# Results of the experimental campaigns

Florian Hulin

DIMPACT project, France Énergies Marines

A. Tassin, Ifremer

J.F. Filipot, France Énergies Marines

N. Jacques, ENSTA Bretagne

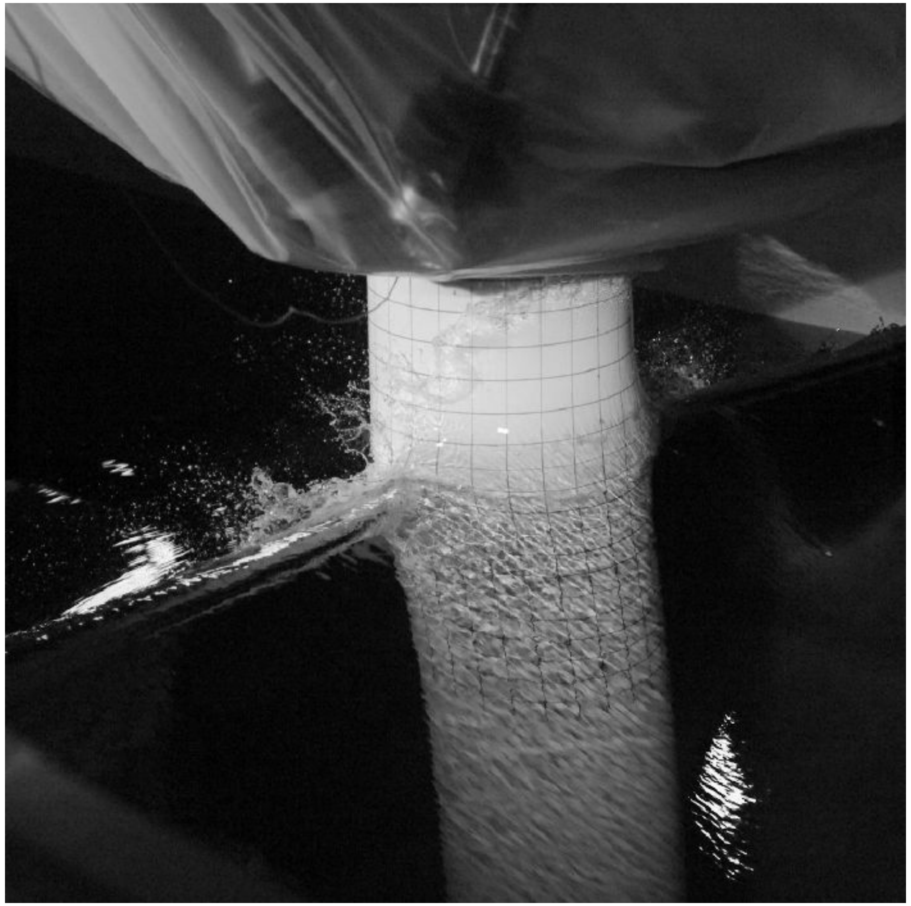


FRANCE ENERGIES MARINES ENSTA BRETAGNE Ifremer

# Outline of the presentation

- Context and objectives
- Experimental setup
- Breaking waves
- A novel methodology to compensate for the force oscillations induced by the vibrations of the mockup
- Experimental results

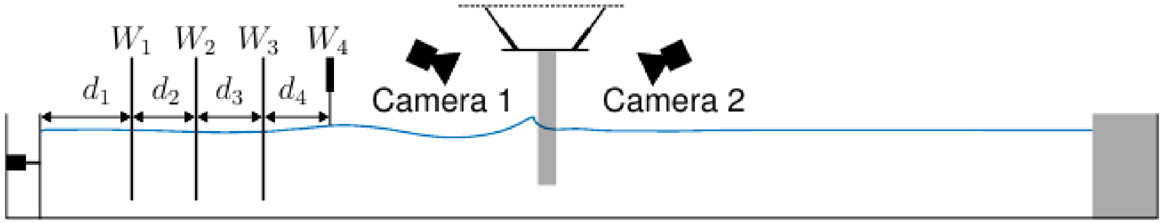
# Objectives of the experimental campaigns

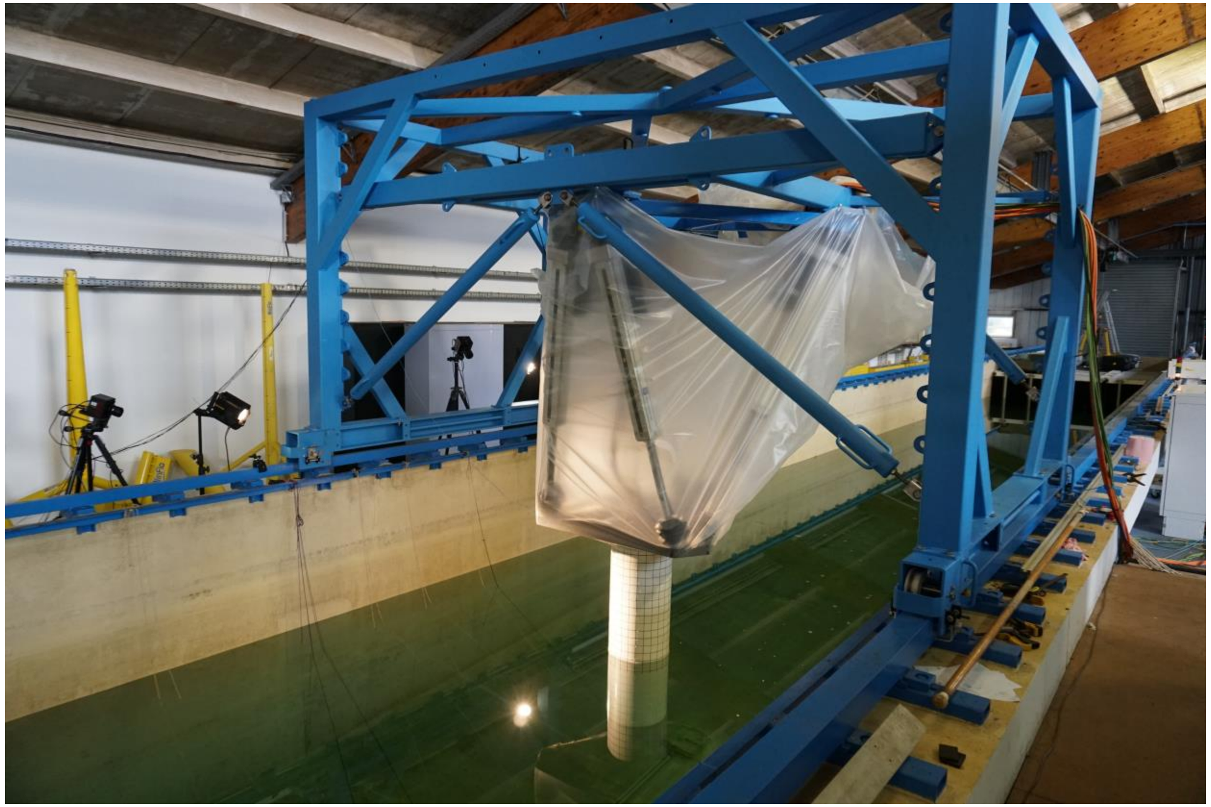


- Objectives:
  - Study the influence of several parameters on the impact load (breaking location, pitch angle, mockup velocity, breaking severity)
  - Validate probabilistic, semi-analytical and numerical impact models

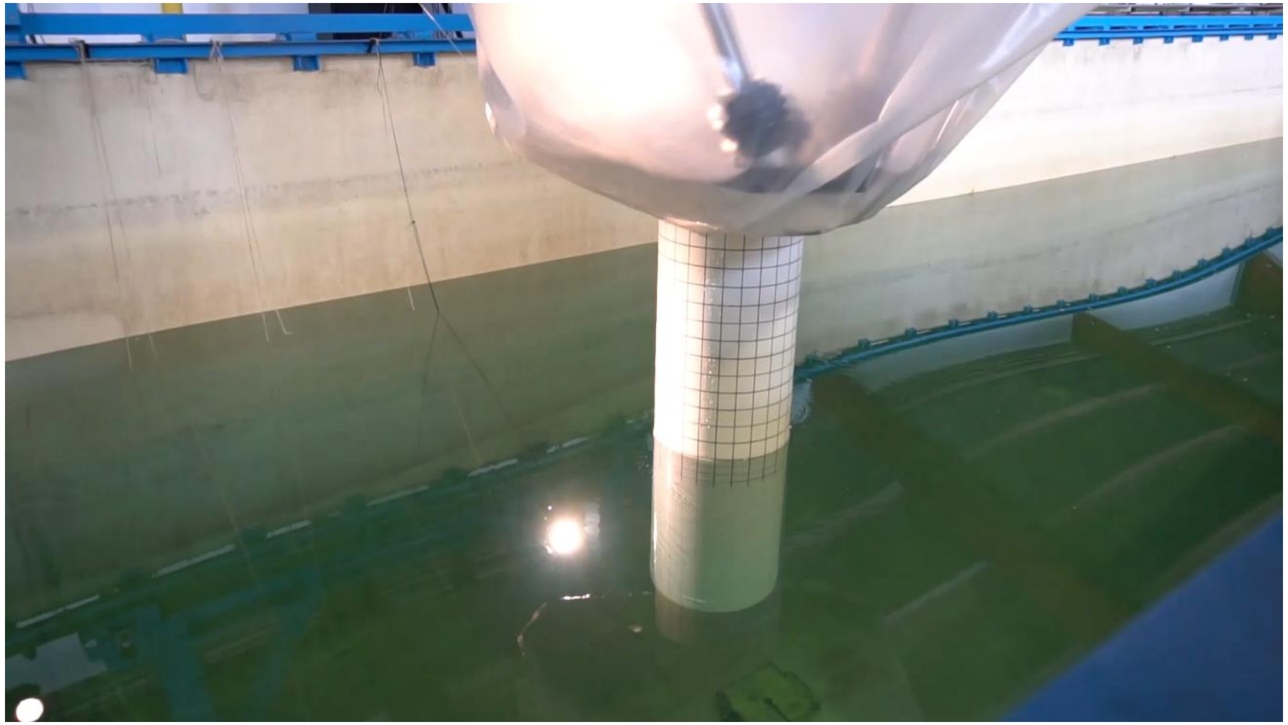
# Experimental setup

# Experimental setup

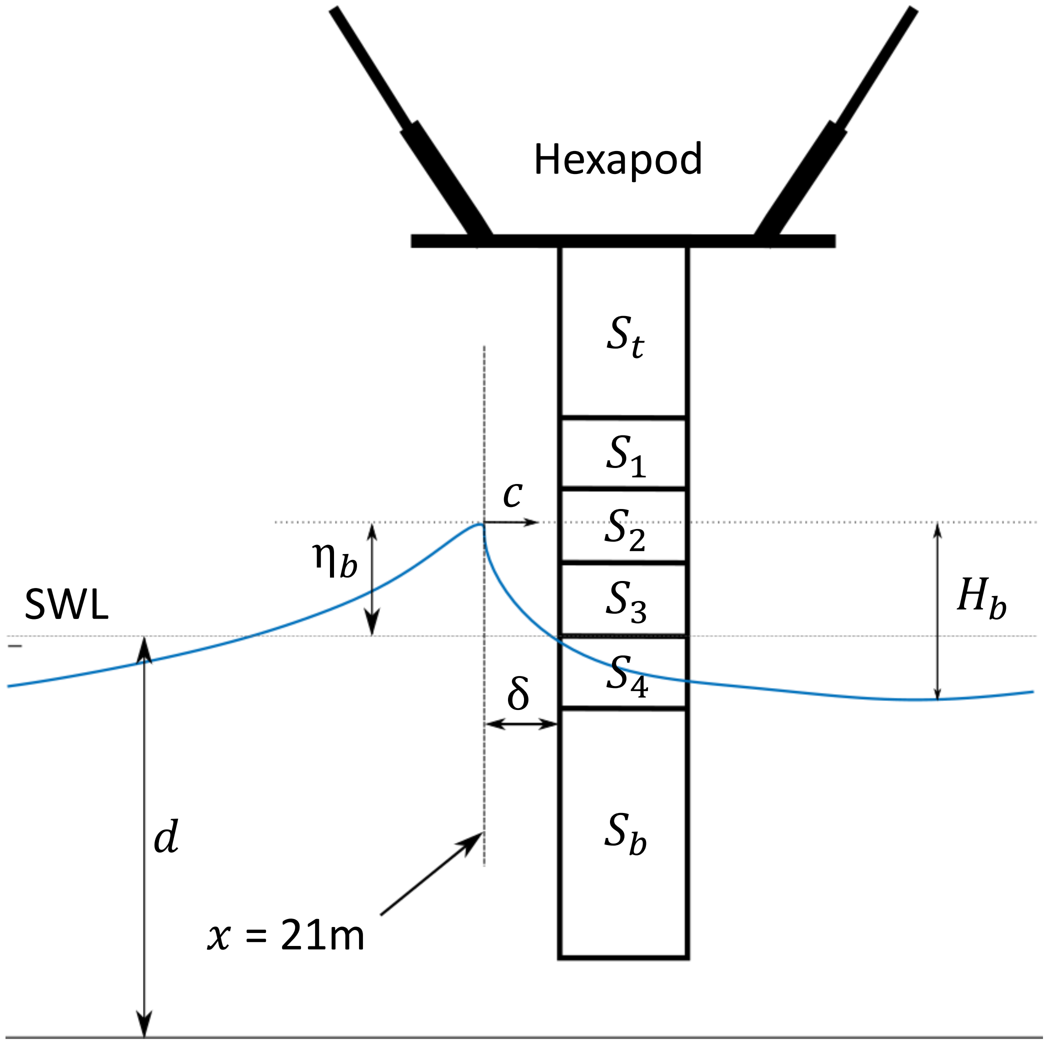


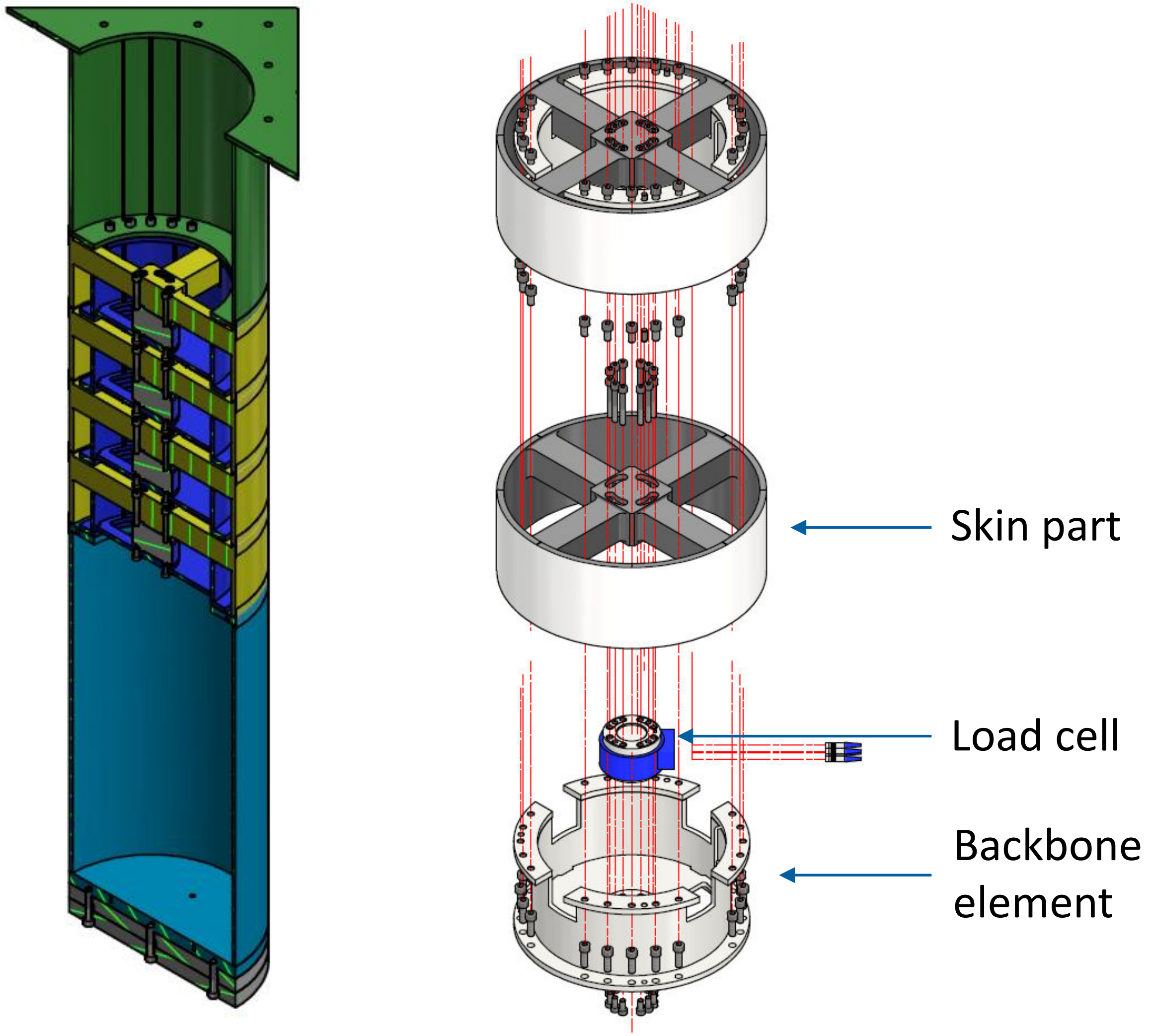



- 6 degrees of freedom hexapod
- The speed and position of the mockup are precisely known
- 1/25 scale



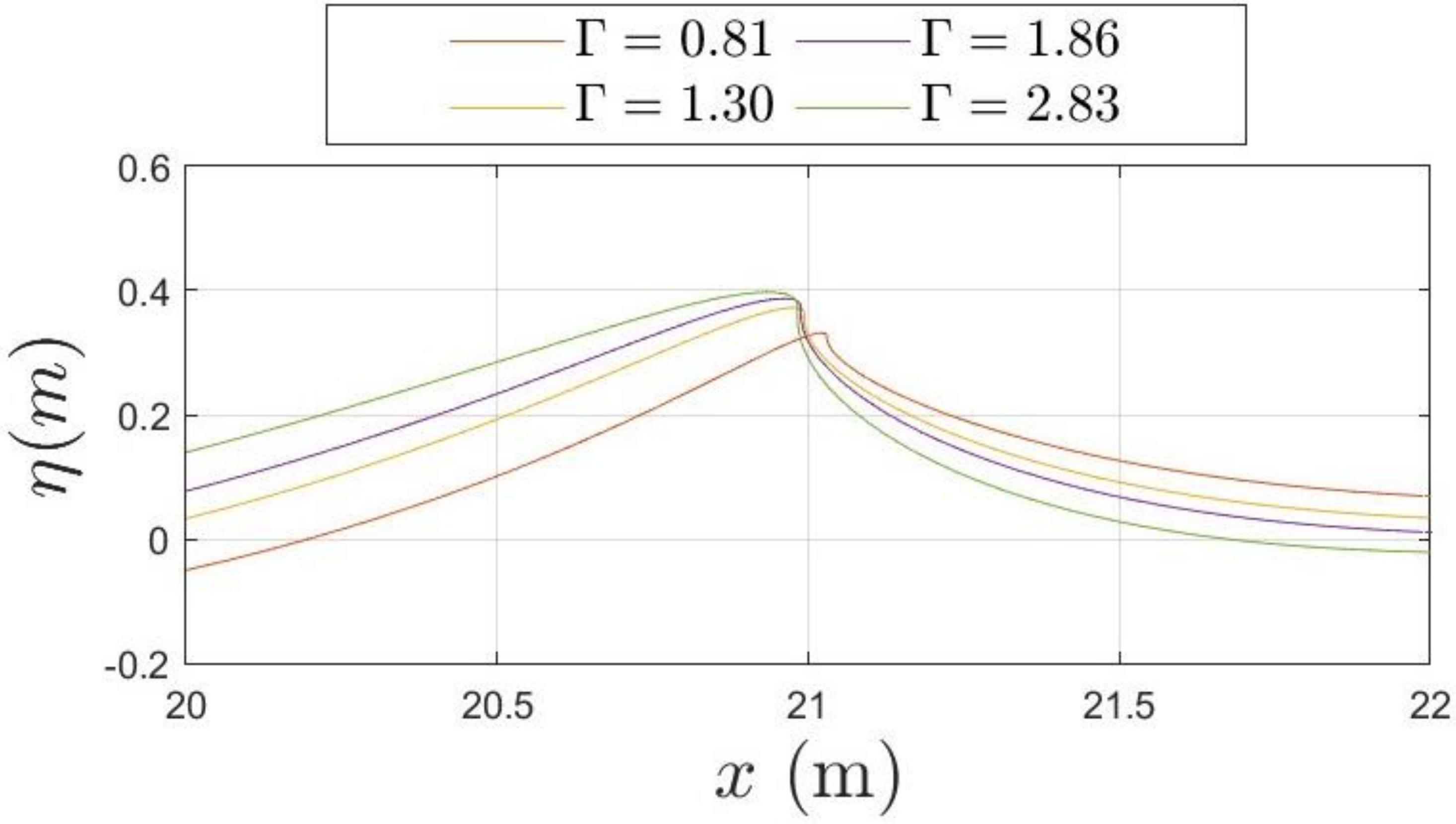
# Details of the mockup



# Investigated breaking wave cases

# Generation and characterization of the breaking waves




Fully non-linear wave profiles

- Breaking waves are generated through focalization
- Modelling of the waves using a numerical wave tank
- Characterization of the breaking intensity (Derakhti, 2018):

$$\Gamma = T_b \frac{dB}{dt}\bigg|_{B=0,85}, B = \frac{u}{c}$$

# Breaking wave cases

| Wave N. | $T_p$ (s) | $H_s$ (m) | γ | Γ |
|---|---|---|---|---|
| 1 | 2.25 | 0.12 | 3.3 | 0.97 |
| 2 | 2.25 | 0.13 | 3.3 | 0.81 |
| 23 | 2.25 | 0.135 | 3.3 | 1.30 |
| 24 | 2.25 | 0.14 | 3.3 | 1.86 |
| 3 | 2.25 | 0.15 | 3.3 | 2.83 |
| 4 | 2.25 | 0.17 | 3.3 | 2.04 |
| 5 | 2.25 | 0.20 | 3.3 | 3.62 |
| 7 | 2.49 | 0.13 | 1.4 | 1.90 |
| 8 | 2.49 | 0.14 | 1.4 | 1.12 |
| 9 | 2.49 | 0.15 | 1.4 | 2.21 |
| 10 | 2.49 | 0.16 | 1.4 | 2.85 |
| 12 | 2.49 | 0.18 | 1.4 | 3.69 |
| 15 | 2 | 0.10 | 3.3 | 1.74 |

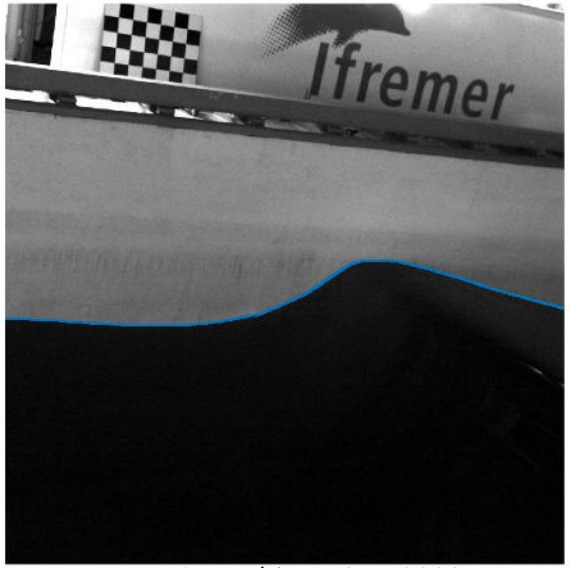
Focused wave (row 1)

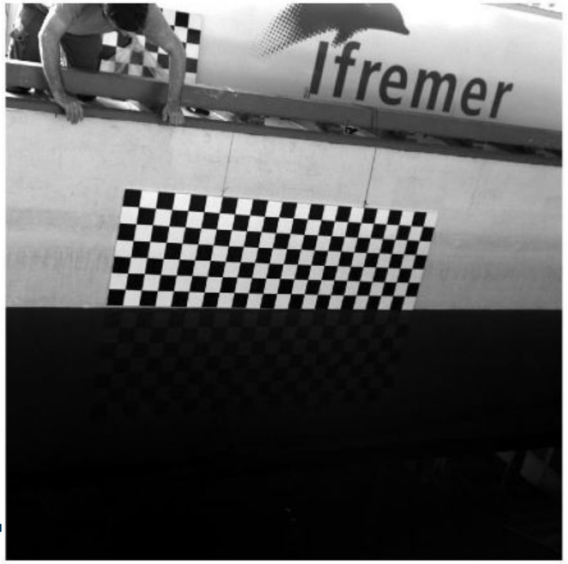
1 wave before (rows 2, 23, 24, 3)

2 waves before (rows 4, 5)

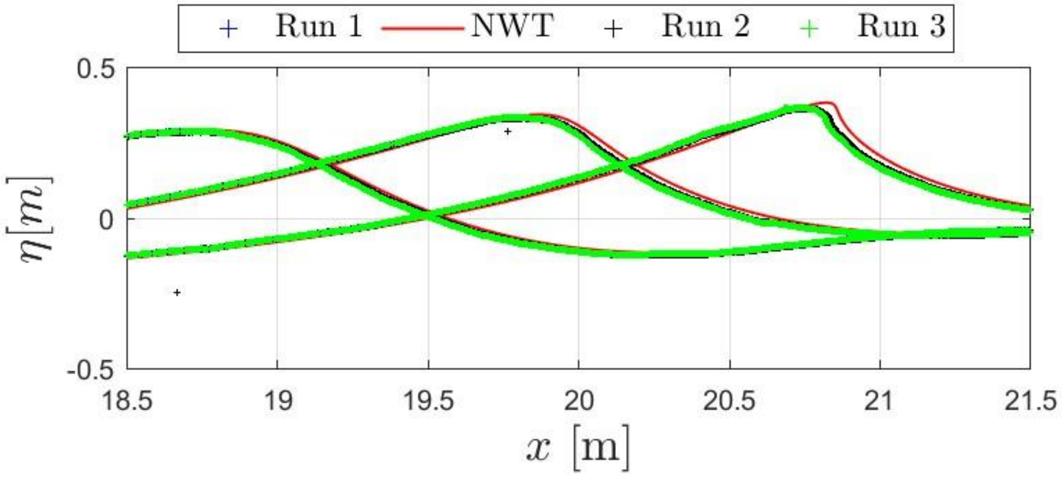
# Free surface profile measurement of the breaking waves

- Each breaking wave is filmed using a high speed video camera
- The interface is detected with a contour algorithm
- A checkerboard allows to obtain the profile coordinates in the basin frame of reference



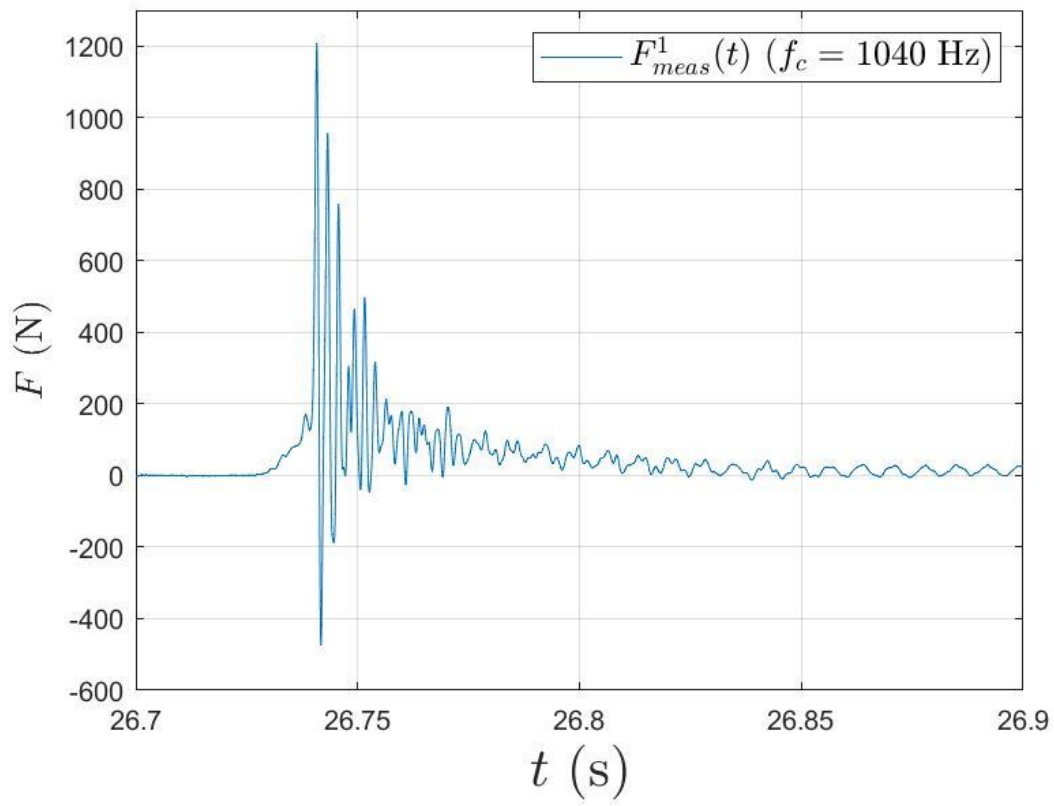

- Good accordance with the profiles obtained using the numerical wave tank



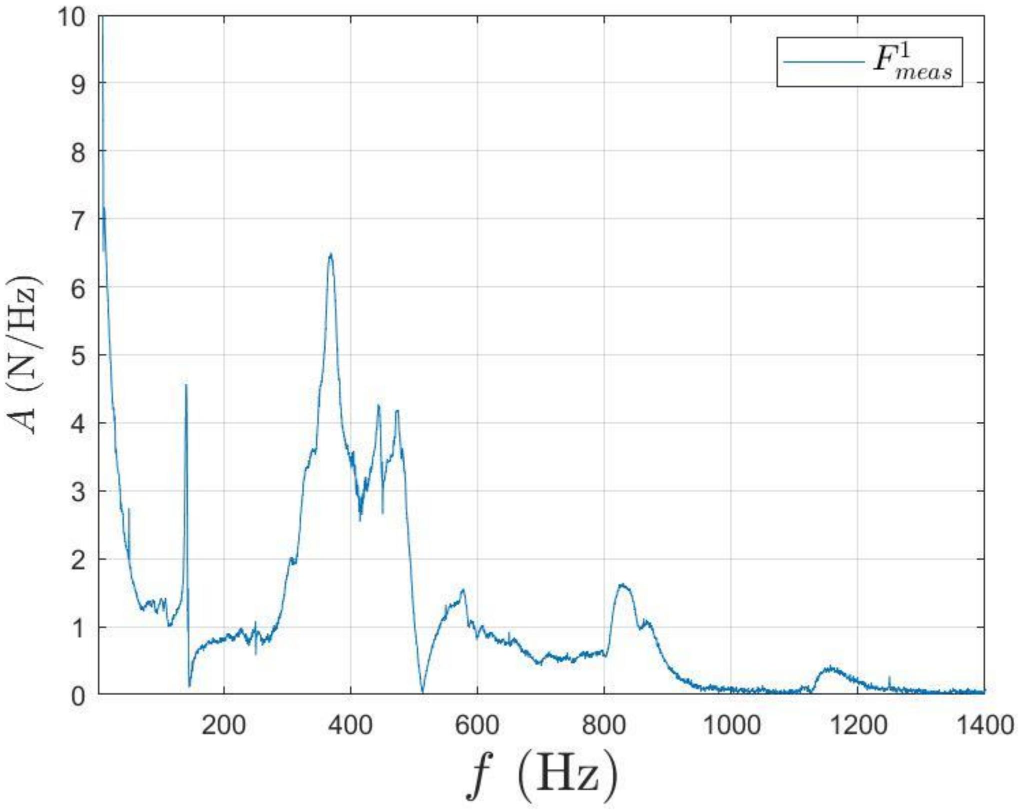
## Compensation of the oscillations in the force signal

# Oscillatory behavior of the signal

- Impact of wave 3 (upper section)

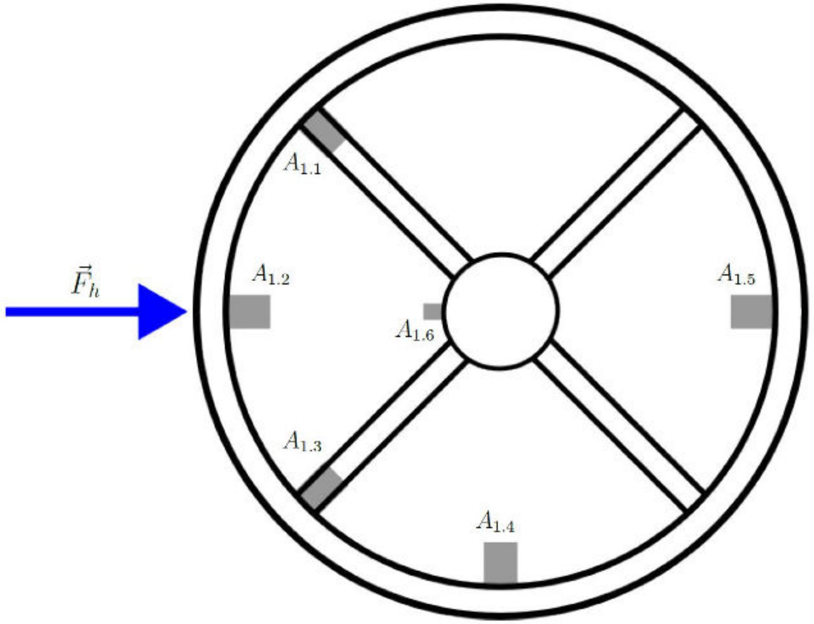



- Excitation of different modes of the mockup
- Complicates the interpretation of the results

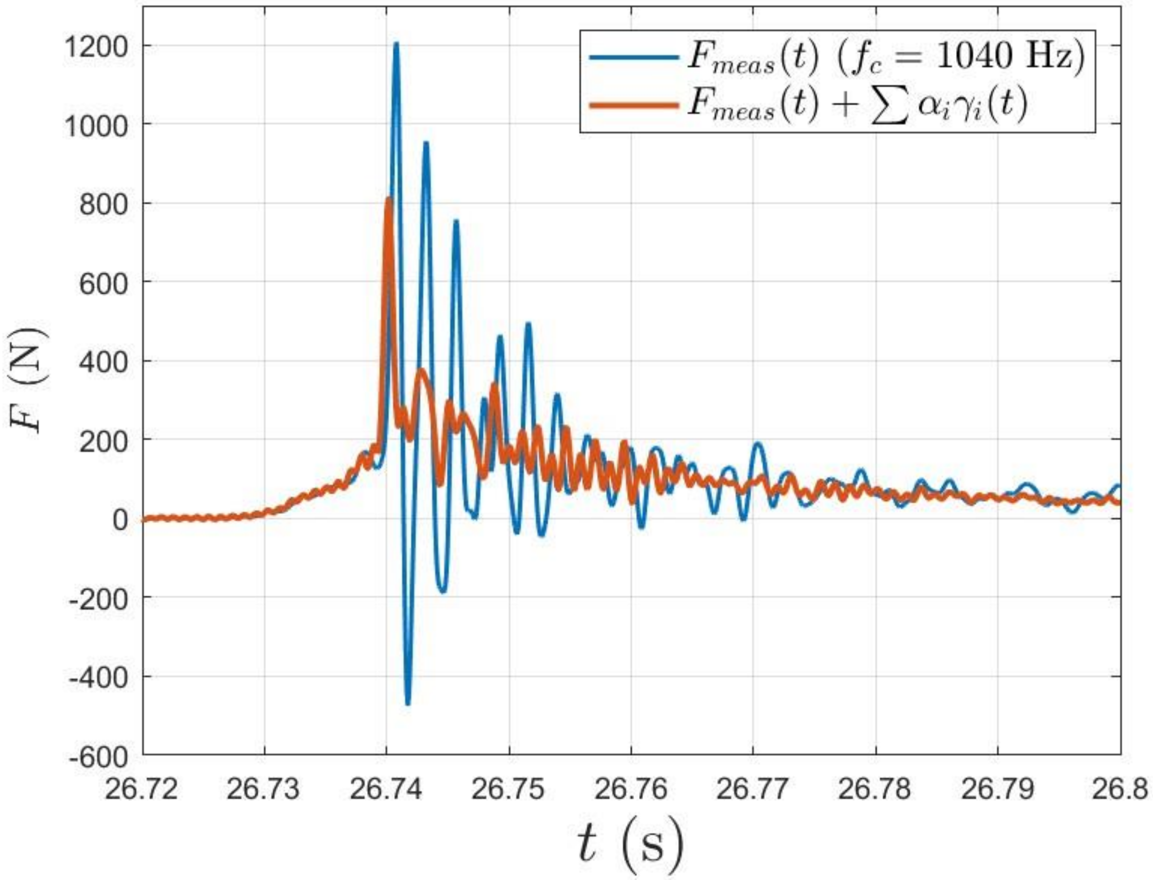


# Compensation of the oscillatory part of the force signal

- 6 accelerometers are attached to the 2 upper sections
- Identification of the coefficients is done after the hammer test

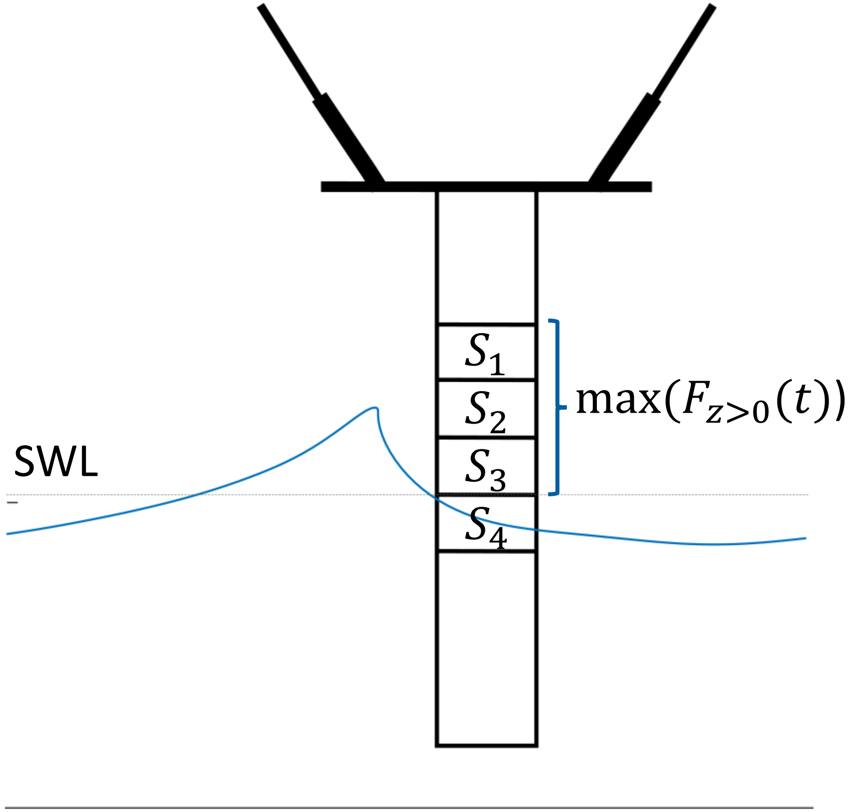






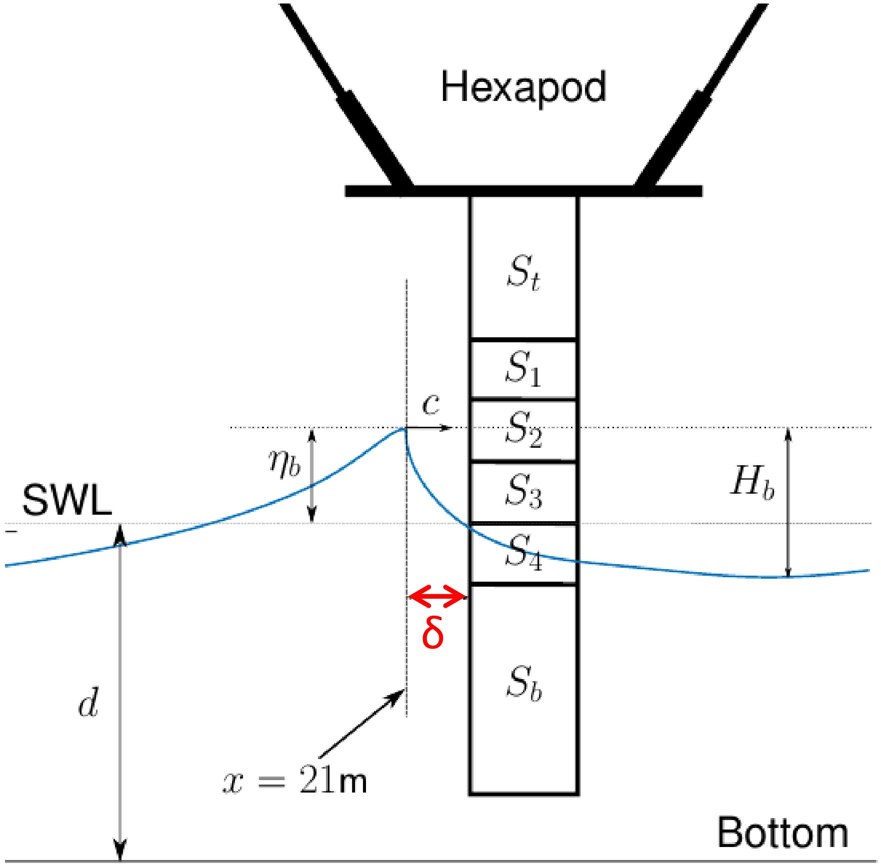
## Experimental results:

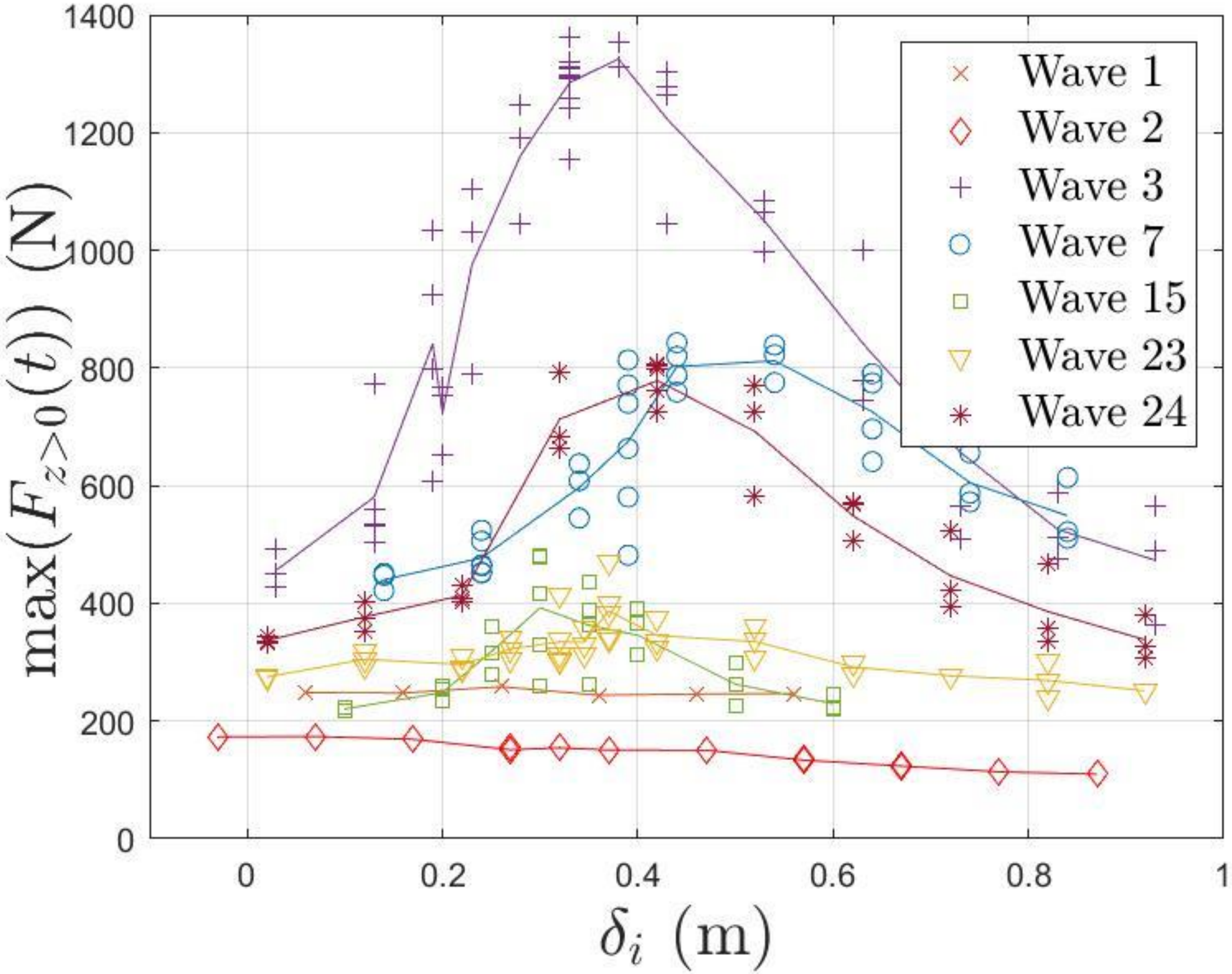
- Position with respect to breaking
- Breaking intensity
- Inclination
- Horizontal velocity



# Influence of the distance between the breaking location and the cylinder

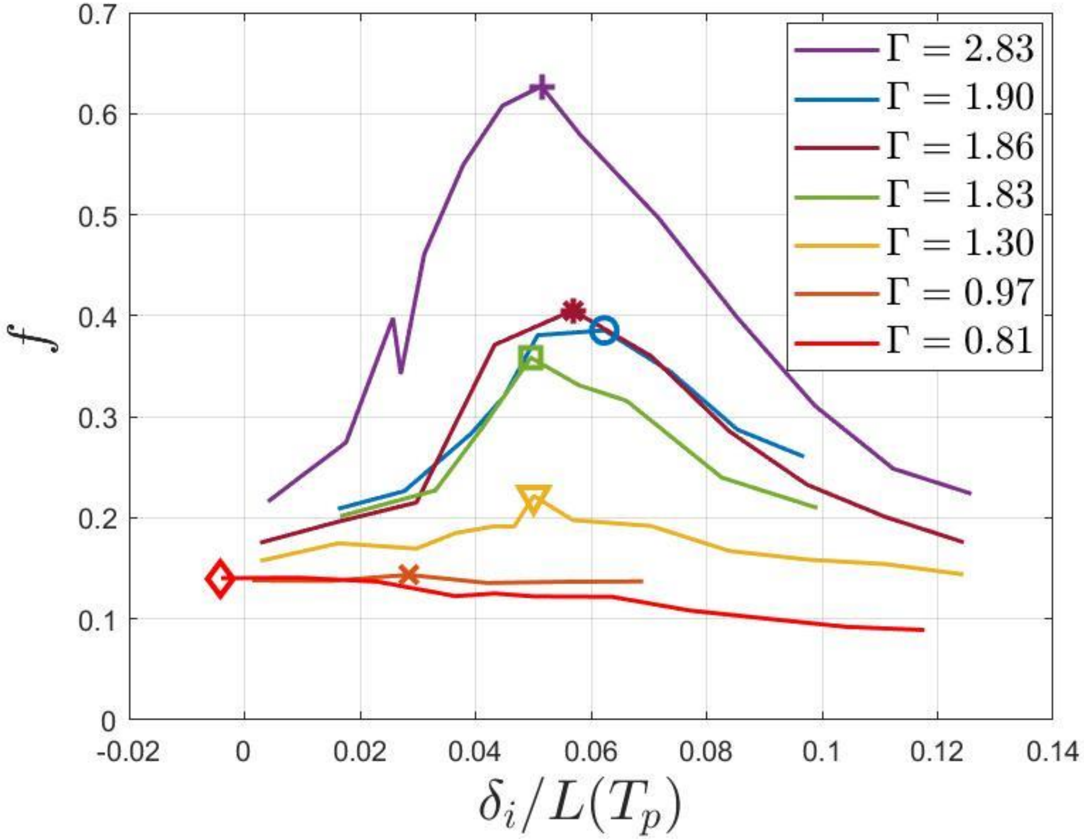
- High dependence of the slamming force to δ



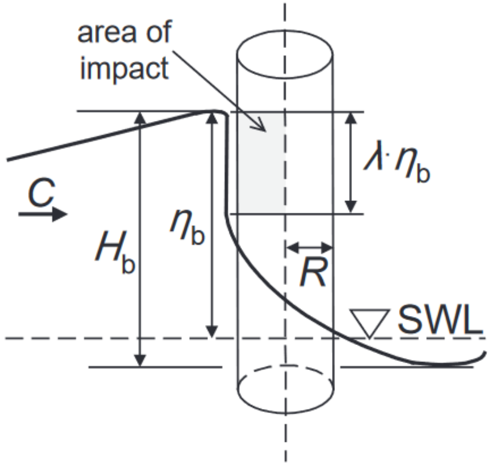



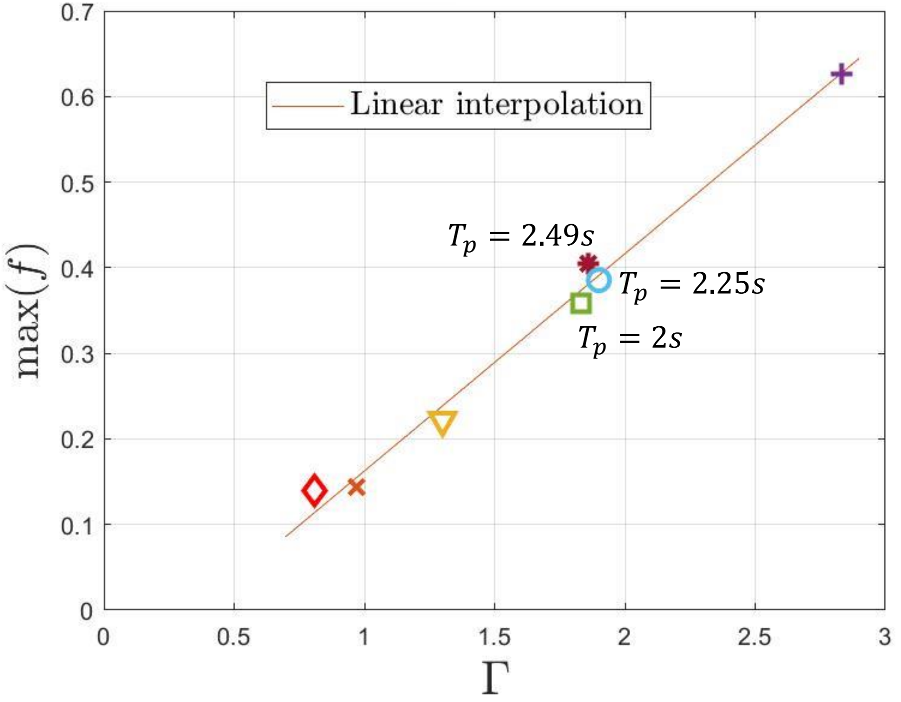
# Evolution of the impact force with $\Gamma$

- Influence of $\delta$ is studied on 7 different waves with different breaking intensities



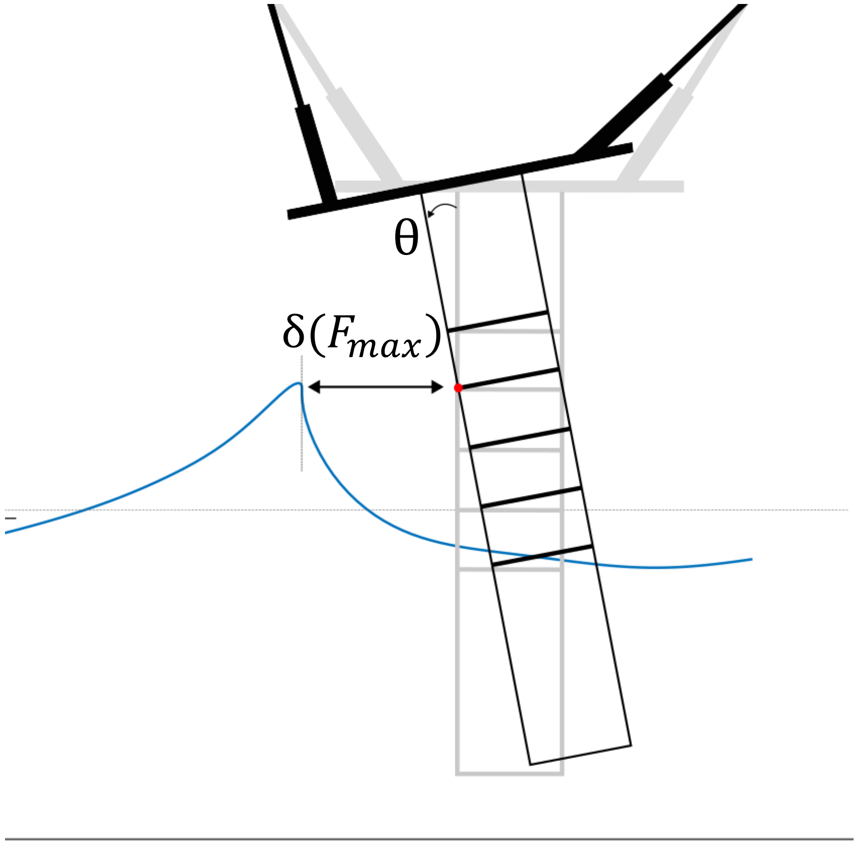

$$f = \frac{F}{\eta_b \pi \rho R C^2} = \lambda$$

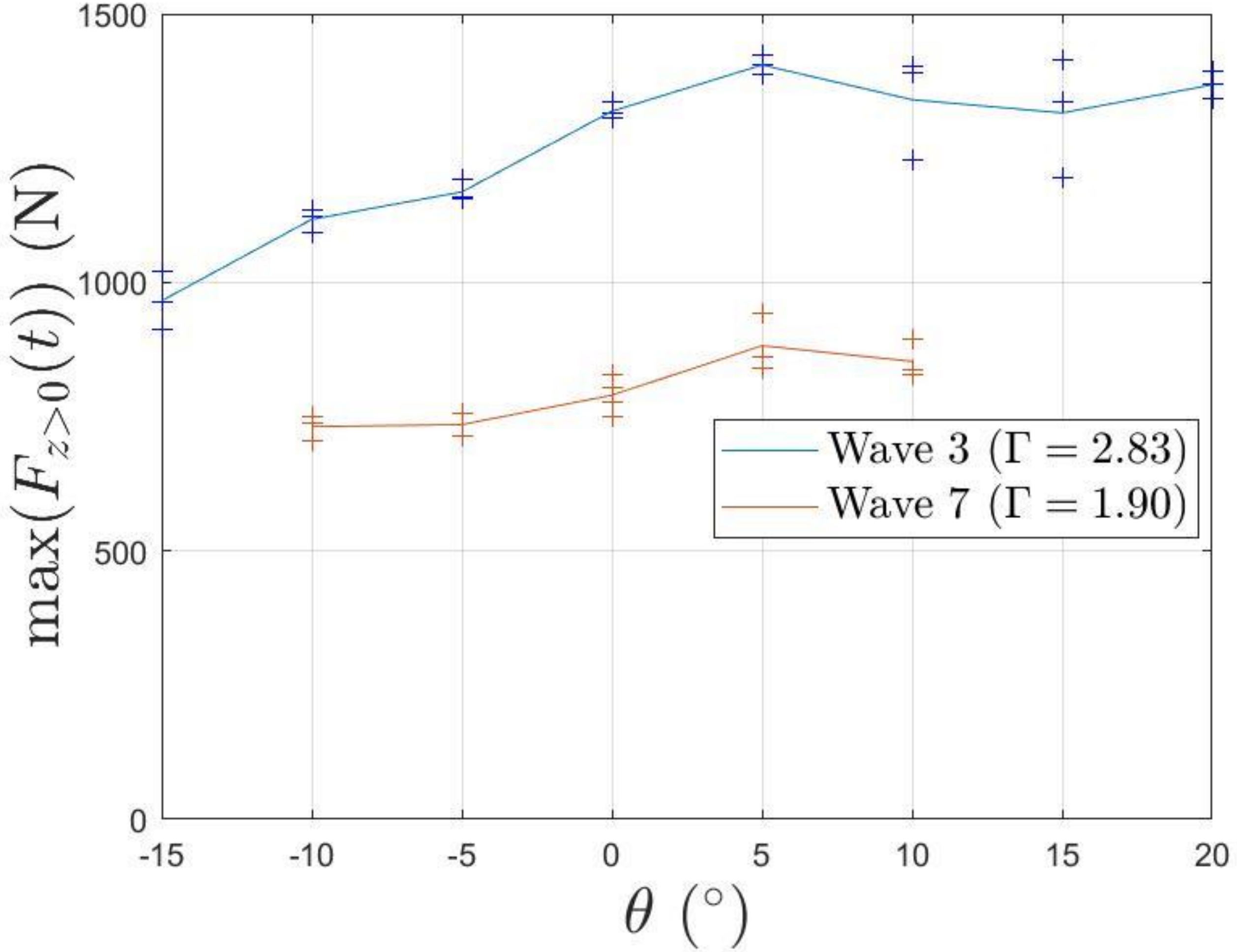


# Influence of the pitch angle

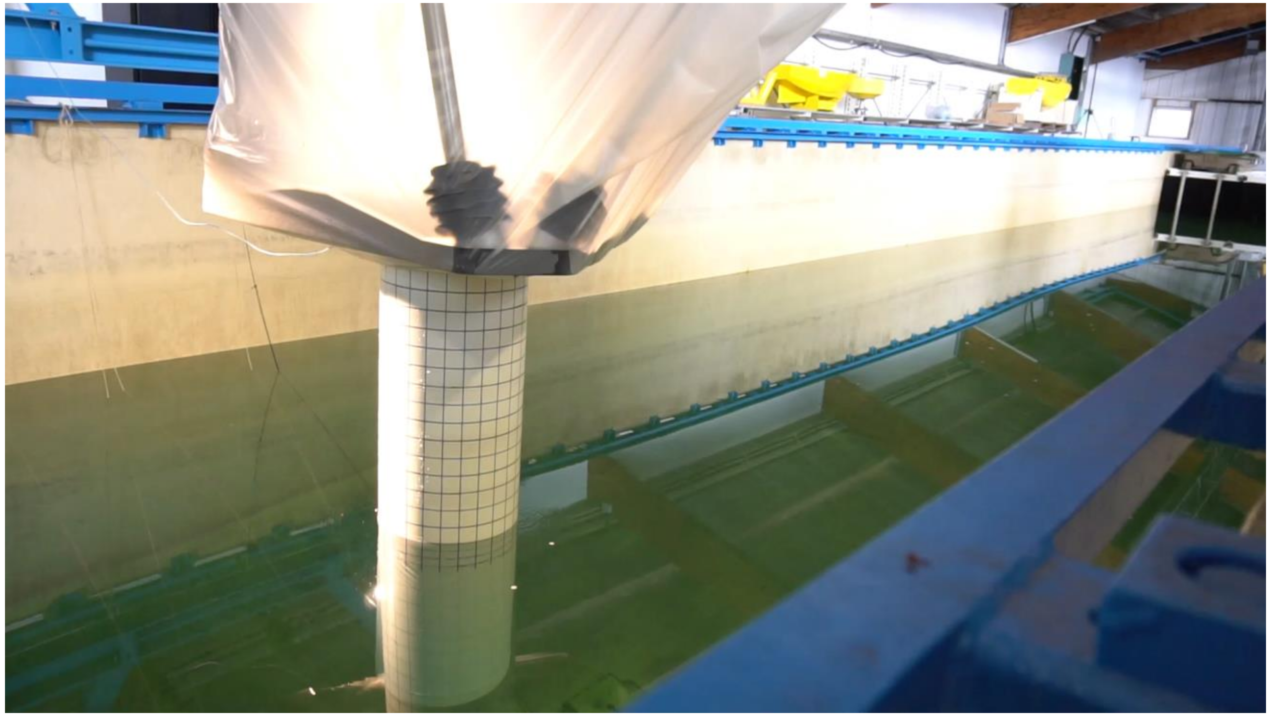
- Wave 3, $T_p = 2{,}25\text{s}$, $\Gamma = 2{,}83$

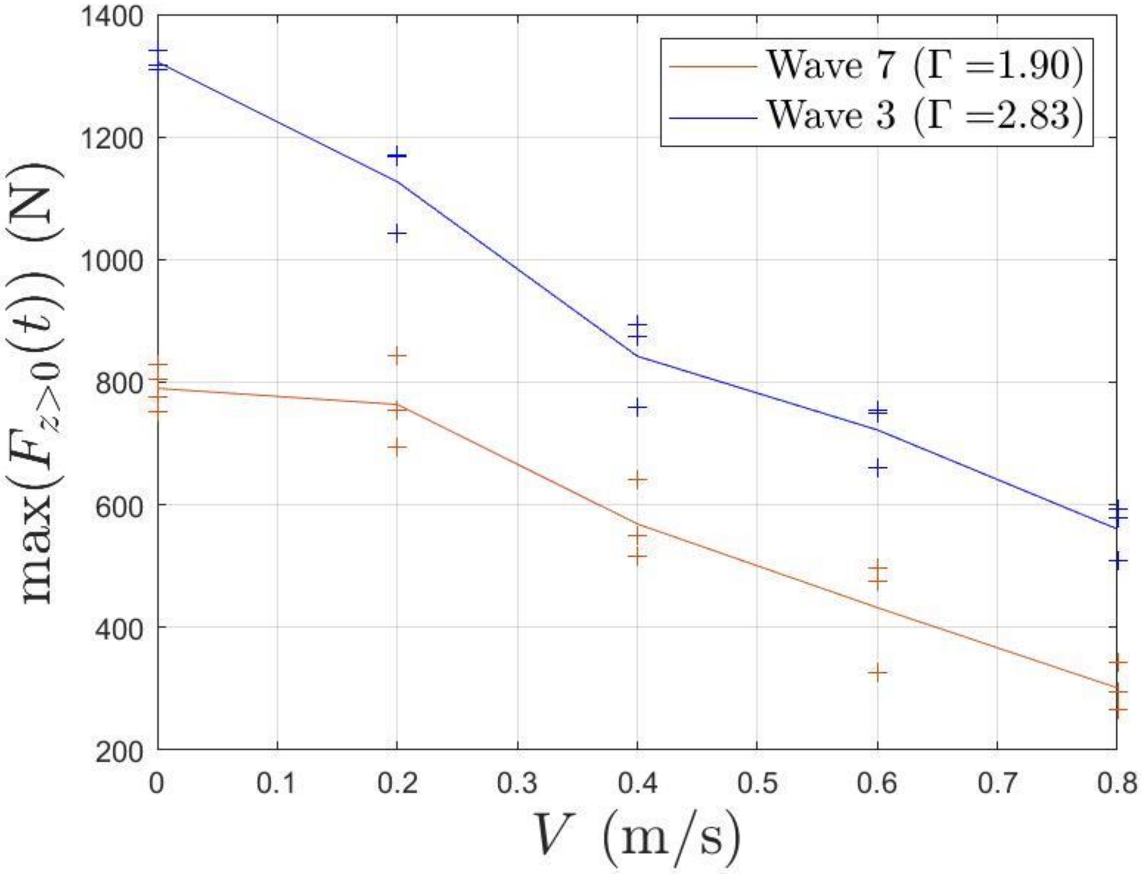


# Influence of the horizontal velocity

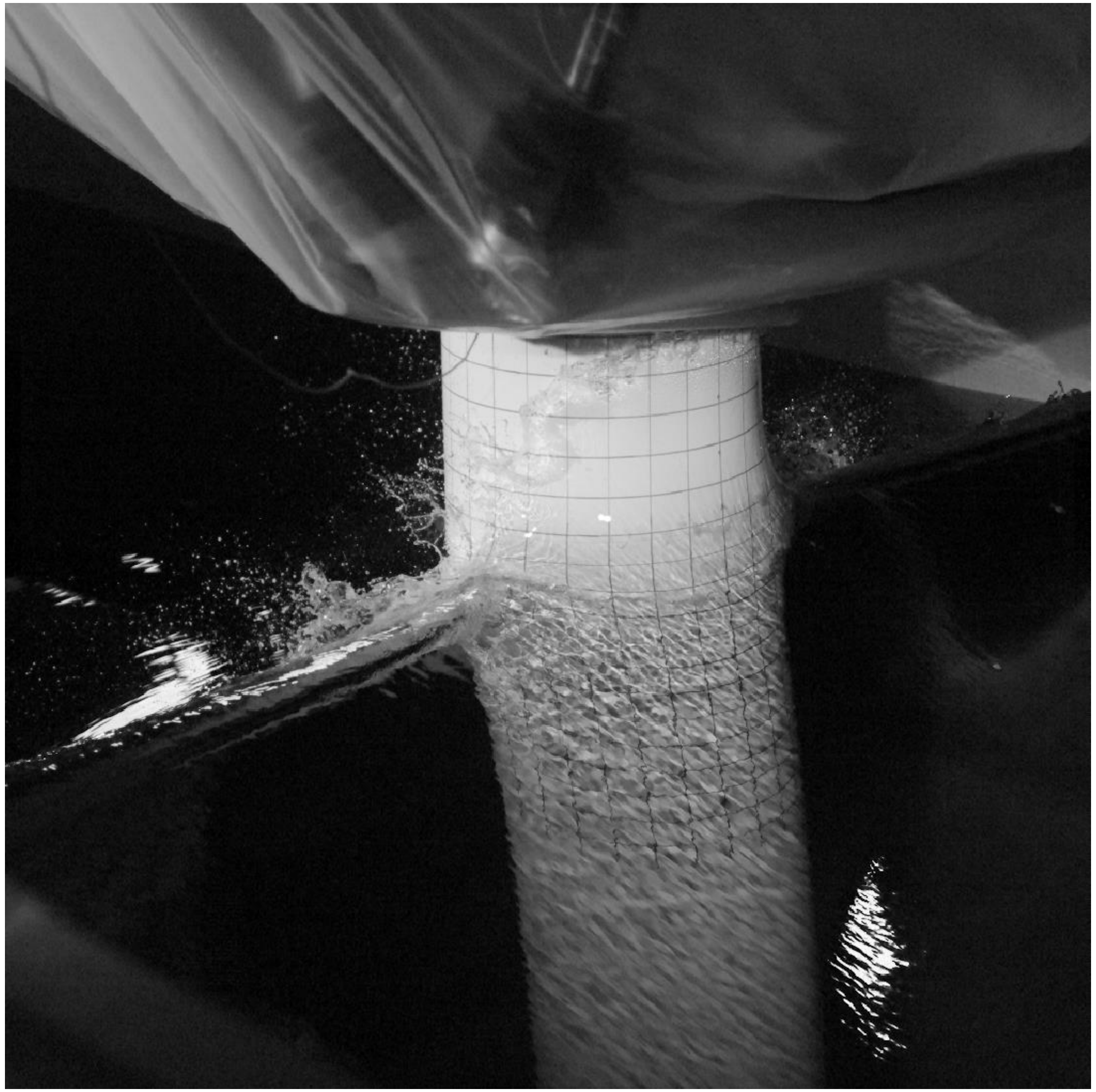
- Wave 3: $T_p = 2{,}25\text{s}, \Gamma = 2{,}83, C = 2{,}88$ m/s
- $V = 0.8$ m/s





# Conclusions

- Improvement of the accuracy of the load measurement
- The influence of $\Gamma$ , $\delta$, V and $\theta$ on the slamming loads was studied



Conclusions:

- A pitch in the wave propagation directions tends to decrease the impact load
- A velocity in the wave propagation direction tends to decrease the impact load
- The $\delta$ parameter is of primary importance
- $\Gamma$ appears as a good candidate to account for the breaking severity

# Questions

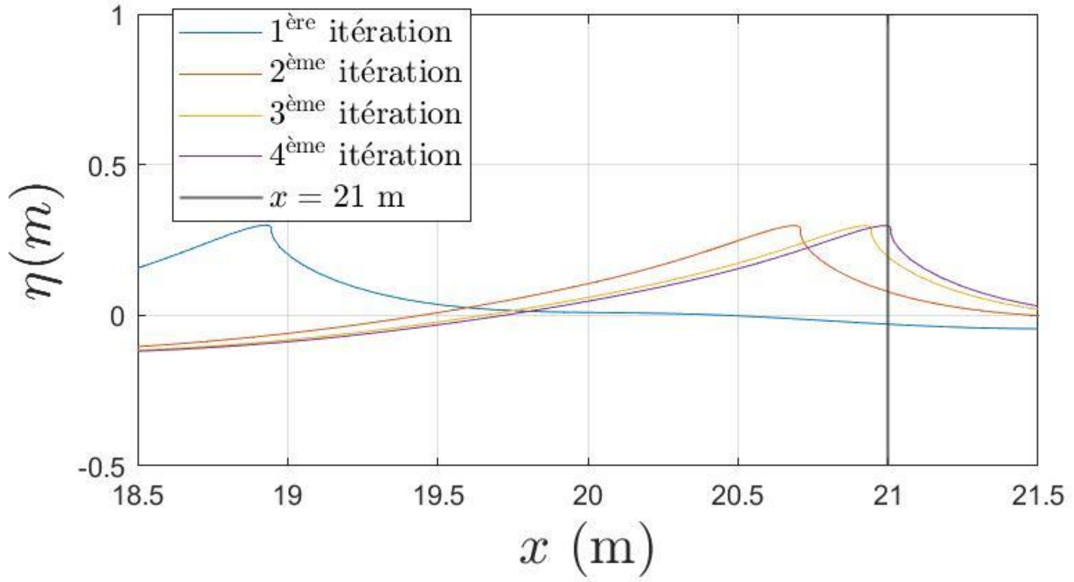
# Iterative breaking wave generation methodology

- Breaking is obtained by focalization of a truncated JONSWAP spectrum:

$$\eta(x,t) = \sum_{n=1}^{N} a_n \cos(k_n x - \omega_n t - \varphi_n)$$

- The Biésel transfer function are uses to determine the paddle motion
- A numerical wave tank allows to determine the effective breaking position
- The focusing point is iteratively modified:

$$x_{foc}^{i+1} = x_{foc}^{i} - (x_b^i - x_{tar})$$

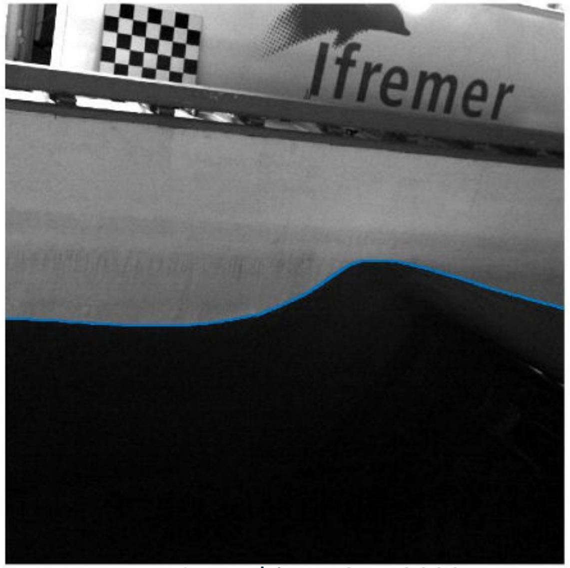


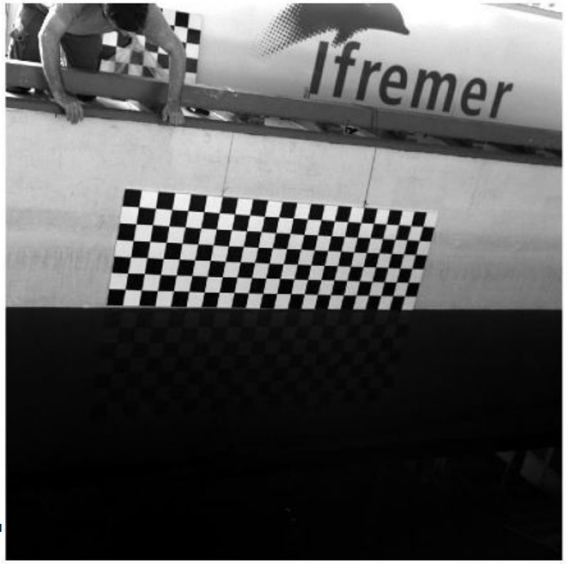
# Parameters of the different breaking waves

| Wave | $\Gamma$ | $\eta_b$ (m) | $C_c$ (m/s) | $F_i$ (N) |
|---|---|---|---|---|
| 1 | 0,98 | 0,37 | 2,63 | 0 |
| 2 | 0,79 | 0,31 | 2,45 | 0 |
| 3 | 2,78 | 0,40 | 2,88 | 740 |
| 23 | 1,31 | 0,37 | 2,72 | 79 |
| 24 | 1,84 | 0,38 | 2,84 | 375 |
| 15 | 1,74 | 0,30 | 2,43 | 115 |
| 7 | 1,82 | 0,40 | 2,87 | 305 |

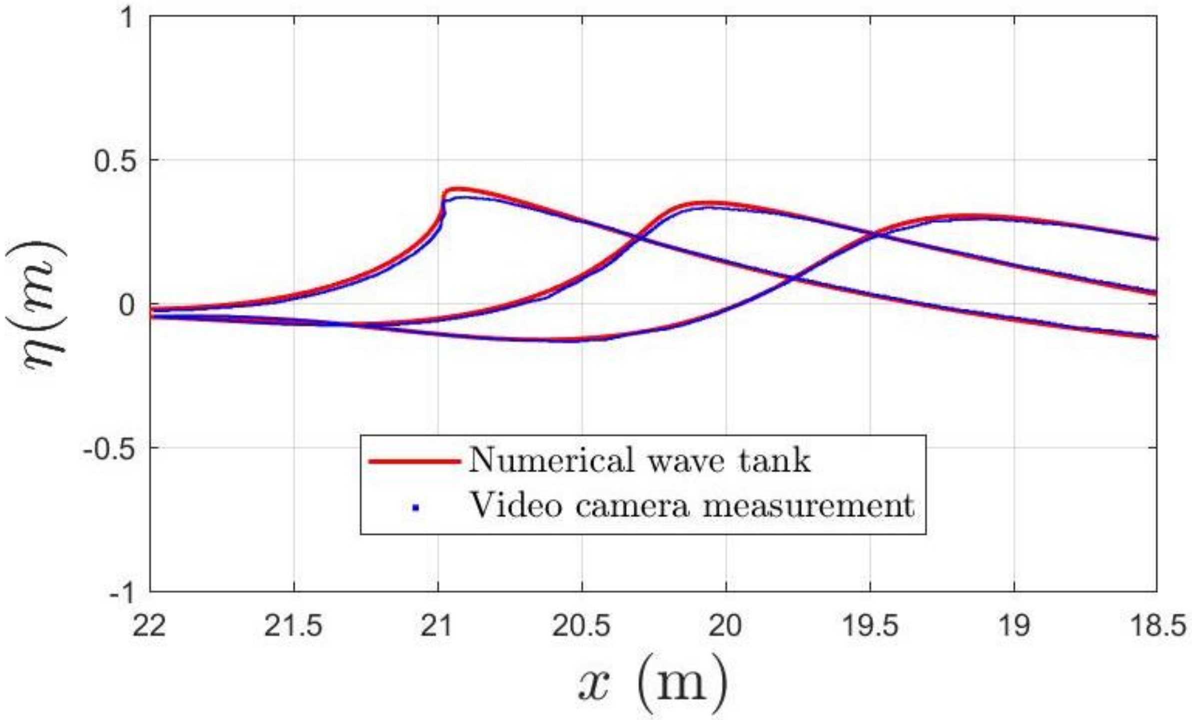
# Free surface profile measurement of the breaking waves

- Each breaking wave is filmed using a high speed video camera
- The interface is detected with a contour algorithm
- A checkerboard allows to obtain the profile coordinates in the basin frame of reference




- Good accordance with the profiles obtained using the numerical wave tank

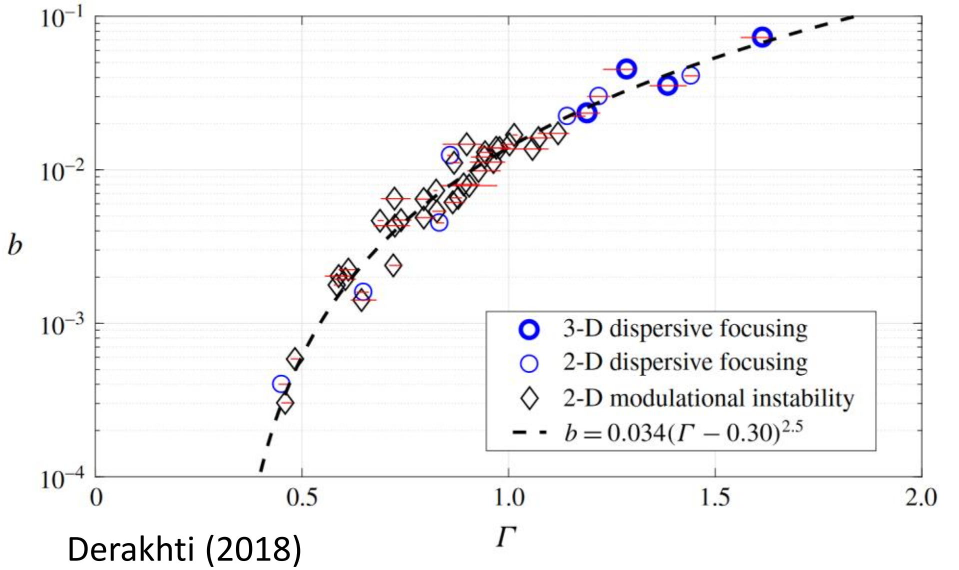


# Characterization of the breaking intensity of the generated waves

- Following Derakhti (2018):

$$\Gamma = \left.\frac{d\,{}^{u}/_{c}}{dt}\right|_{B=0,85}$$

- $c$ the crest speed and $u$ the fluid velocity at the crest

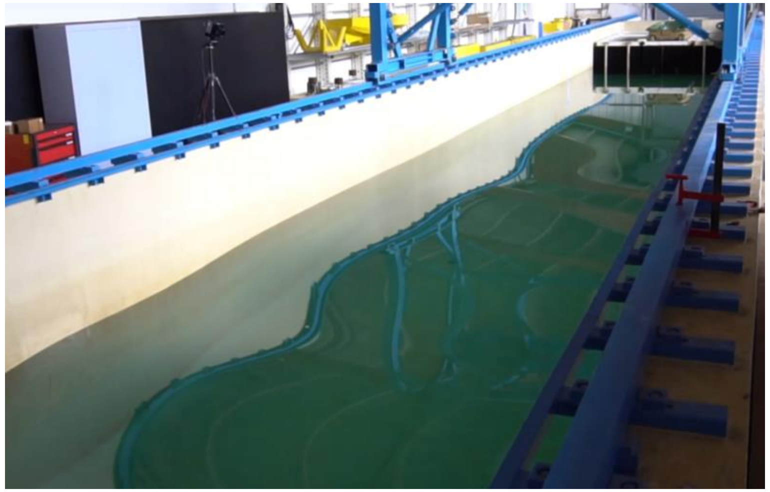



Derakhti (2018)

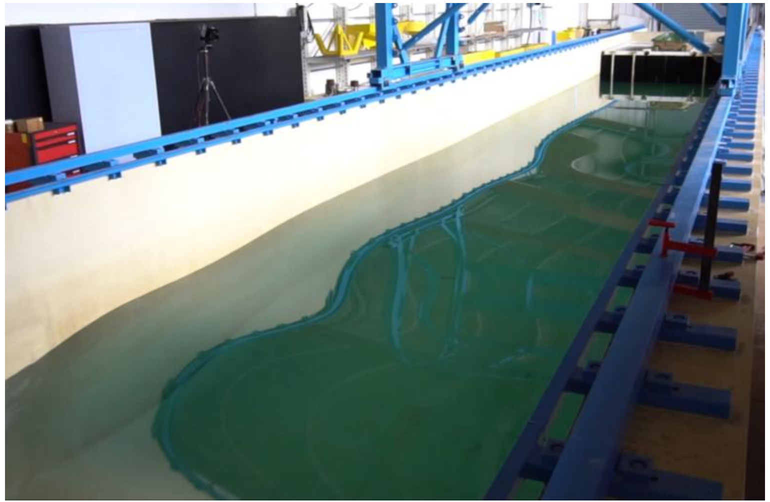
- Waves displaying different $\Gamma$ were generated:

| Wave | $\Gamma$ |
|---|---|
| 1 | 0,98 |
| 2 | 0,79 |
| 3 | 2,77 |
| 7 | 1,82 |
| 15 | 1,74 |
| 23 | 1,31 |
| 24 | 1,84 |

Wave 2



Wave 3



# Compensation of the oscillatory part of the force signal: theory

- Under the small perturbations assumption:

$$\sum \vec{F} \approx \iiint_{\mathcal{D}_0} \rho_0(x_0, y_0, z_0) \frac{\partial^2}{\partial t^2} \vec{T}(x_0, y_0, z_0, t) \mathrm{d}x_0 \mathrm{d}y_0 \mathrm{d}z_0$$

- Assuming that the displacement field can be approached by a linear combination of N modes of the body:

$$\vec{T}(\vec{X}, t) \approx \vec{X}_0 + \sum^{N} a_i(t) \vec{w}_i(\vec{X}_0)$$

- Thus: $$\sum \vec{F} \approx \sum_{i=1}^{N} \ddot{a}_i(t) \underbrace{\iiint_{\mathcal{D}_0} \rho_0(x_0, y_0, z_0) \vec{w}_i(x_0, y_0, z_0) \mathrm{d}x_0 \mathrm{d}y_0 \mathrm{d}z_0}_{\vec{m}_i}$$

- The hydrodynamic force can be written as: $$\vec{F}_{hyd} \approx \vec{F}_{meas} + \sum_{i=1}^{N} \ddot{a}_i(t) \vec{m}_i$$

# Compensation of the oscillatory part of the force signal: theory

- Assuming that N accelerometers are placed on the body:

$$\underbrace{\begin{bmatrix} \gamma_1(t) \\ \vdots \\ \gamma_N(t) \end{bmatrix}}_{\boldsymbol{\Gamma}(t)} = \underbrace{\begin{bmatrix} \vec{w}_1(\vec{Z}_1)\cdot\vec{n}_1 & \cdots & \vec{w}_N(\vec{Z}_1)\cdot\vec{n}_1 \\ \vdots & \vdots & \vdots \\ \vec{w}_1(\vec{Z}_N)\cdot\vec{n}_N & \cdots & \vec{w}_N(\vec{Z}_N)\cdot\vec{n}_N \end{bmatrix}}_{\mathbf{W}} \begin{bmatrix} \ddot{a}_1(t) \\ \vdots \\ \ddot{a}_N(t) \end{bmatrix}$$

- If $W$ is invertible: $F_{hyd}(t) \approx F_{meas}(t) + \mathbf{M}\mathbf{W}^{-1}\boldsymbol{\Gamma}(t)$

- During a period with no hydrodynamic force: $F_{meas}(t) + \sum_{i=1}^{N} \alpha_i \gamma_i(t) \approx 0$

- The $\alpha_i$ coefficients are identified by minimizing $\sum_{j=1}^{n} \left( F_{meas}(t^j) + \sum_{i=1}^{N} \alpha_i \gamma_i(t^j) \right)^2$