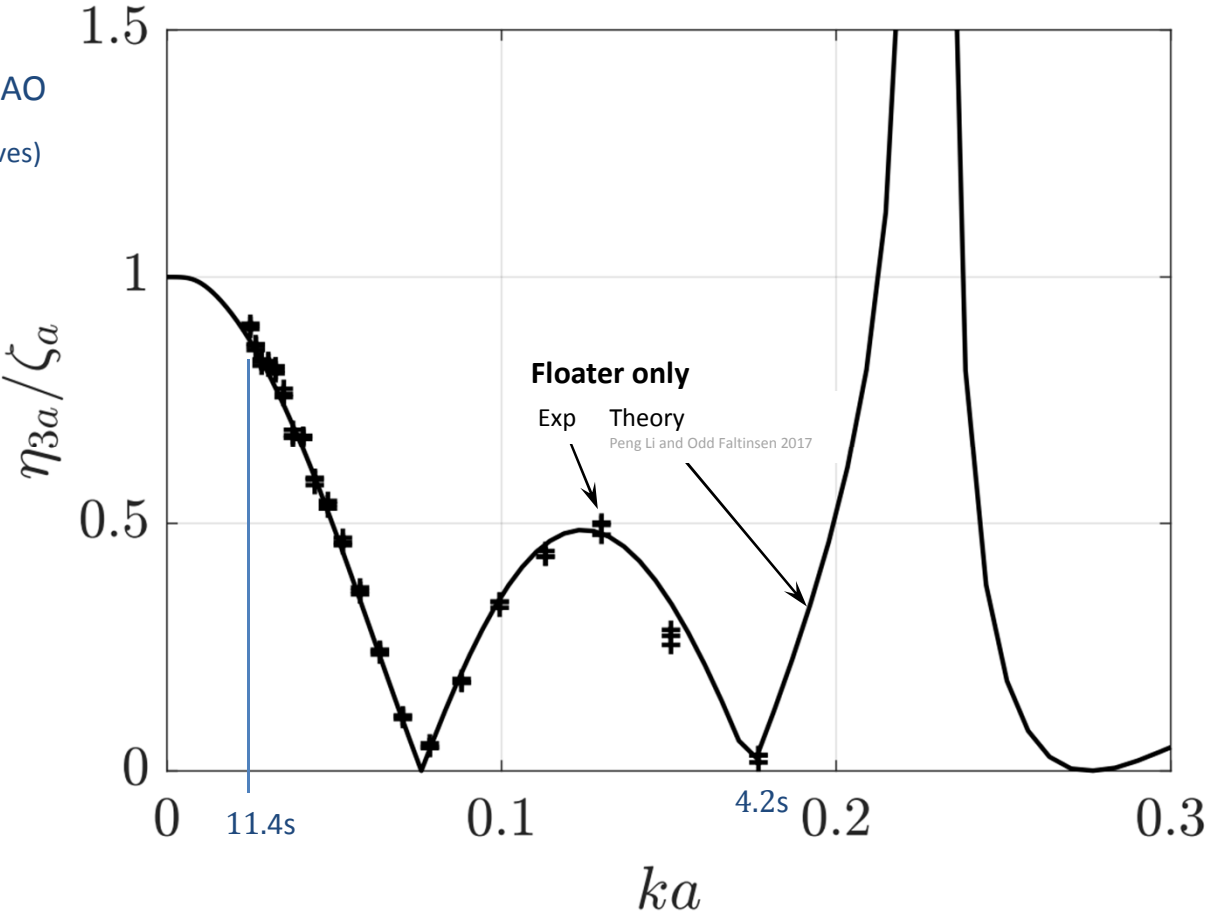
Mass of membrane and skirt

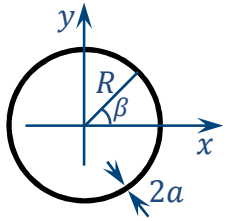
Air cushion restoring force

Froude-Kriloff wave excitation force

Heave RAO

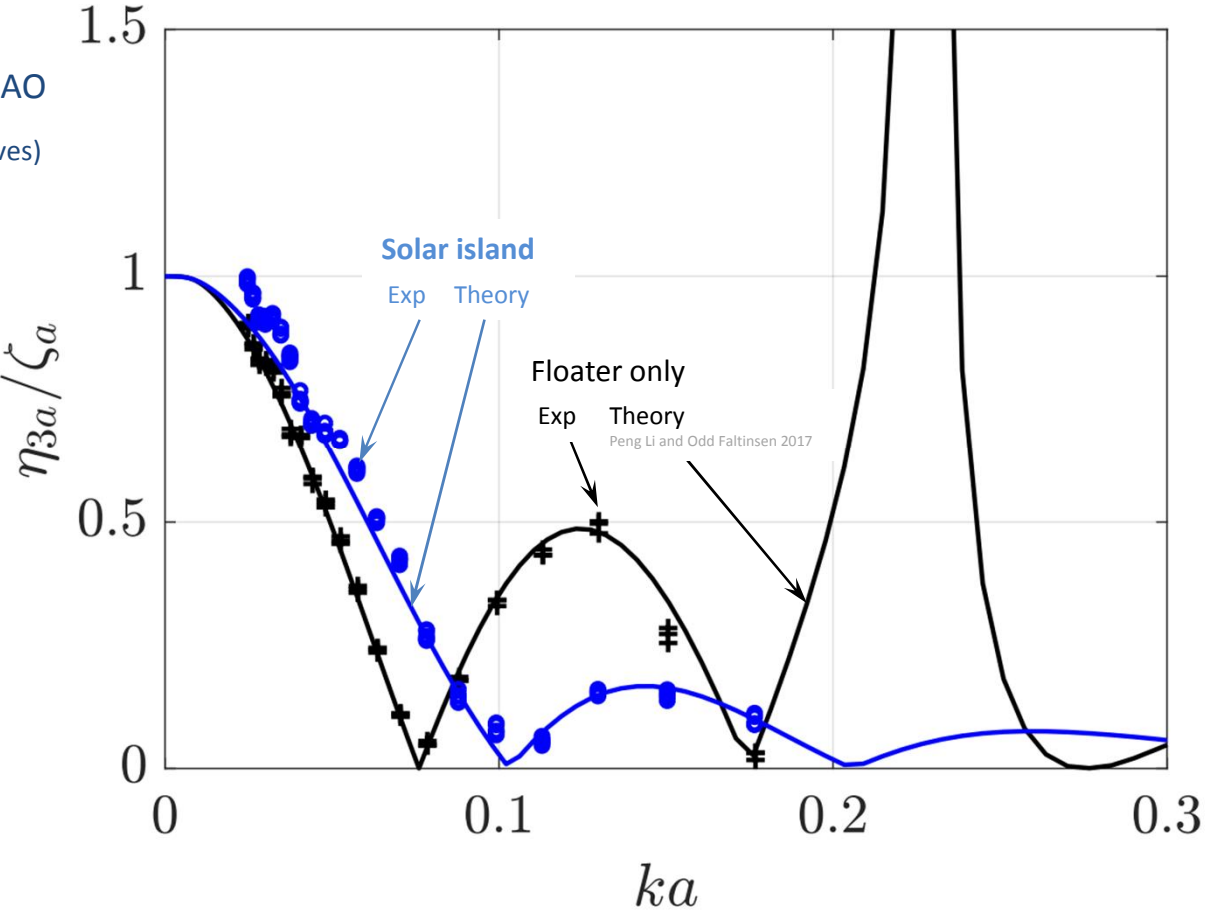
(regular waves)

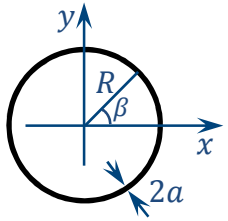




Heave RAO

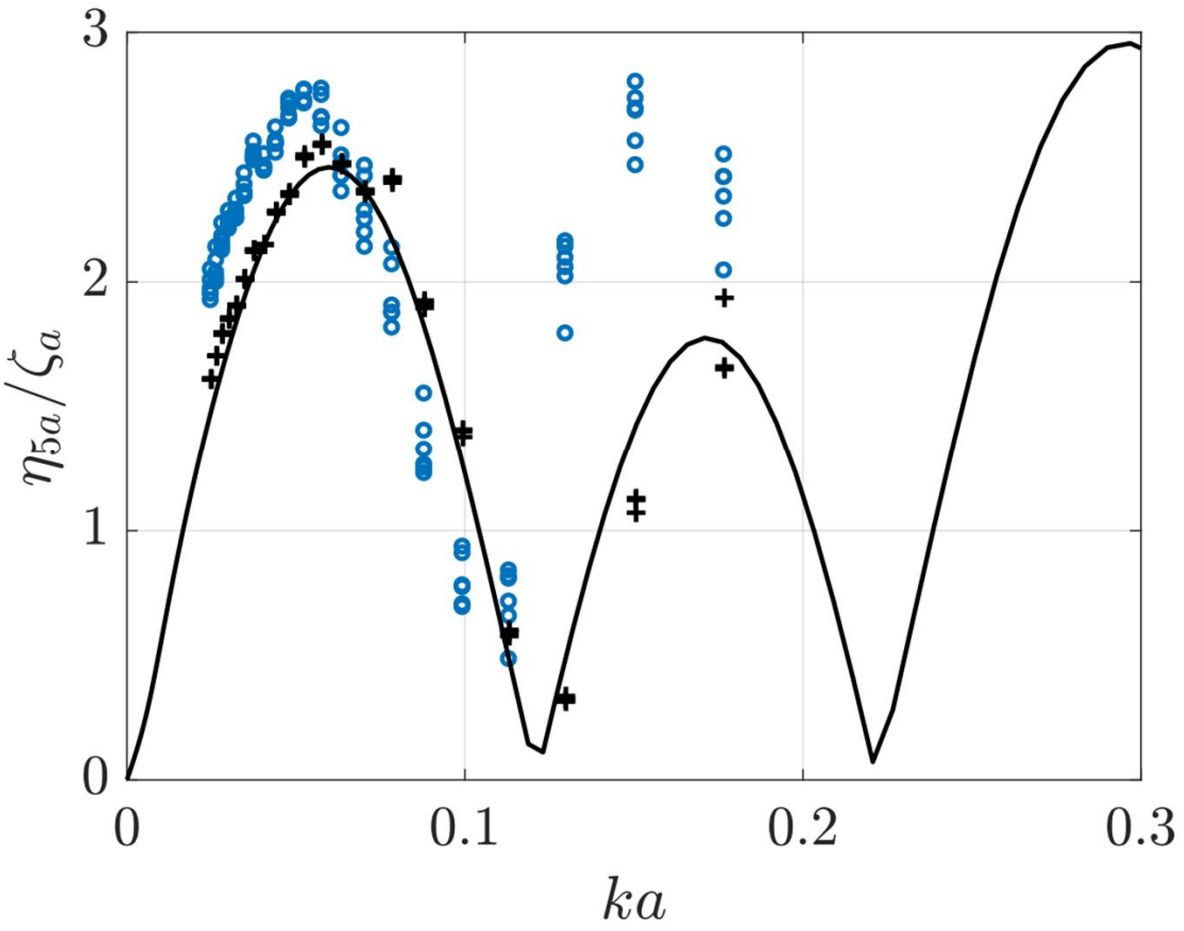
(regular waves)

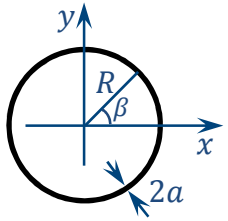




Repeatability

Pitch RAO

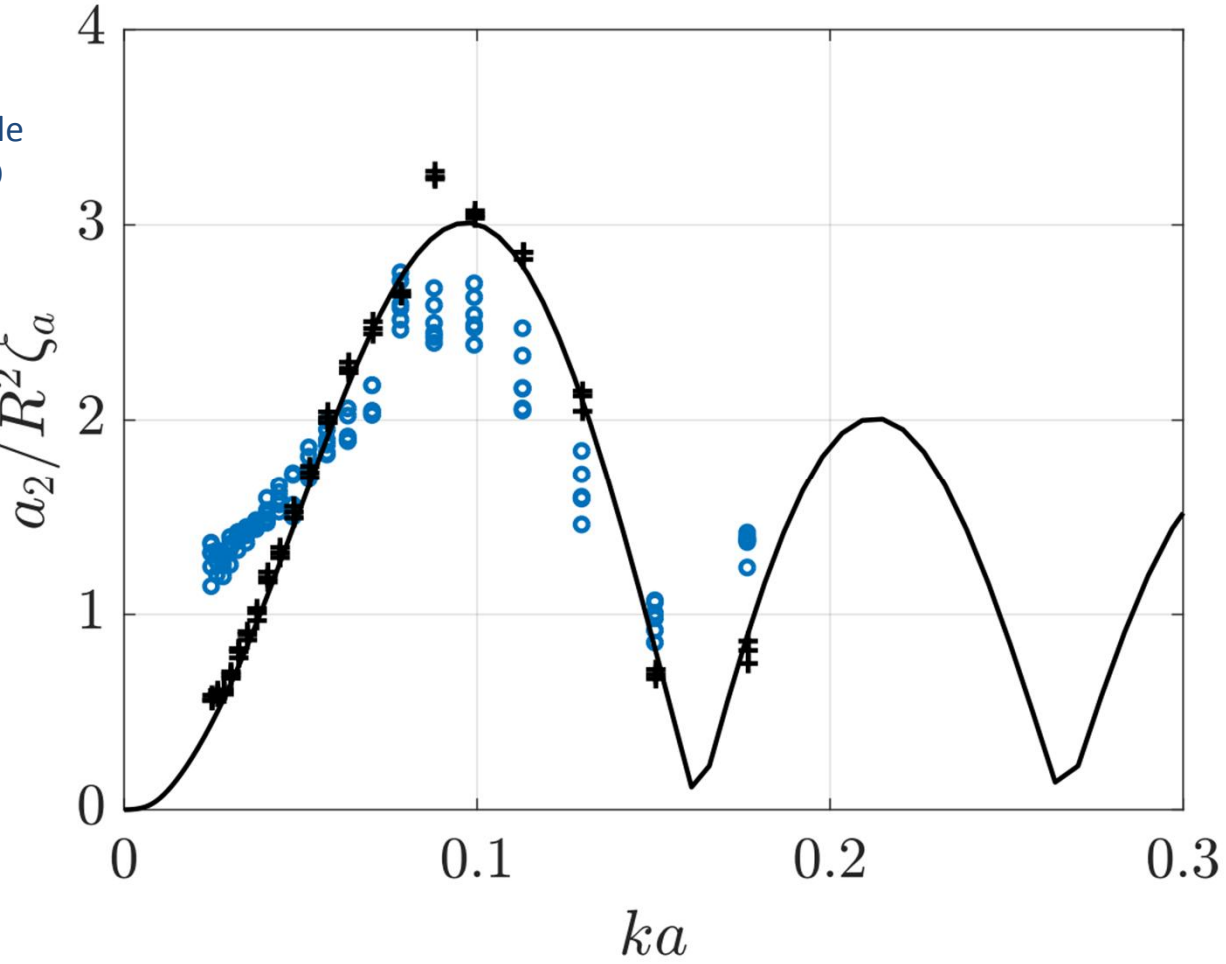


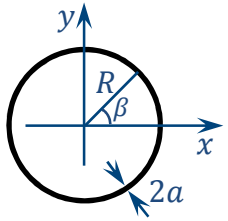


Repeatability?

Air custion makes the island statically unstable

First flexible mode RAO



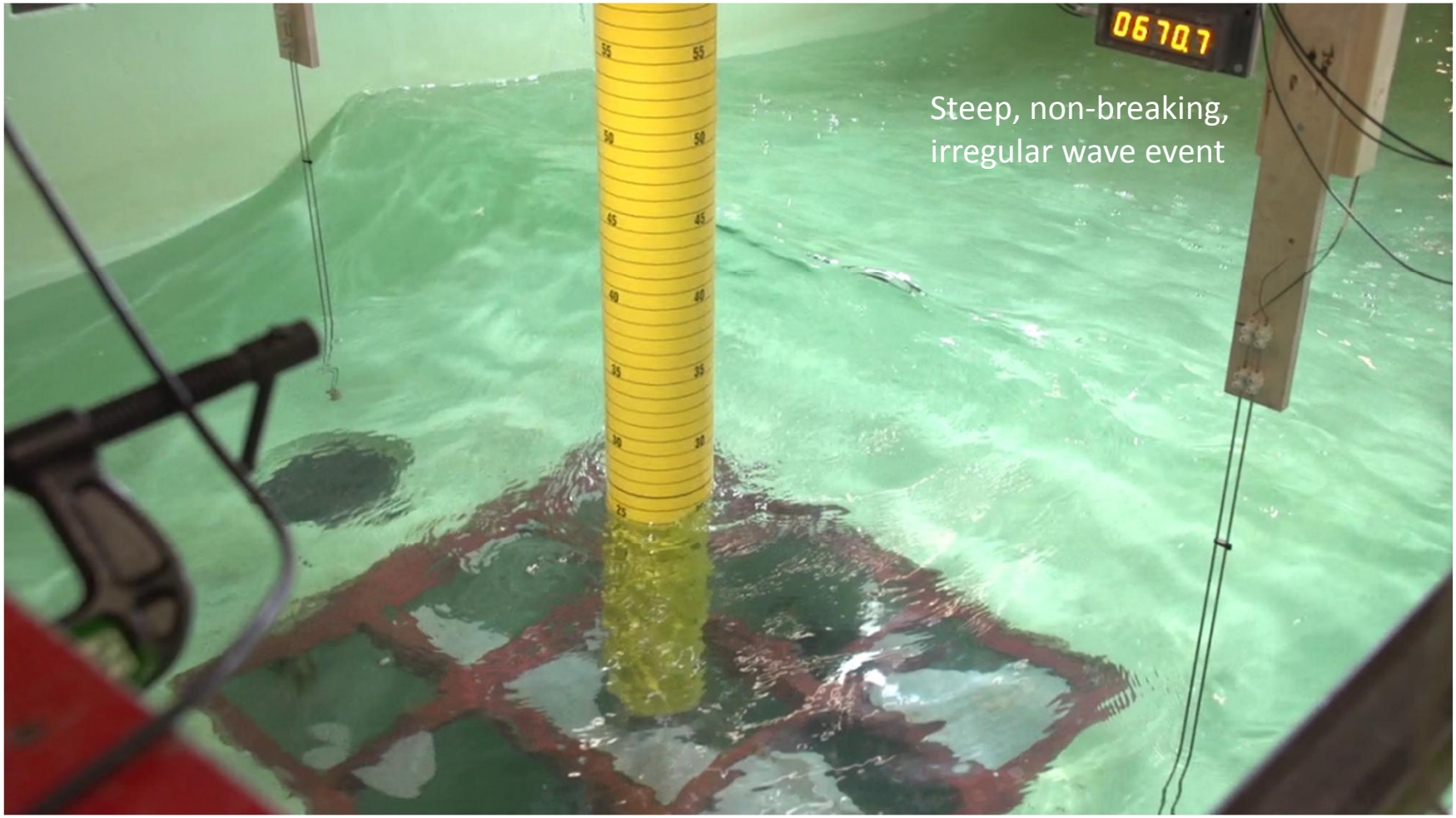


Repeatability?

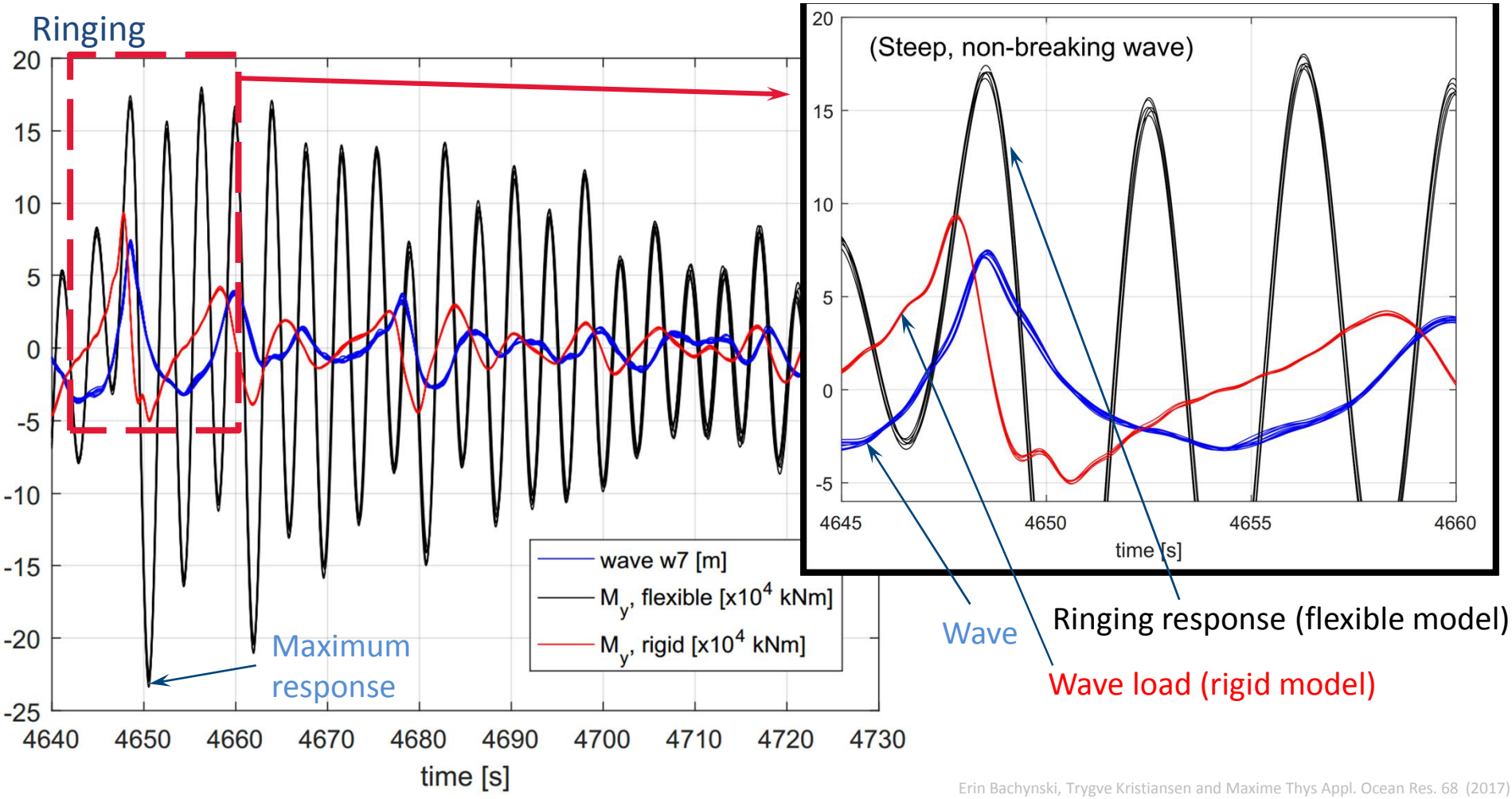
Air custion makes the island statically unstable

(On-going investigation)

Ringing of Offshore Wind turbines


Steep, non-breaking,
irregular wave event

Steep, non-breaking,
irregular wave event



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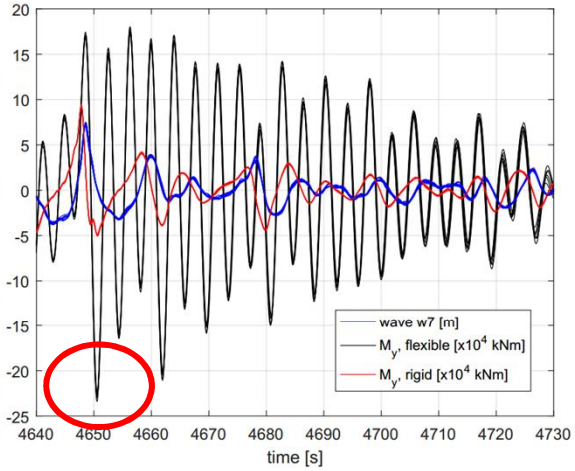
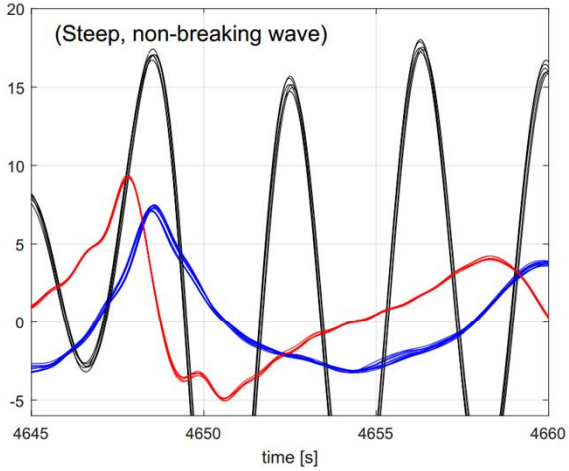
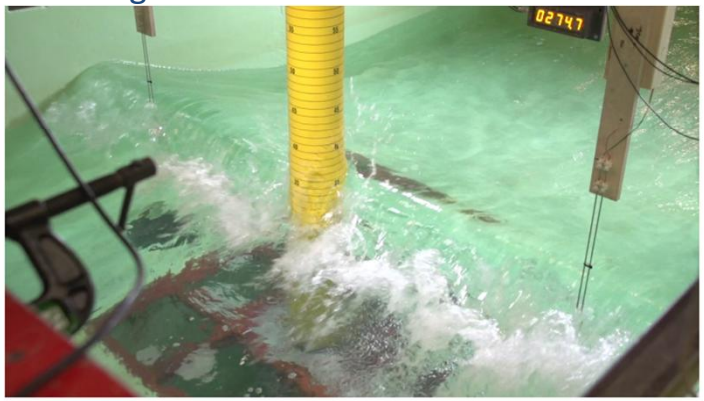
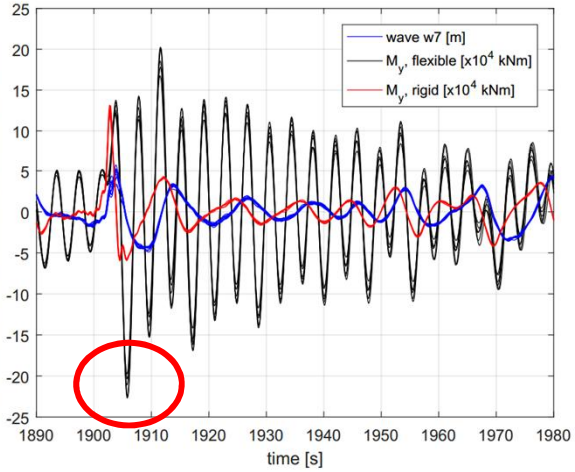
Non-breaking event

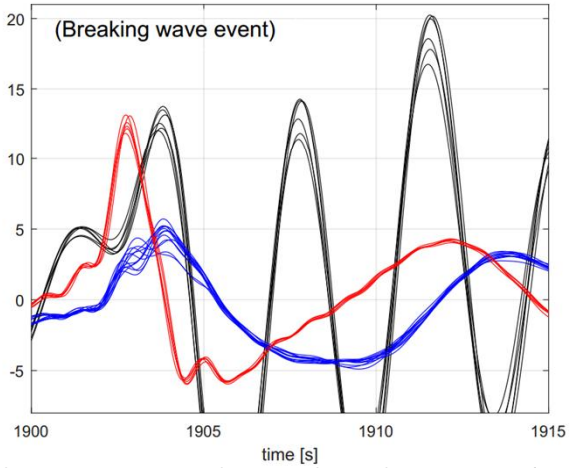




Breaking wave event







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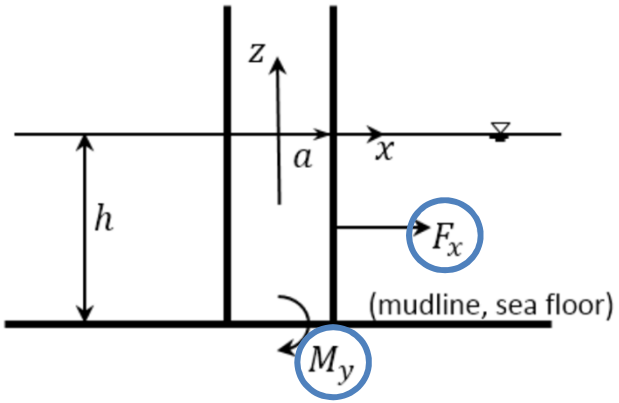
The monopile might break due to ringing

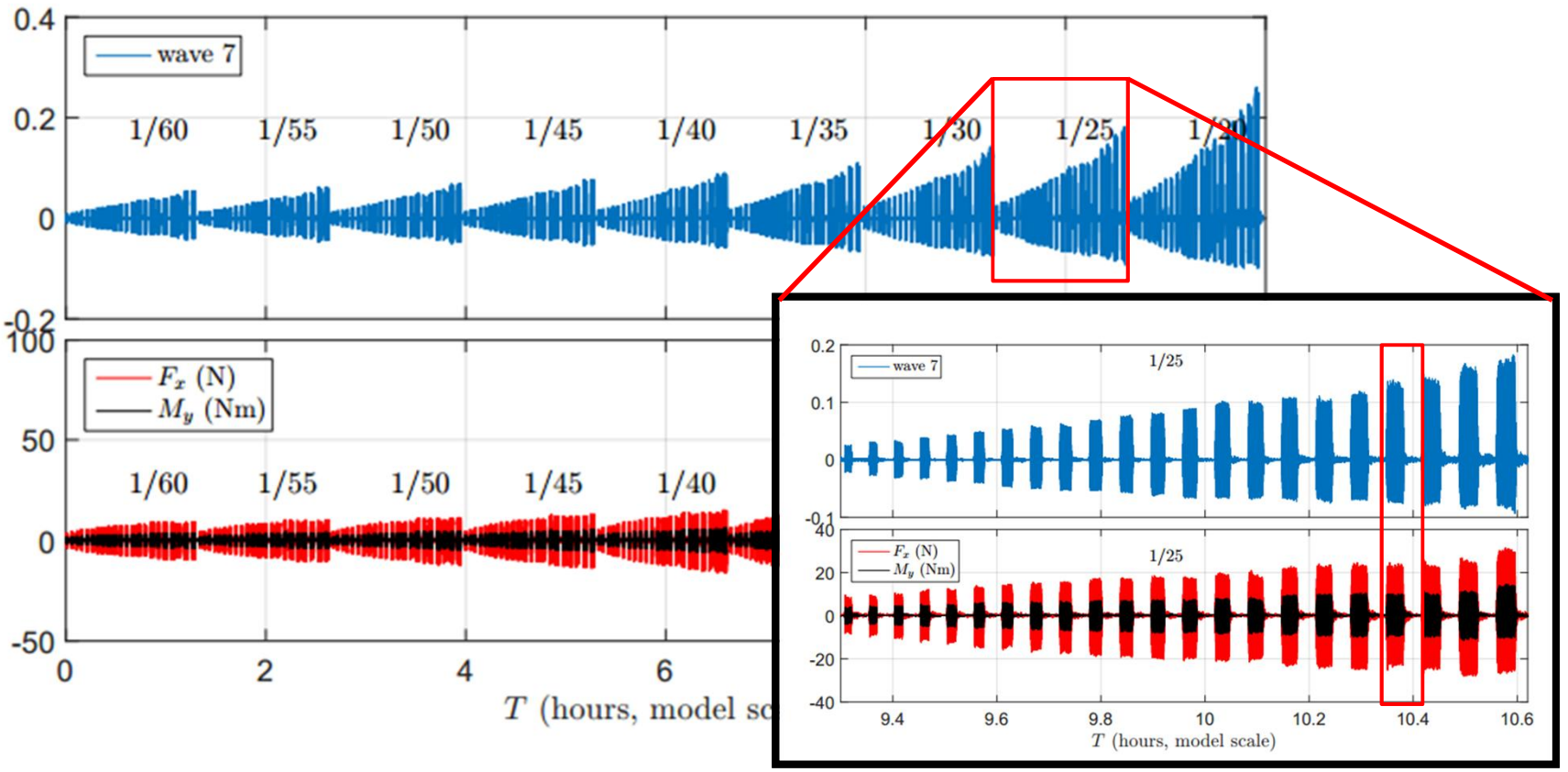
Design problem

Large *irregular* wave events

Load harmonics in *regular waves*



Automated testing



Automated testing

«Quality by quantity»

Repetition tests

Parameter studies

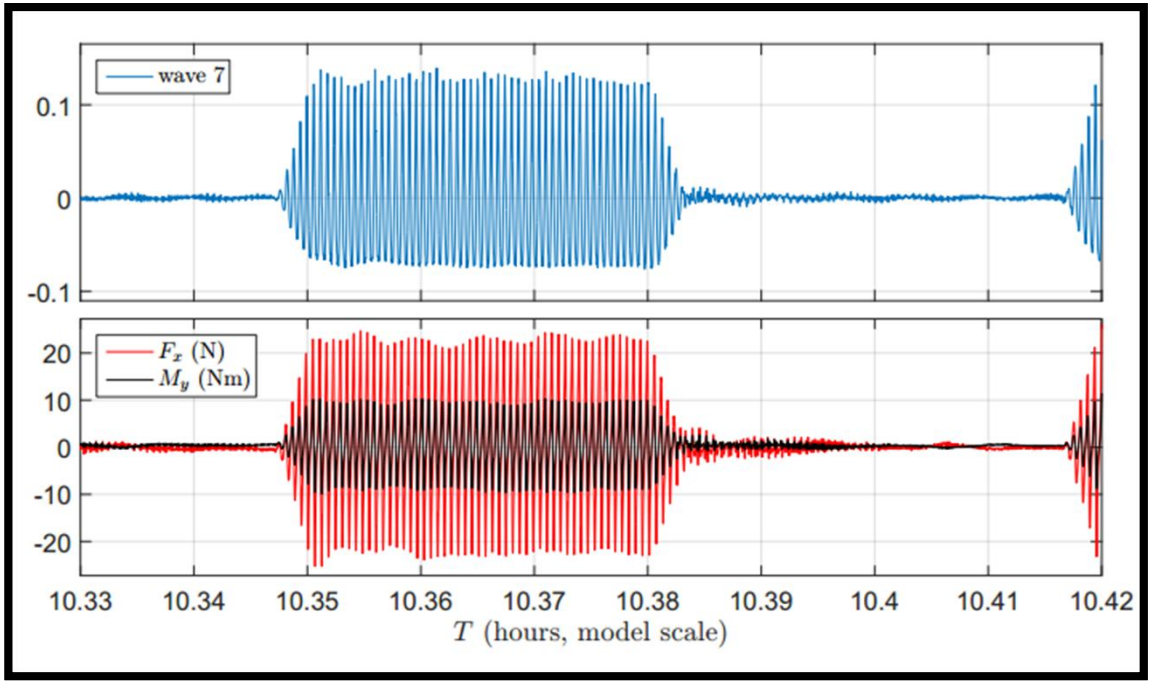
Trends

Flaw detection

Save time!

Duration of test

Pause between tests



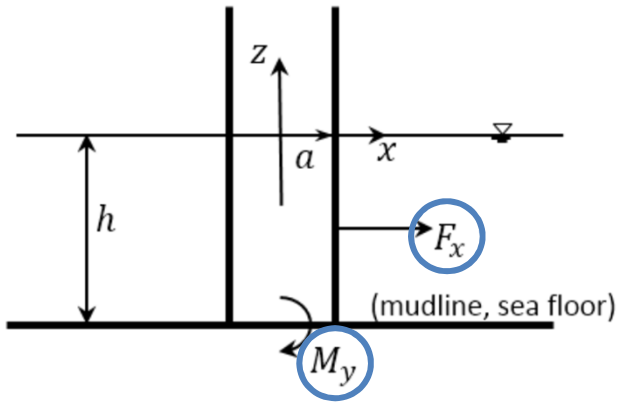
Extensions?

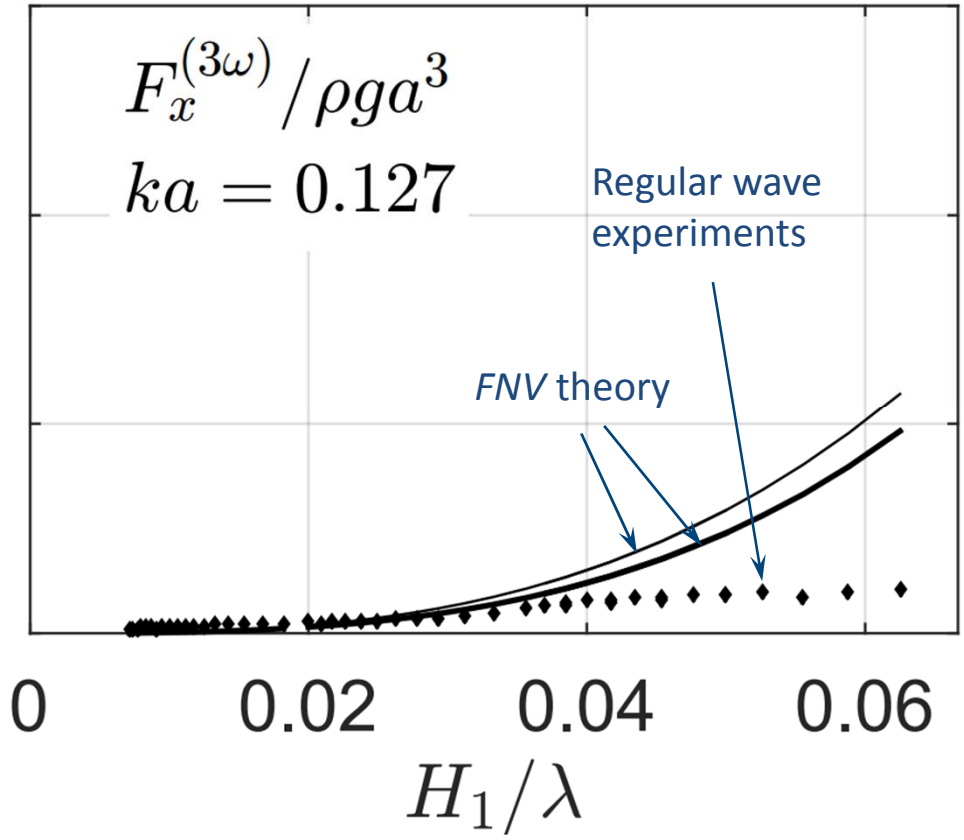
Machine learning

Auto-morphing of models?

Load harmonics in *regular waves*

Focus: discrepancies in the 3ω loads

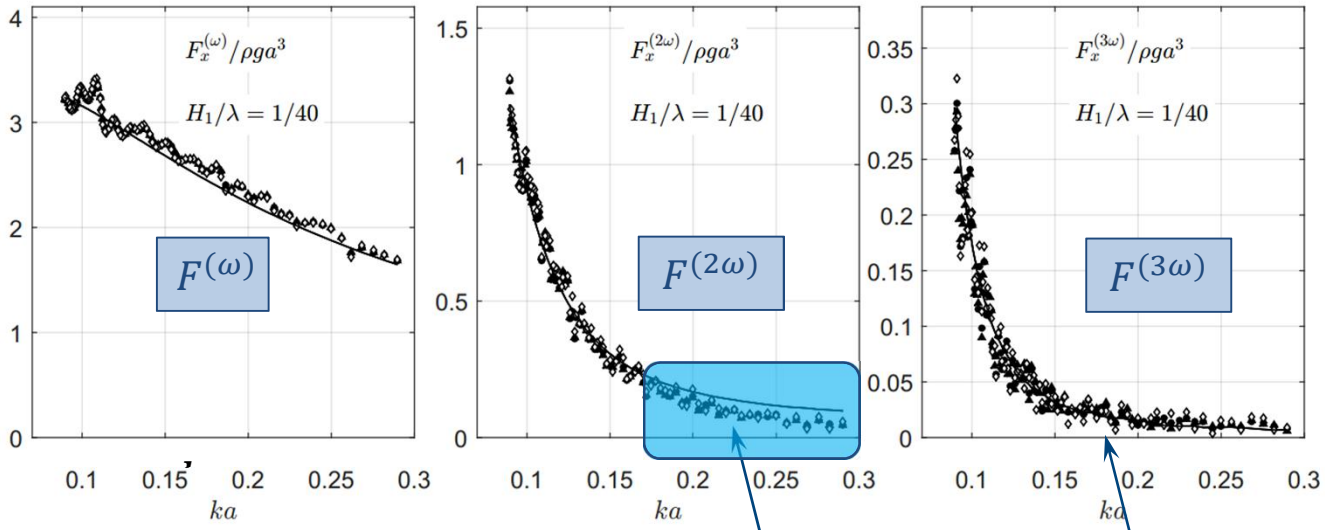




Trygve Kristiansen and Odd M. Faltinsen, JFM (2017)

Load harmonics

$$\frac{H_1}{\lambda} = \frac{1}{40}$$



Second order free-surface diffraction

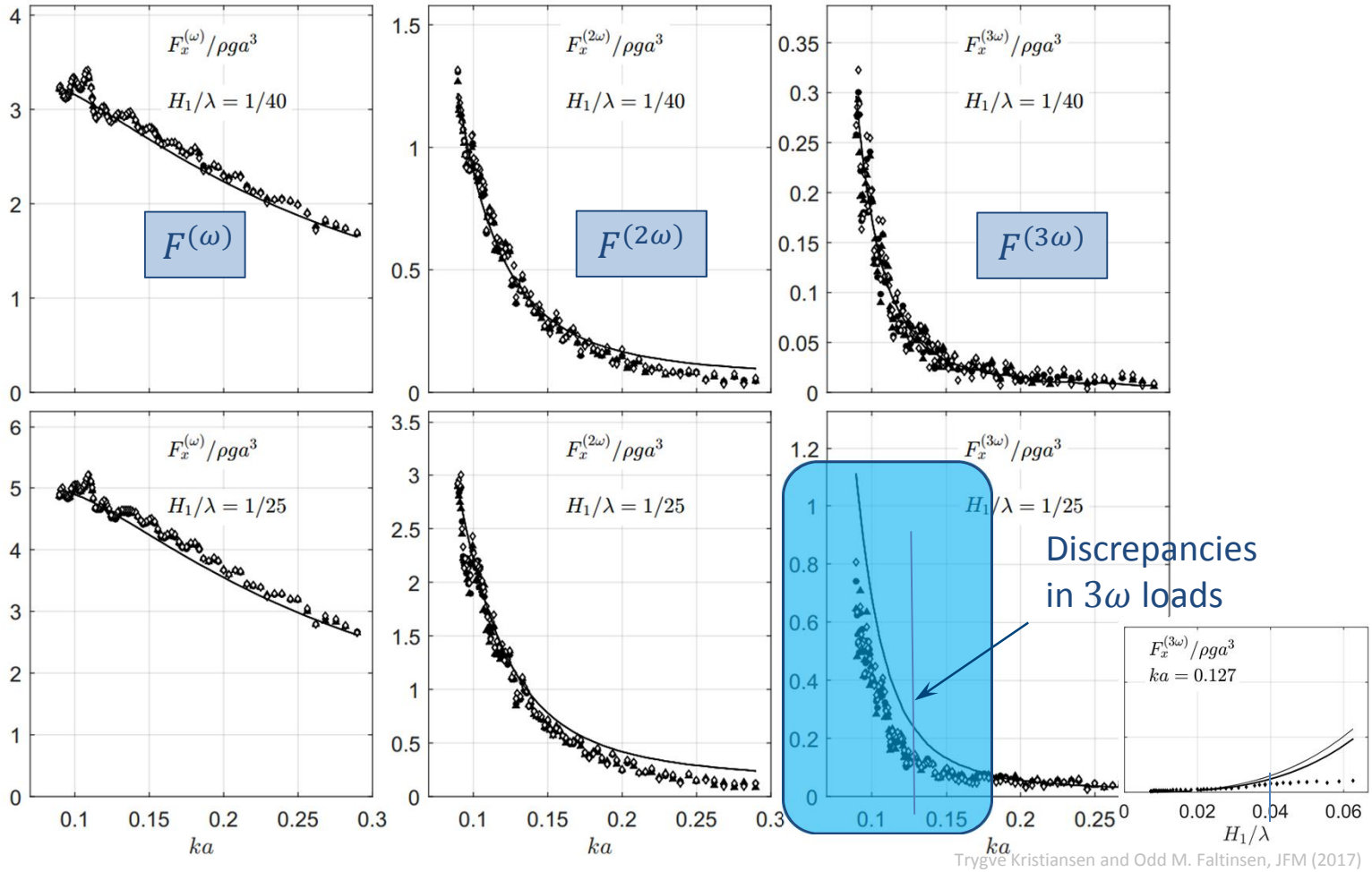
Good agreement in main trends

Trygve Kristiansen and Odd M. Faltinsen, JFM (2017)

Load harmonics

$$\frac{H_1}{\lambda} = \frac{1}{40}$$

$$\frac{H_1}{\lambda} = \frac{1}{25}$$



Trygve Kristiansen and Odd M. Faltinsen, JFM (2017)

FNV theory (Faltinsen, Newman and Vinje, JFM 1995)

Based on potential flow assumption

Froude-Kriloff | Diffraction

Sectional force: $$F'(z,t) = \rho\pi a^2 \left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z}\right) + a_{11}\left(\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z}\right)$$

(Similar to inertia term in Morison's equation)

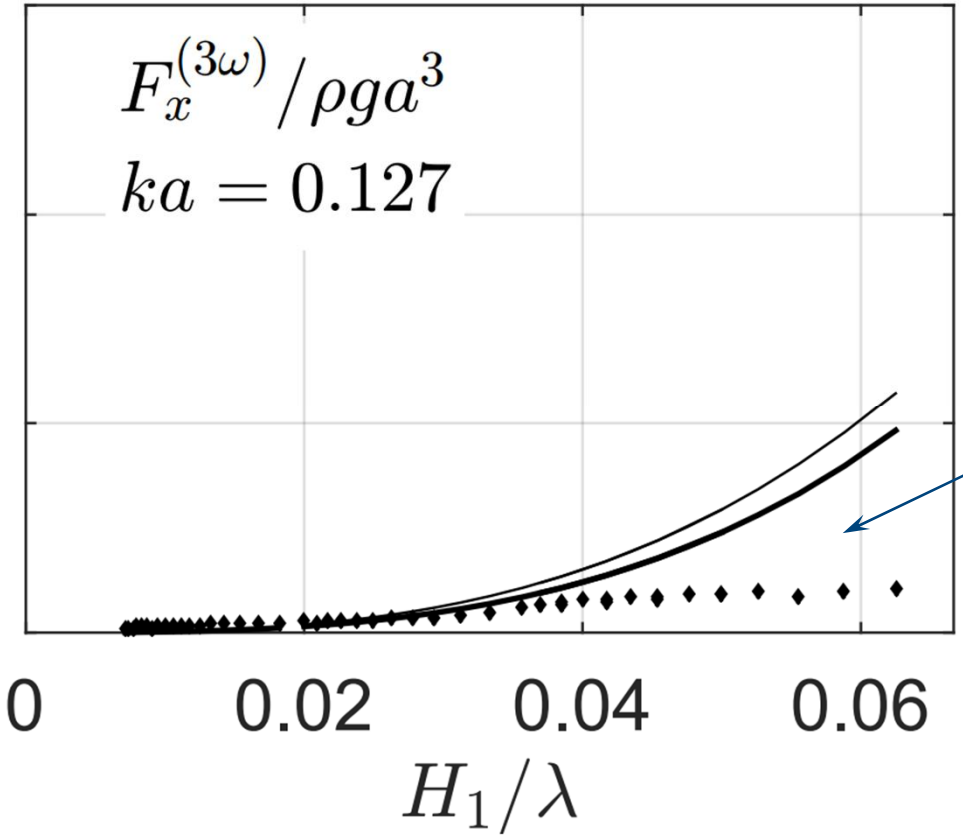
Incident free surface

Total force: $$F_x = \int_{-h}^{\zeta_I} F'(z,t)\,\mathrm{d}z + F^{\Psi}$$

Point force at $z = 0$: $$F^{\Psi} = \rho\pi a^2 u^2 \frac{\partial u}{\partial t}$$

Extension to finite water depth:
use finite water depth wave kinematics

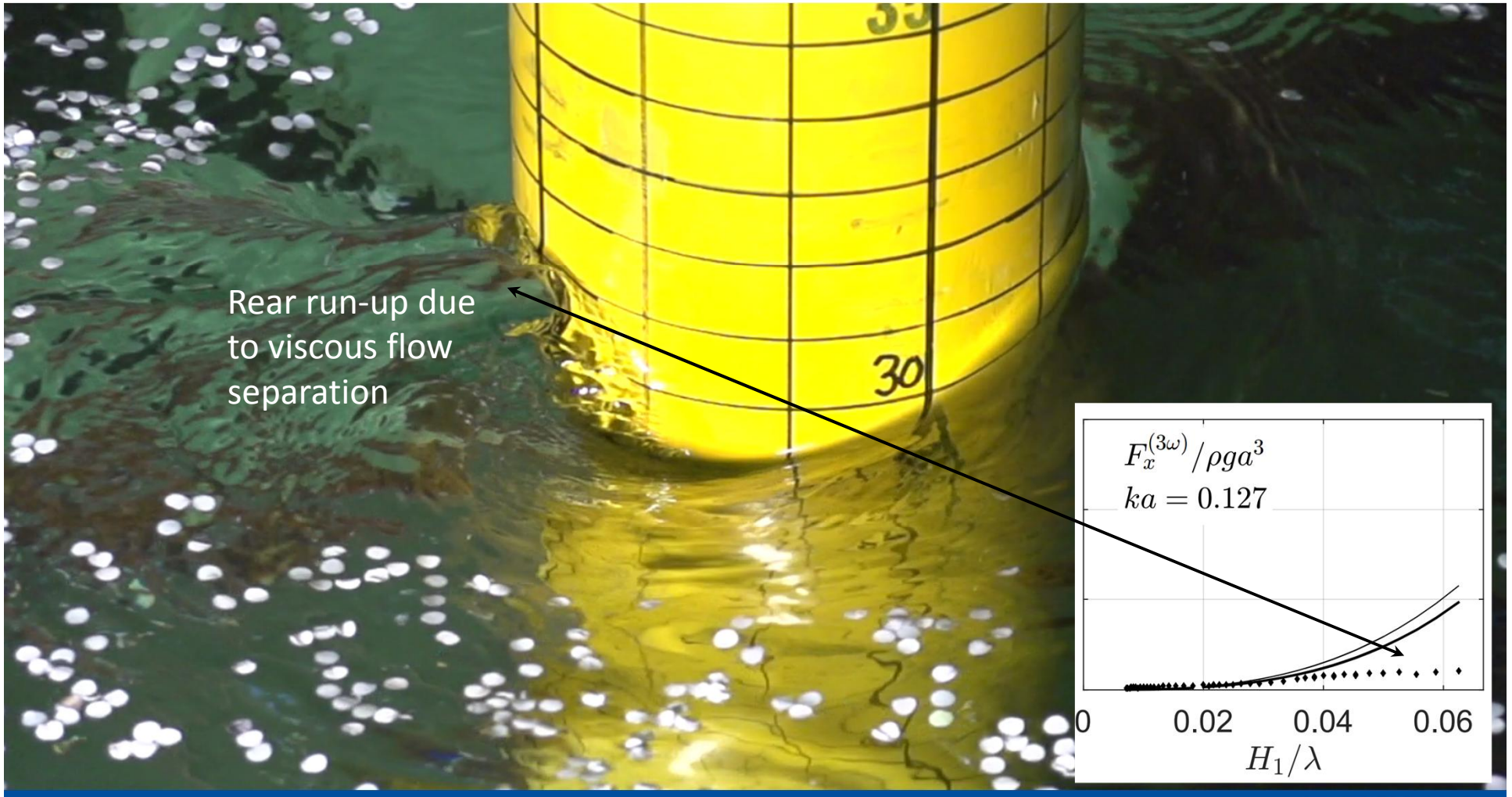
Half the 3ω load in deep water
Loses importance in finite waterdepth



Adding a Morison drag term and KC-dependent C_a is not able to predict the discrepancies

What is the cause?

Movie


Rear run-up due to viscous flow separation
30
$F_x^{(3\omega)}/\rho g a^3$
$ka = 0.127$
0
0.02
0.04
0.06
H_1/λ

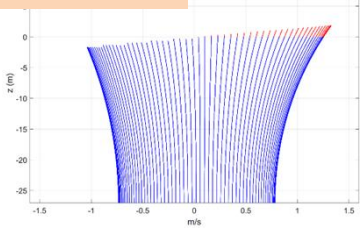
Rear run-up

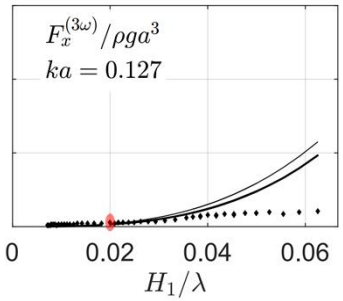
Measure of flow excursions

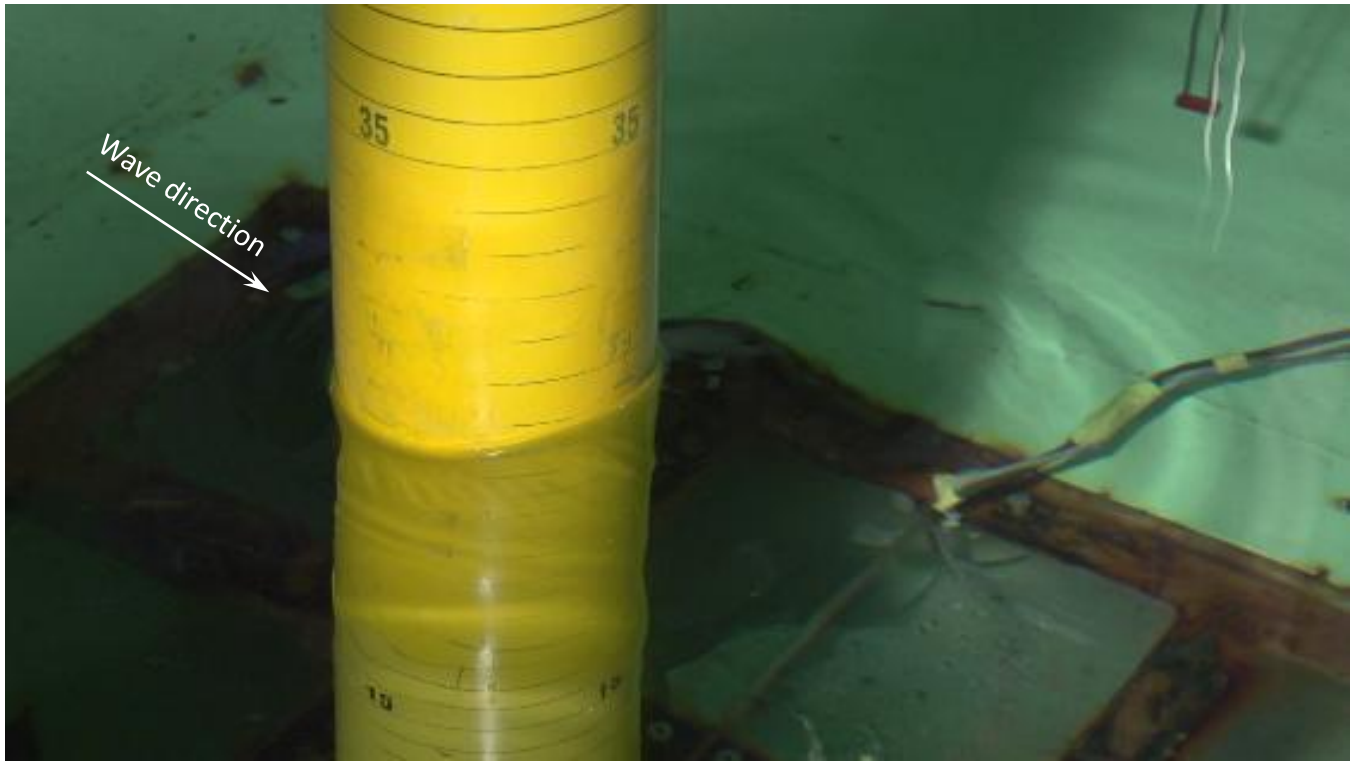
$\mathrm{KC}_5 = \frac{U_{m5}T}{2a}$

$\frac{H}{\lambda} = 1/50$

$\mathrm{KC}_5 = 2.3$

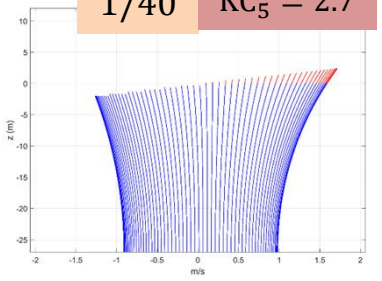


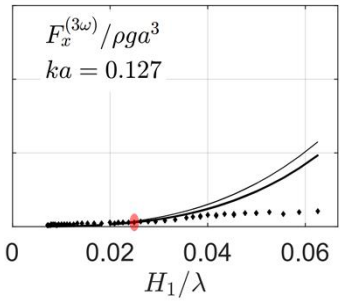


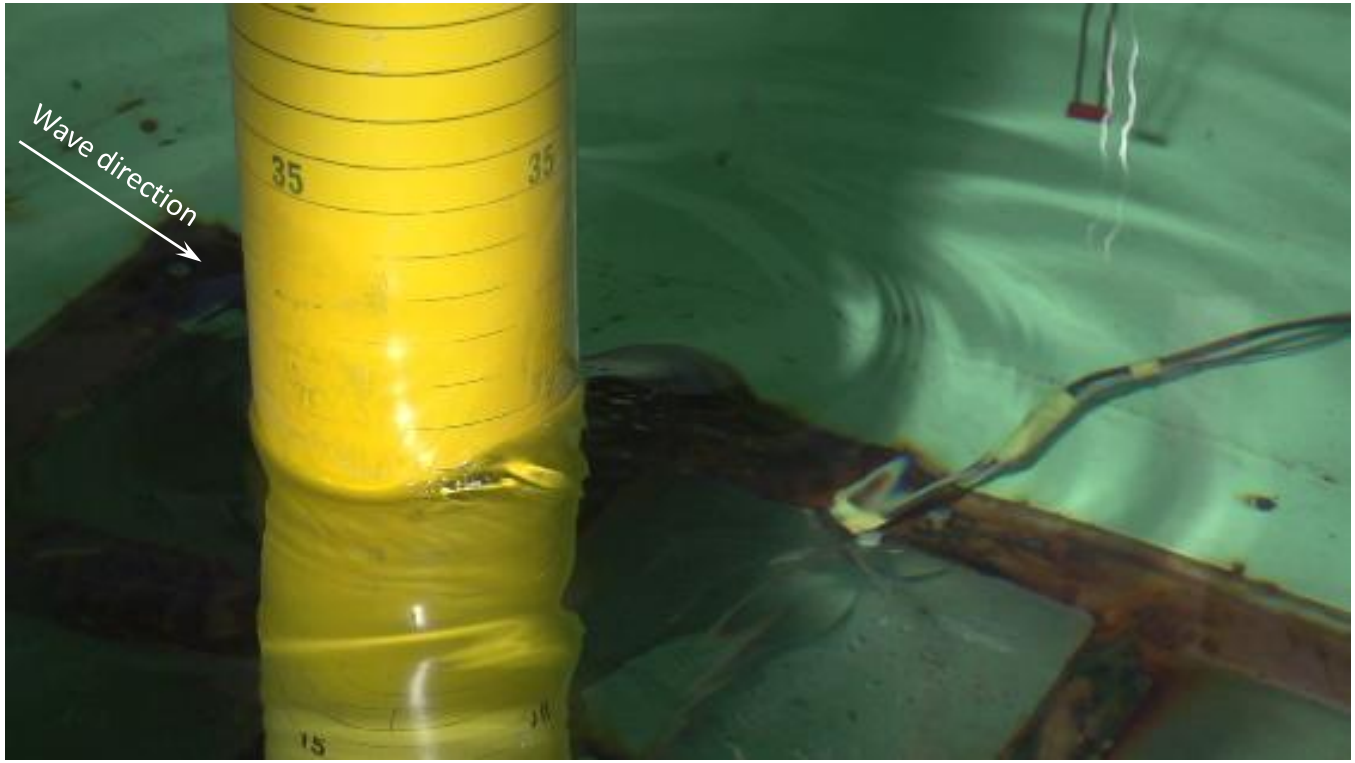


Rear run-up

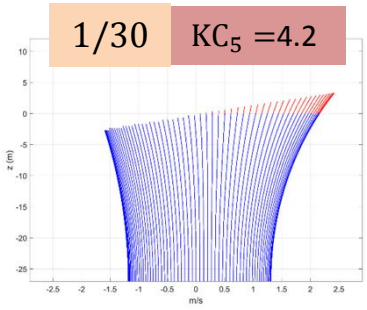
1/40 $\mathrm{KC}_5 = 2.7$

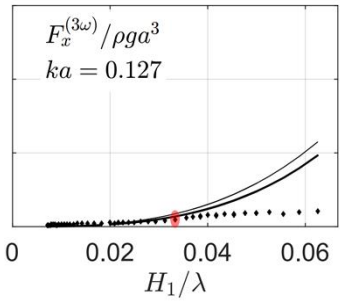


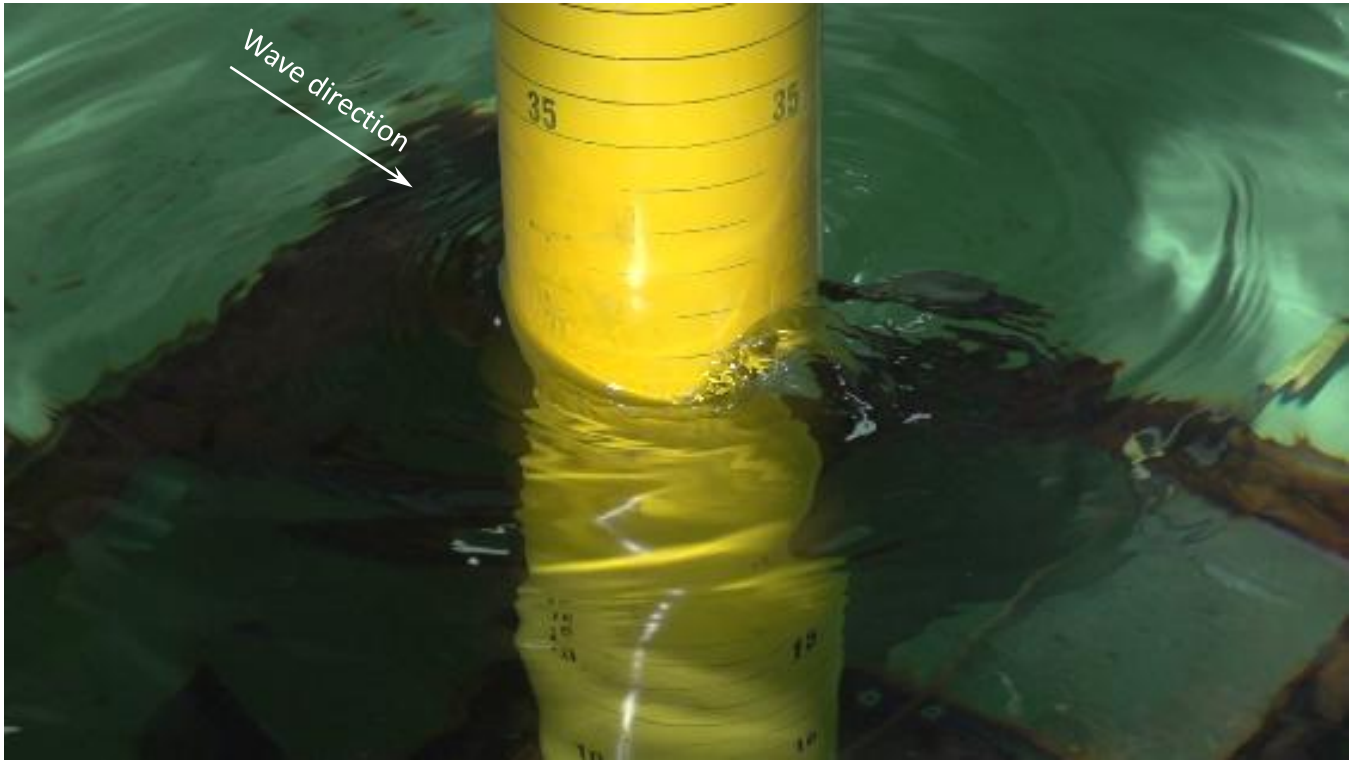




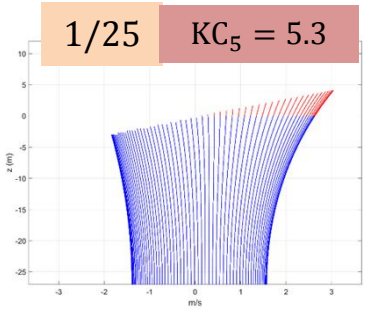
Rear run-up

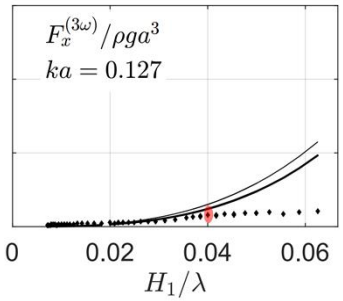

1/30
KC_5 =4.2

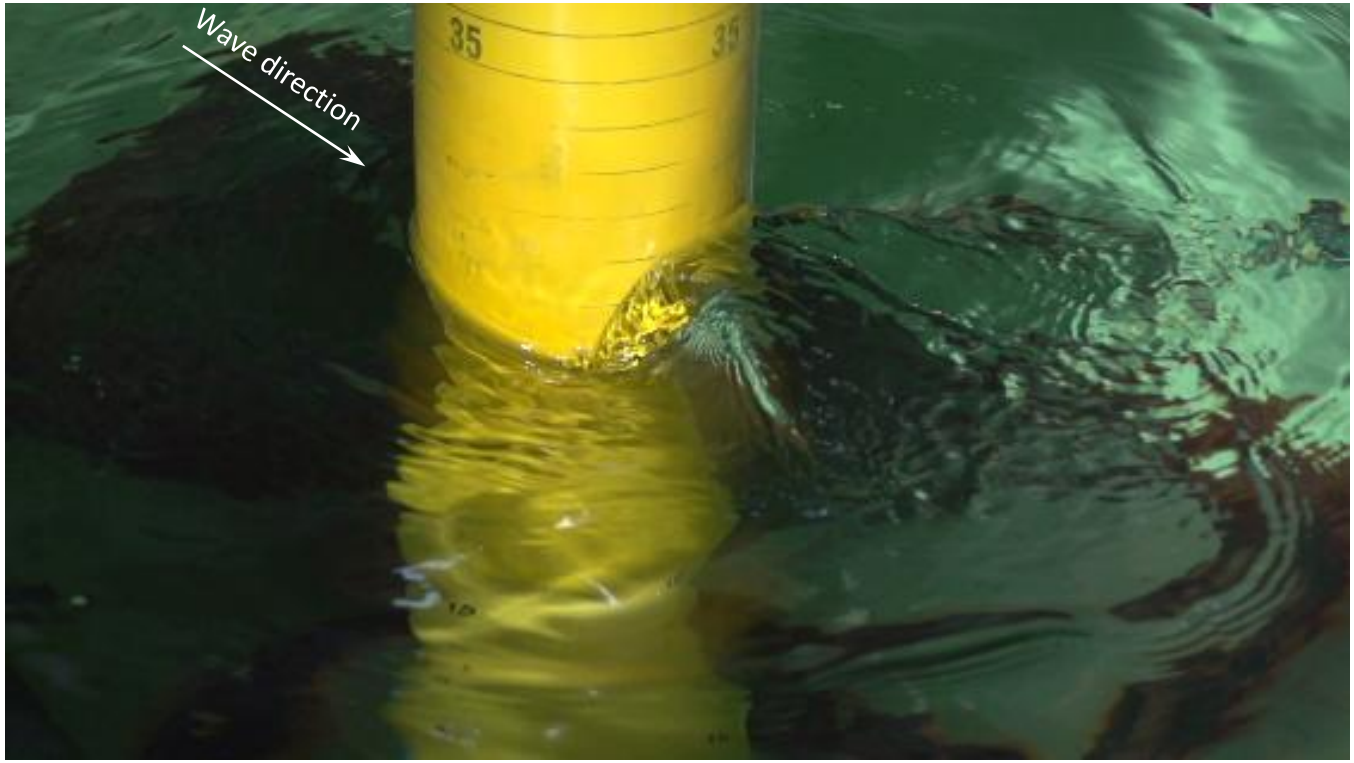

$F_x^{(3\omega)}/\rho g a^3$
$ka = 0.127$
0
0.02
0.04
0.06
H_1/λ


Wave direction

Rear run-up

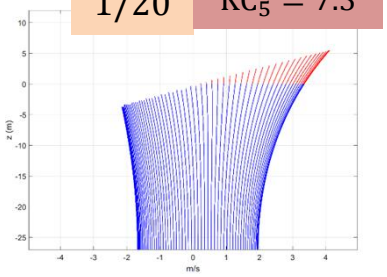

1/25
$KC_5 = 5.3$

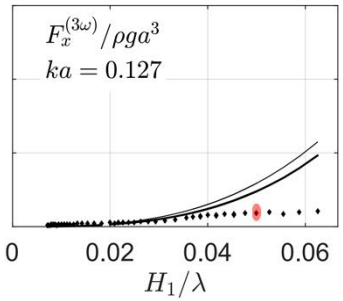

$F_x^{(3\omega)}/\rho g a^3$
$ka = 0.127$
0
0.02
0.04
0.06
H_1/λ

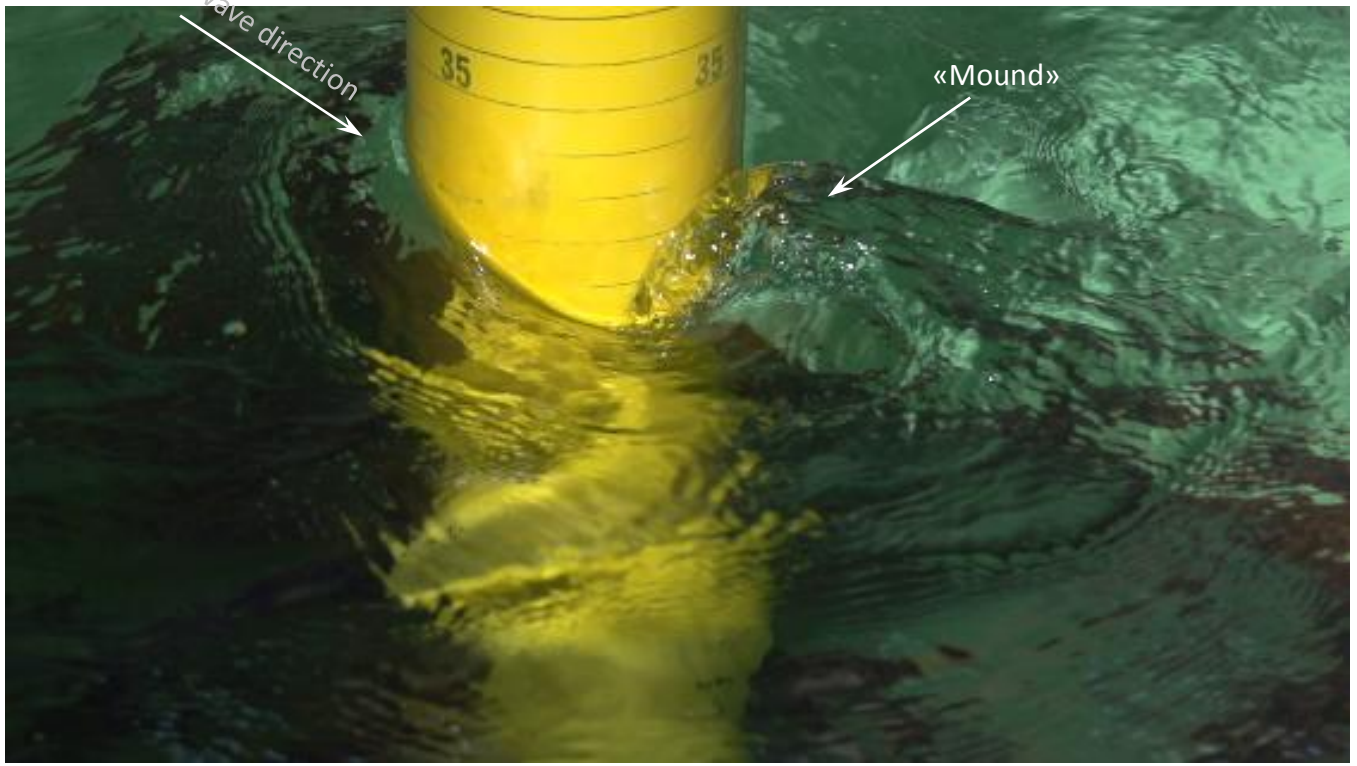

Wave direction
35
35

Rear run-up

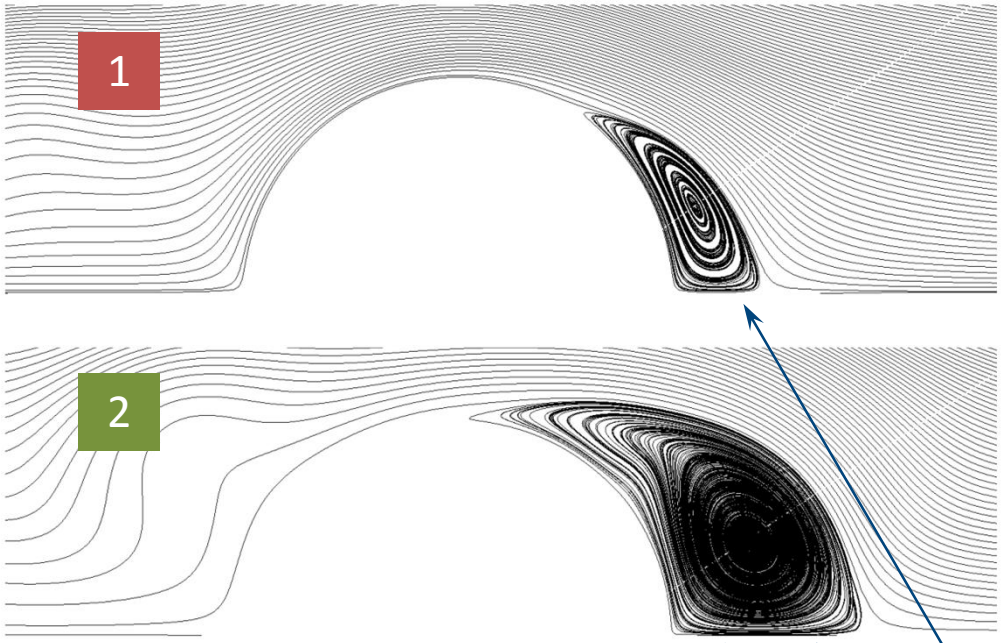
1/20 $KC_5 = 7.3$

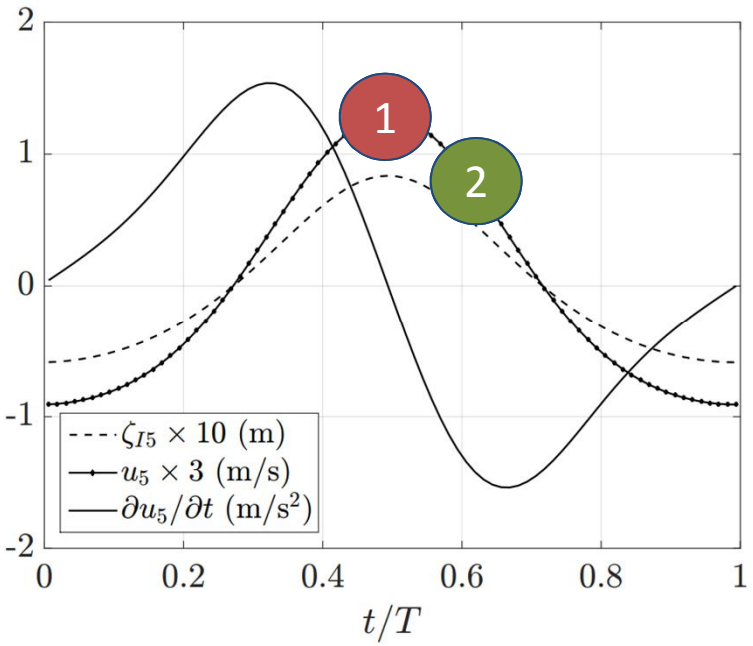






LES-simulations – Flow field examples





High-pressure zone
(different from steady flow)

Clear vortical structures

Trygve Kristiansen and Odd M. Faltinsen, JFM (2017)

Pressure from 2D CFD

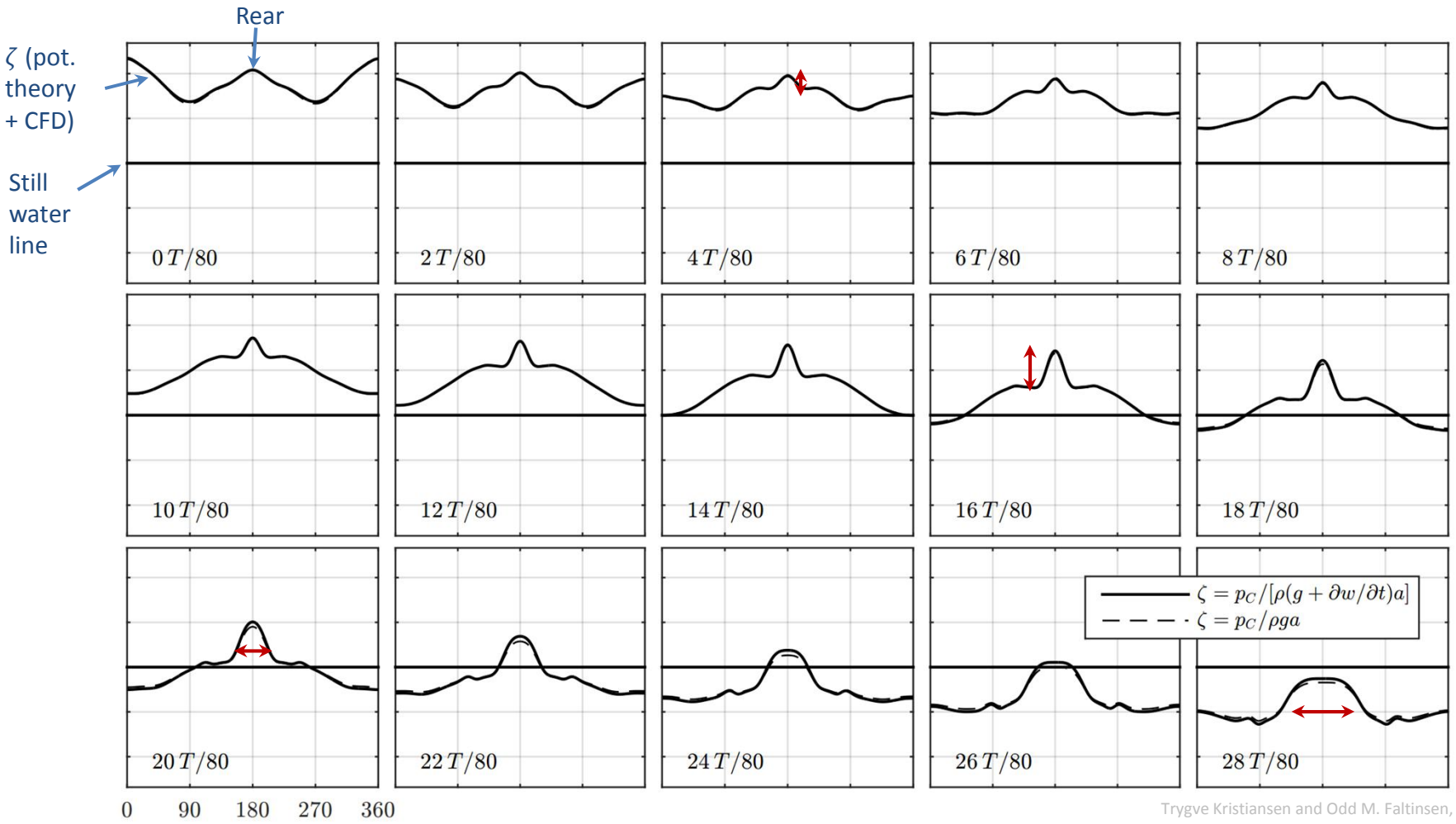
Associated free surface

$$p \simeq \rho\left(g + \frac{\partial w}{\partial t}\right)\zeta$$

Simplified model:

(linearized z-component of Navier Stokes equations, integrated vertically)

Trygve Kristiansen and Odd M. Faltinsen, JFM (2017)



Trygve Kristiansen and Odd M. Faltinsen, JFM (2017)

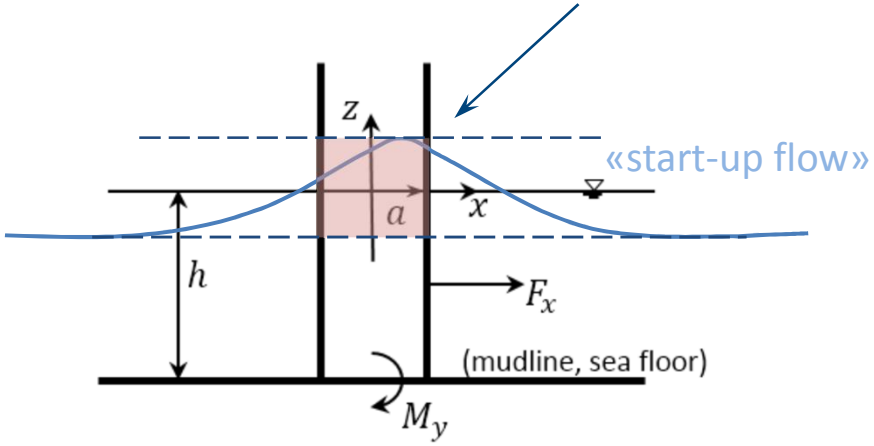
Conclusion:

Clear evidence of flow separation

This is believed be the cause of the discrepancies in the 3ω loads

Additional complexity:

In-and-out of water

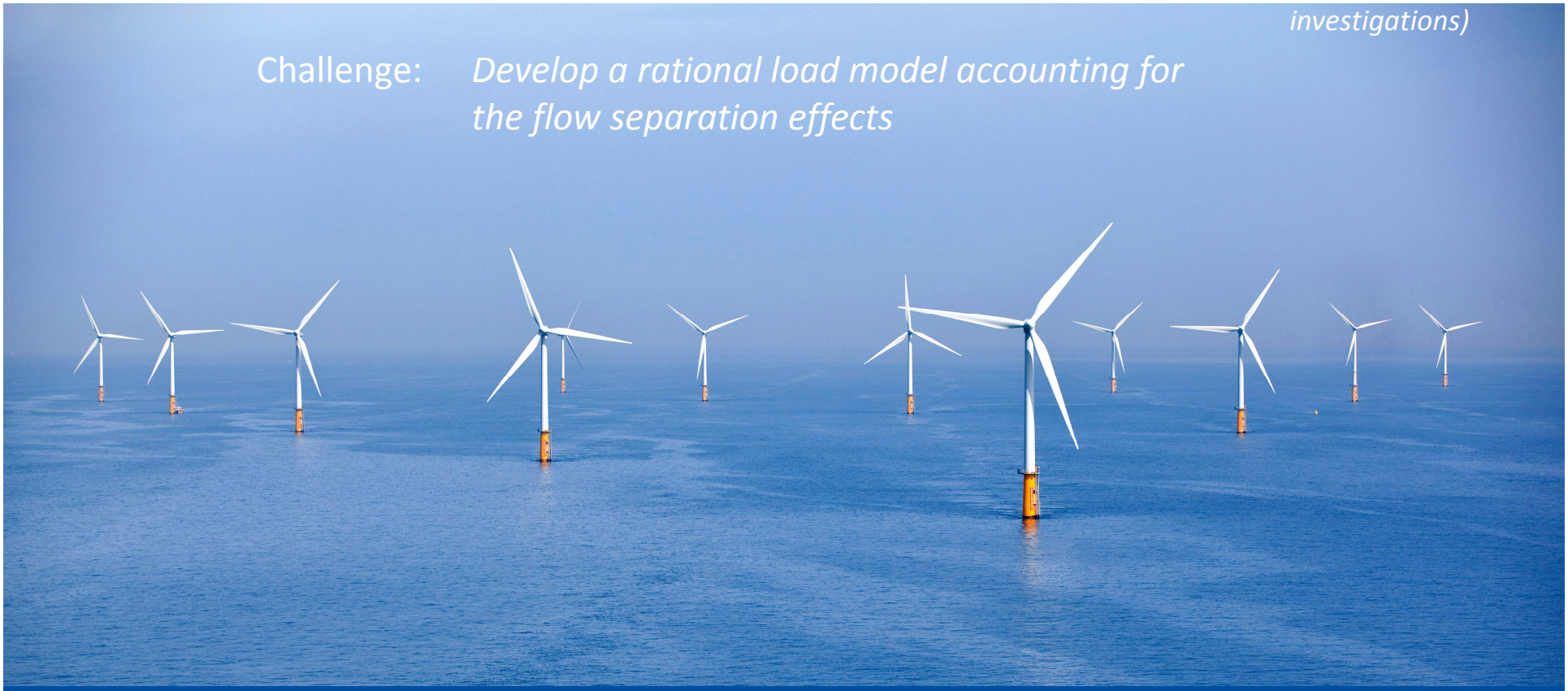


Trygve Kristiansen and Odd M. Faltinsen, JFM (2017)

Open question: Is the effect equally important in *irregular* waves?

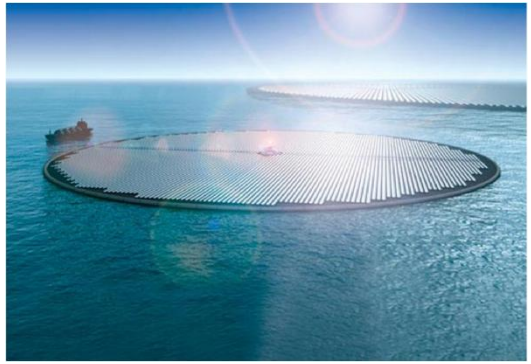
(On-going investigations)

Challenge: *Develop a rational load model accounting for the flow separation effects*



Brief summary

Towards a rational ringing load model



Floating C-based fuel factories at sea

Powered by floating solar islands

The solution for a carbon-neutral future?

Thank you!

AMOS days 2017
Trondheim, Norway, 09.11.2017

Trygve Kristiansen[1]

[1] Dept. of Marine Technology and NTNU AMOS,
Norwegian University of Science and Technology, NTNU