The breaking criteria: a way to predict and characterize a breaking wave

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What is a breaking wave ?

- Geometrical: modification of the asymmetry of the wave profile

- Energetic: augmentation of the energy dissipation rate

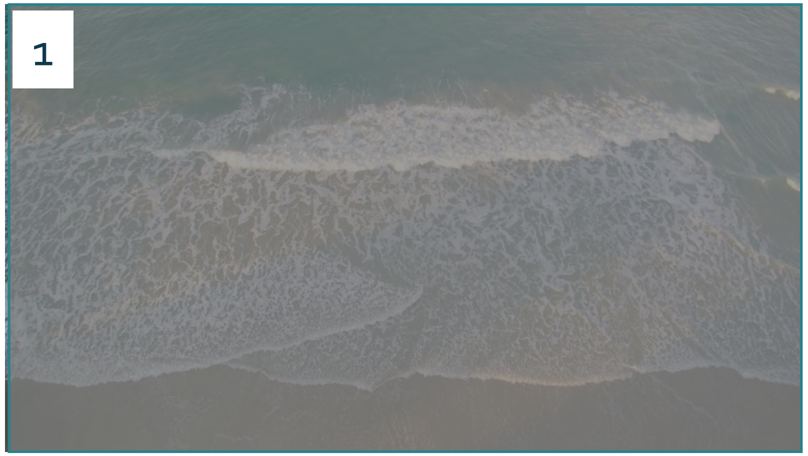
- Dynamic: flow motion becomes rotational
  → Mass transport

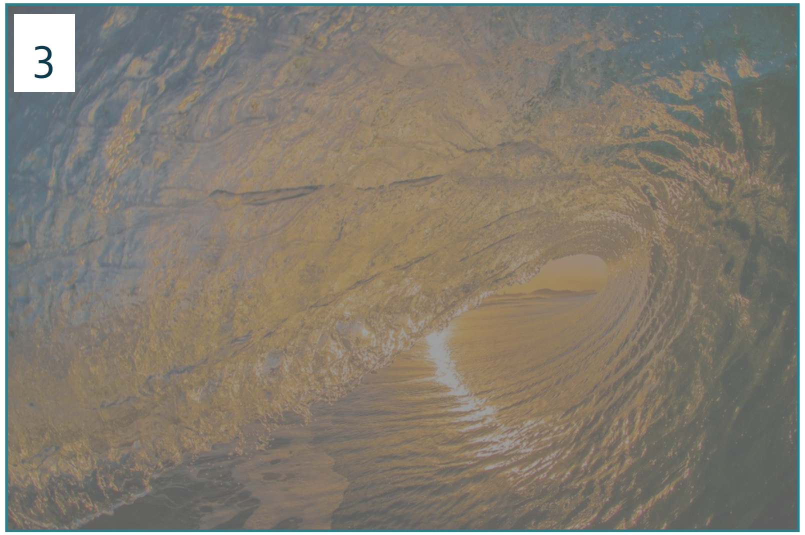
Snapshop from a video made by Olivier Kimmoun (2018) of a breaking wave in a canal

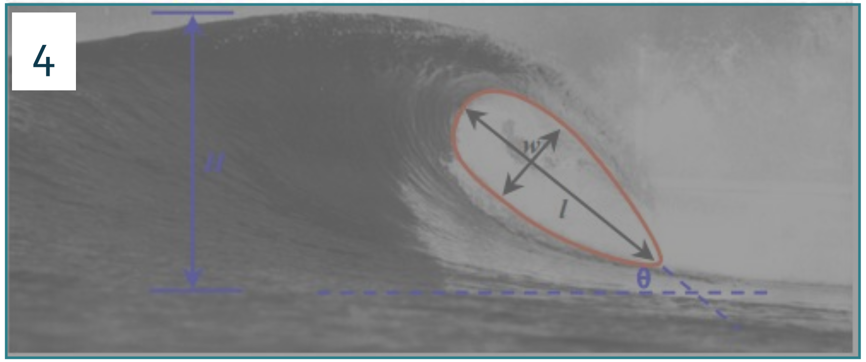
Breaking criteria

- Criteria:

  - Prediction
  - Detection
  - Intensity
  - Classification
  - Characterization







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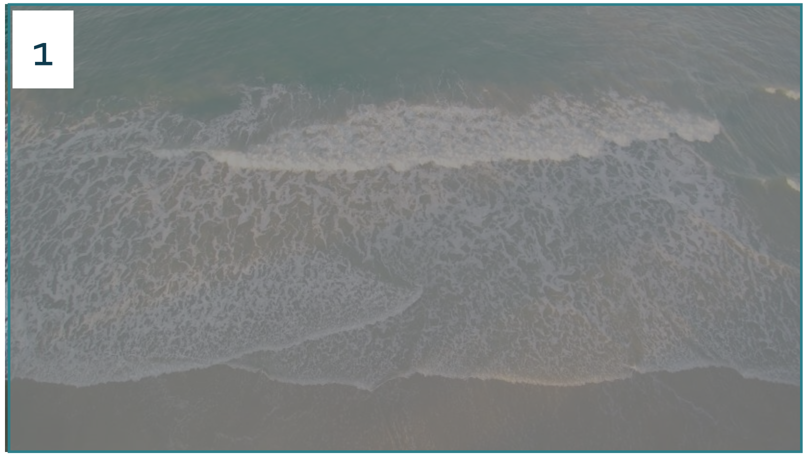

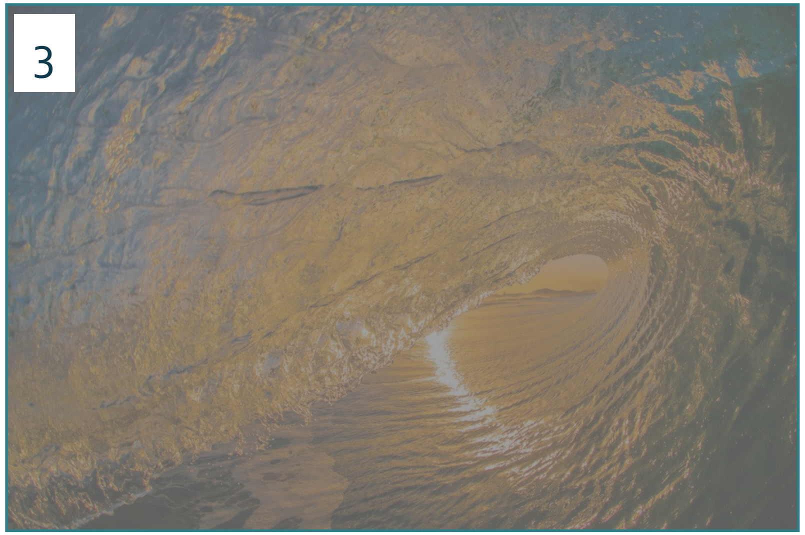

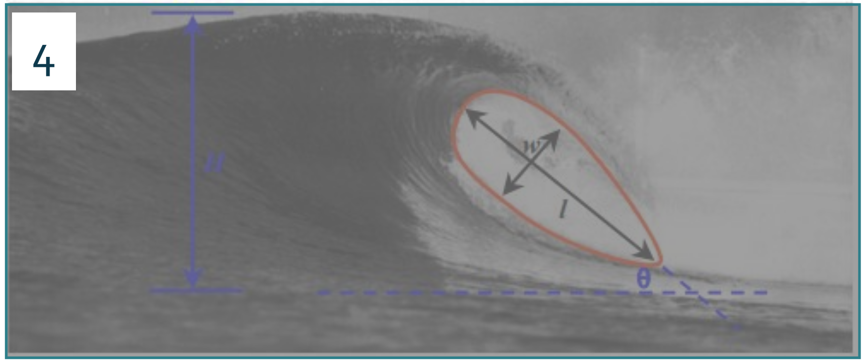

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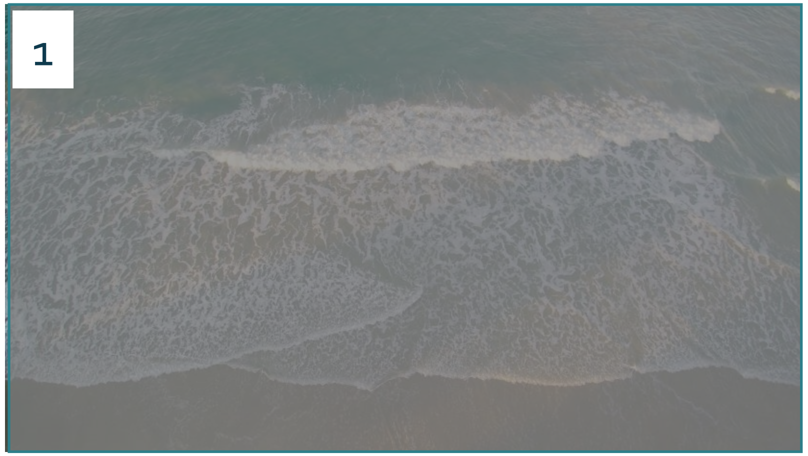

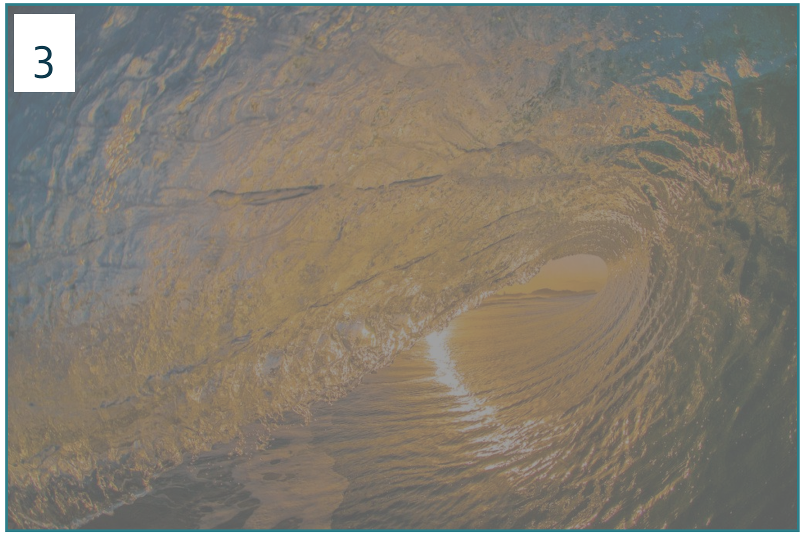

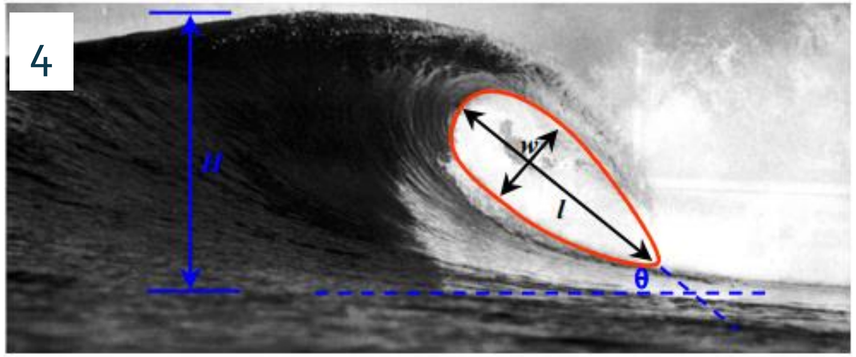

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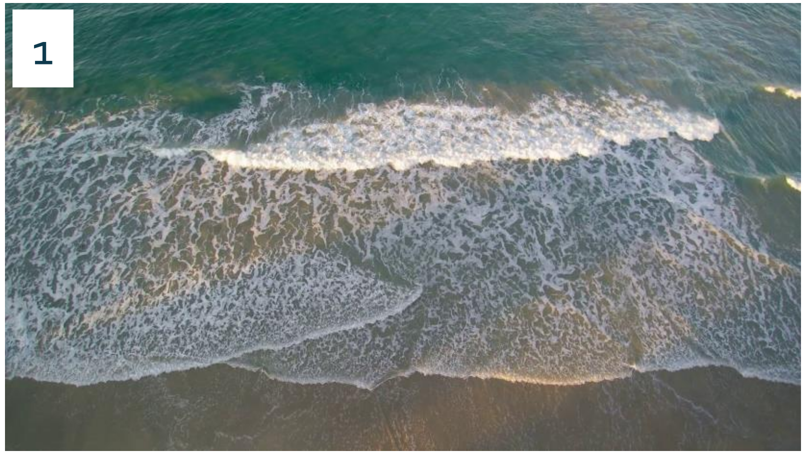

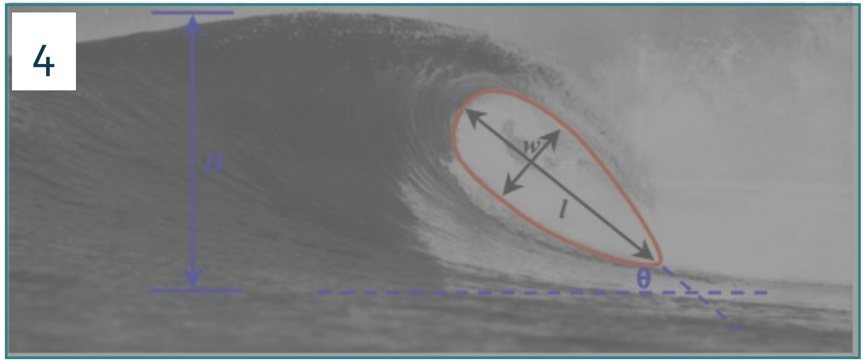

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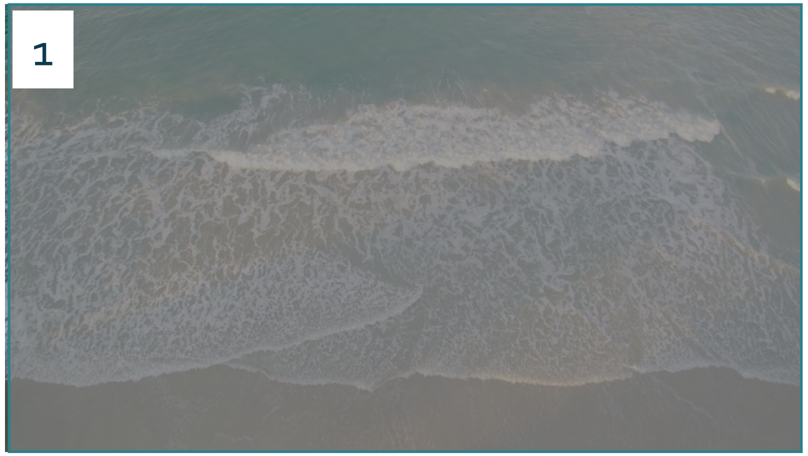

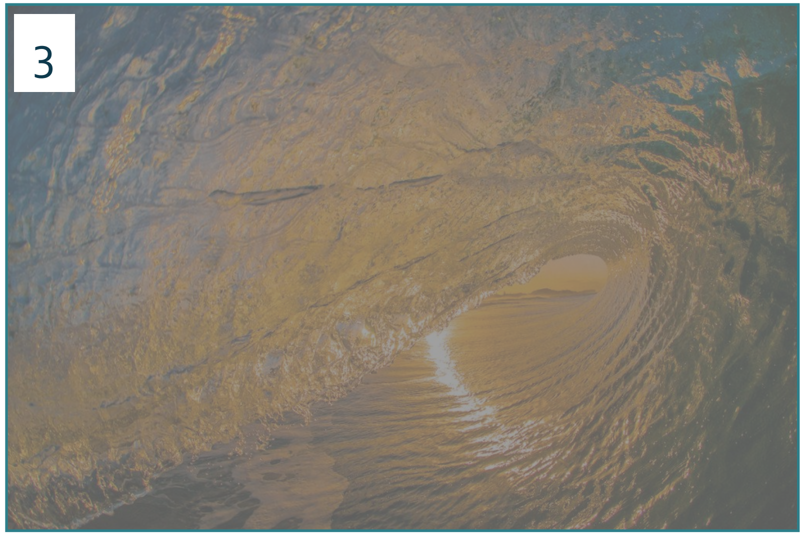

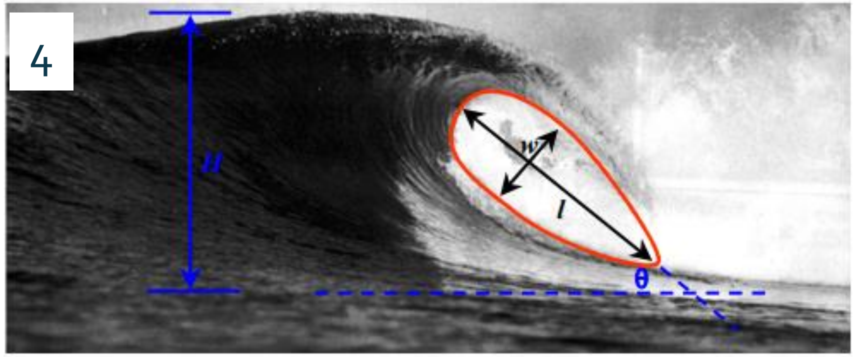

Breaking criteria

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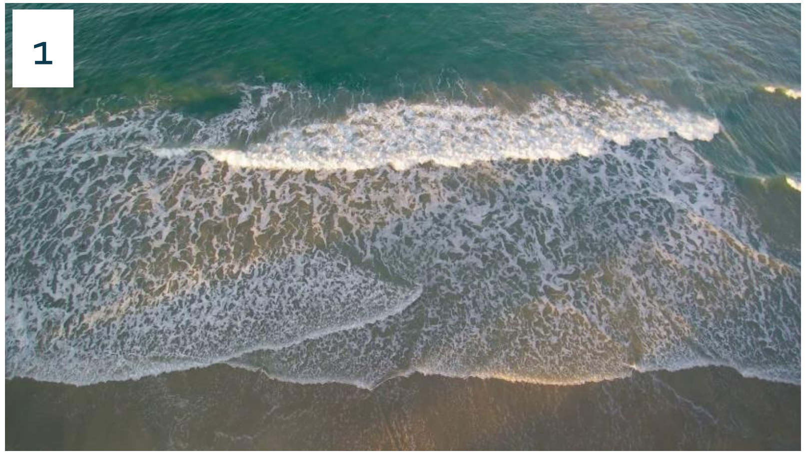
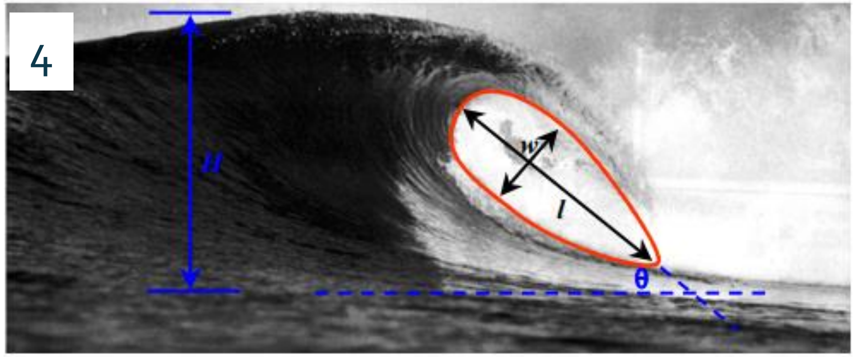
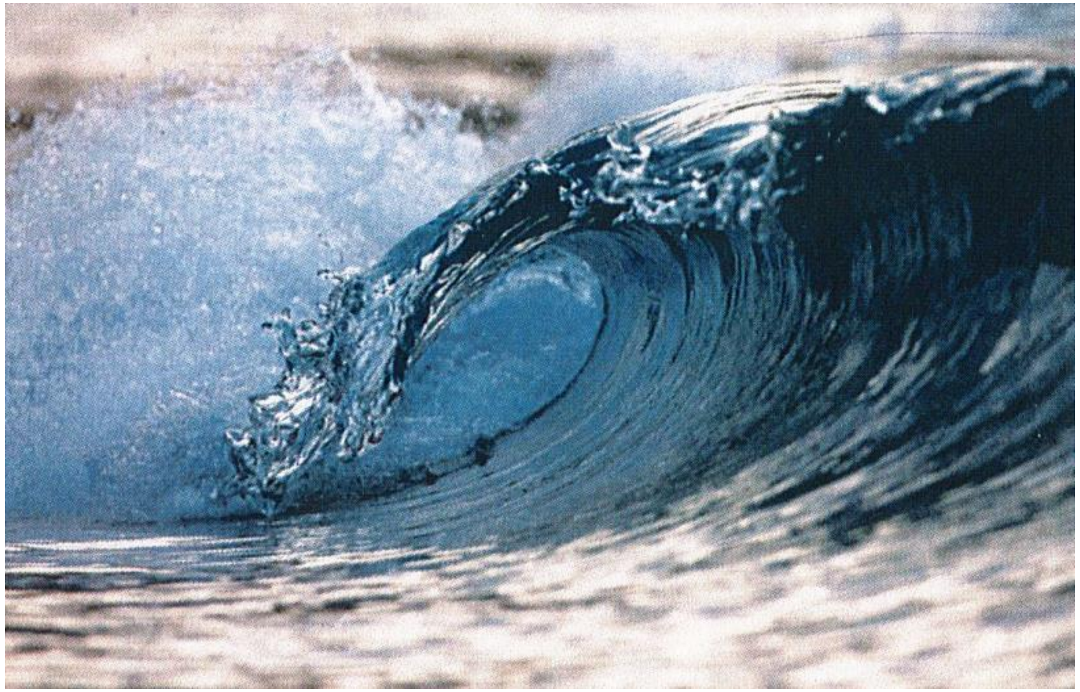
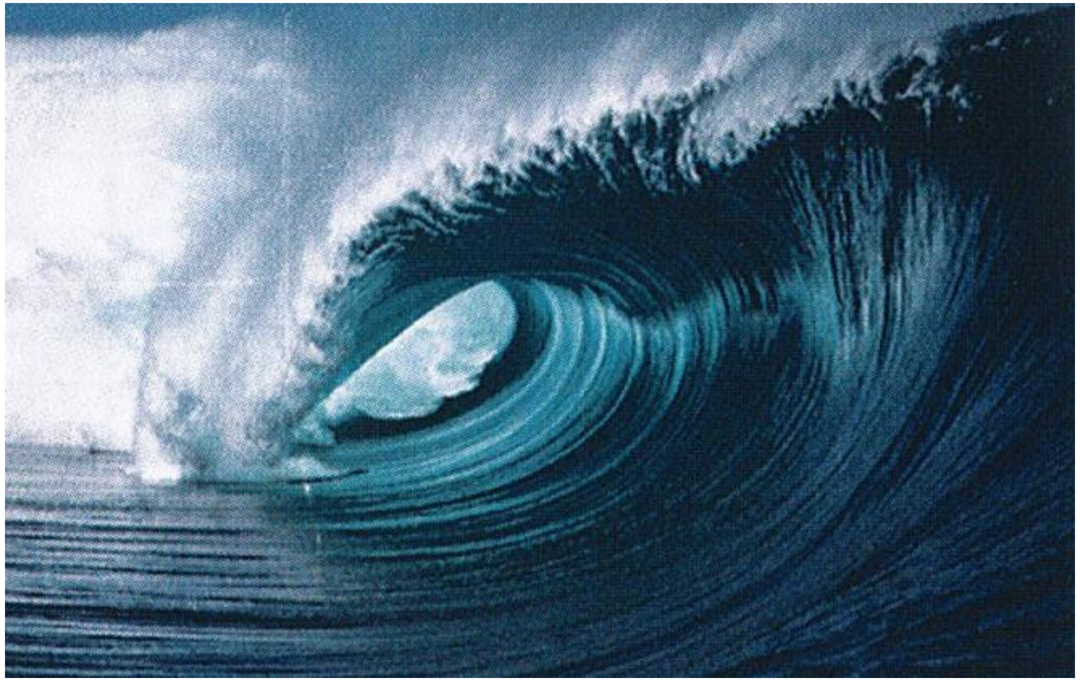




Beginning of my thesis



Small breaking wave



Large breaking wave

Study the breaking wave event following the **wavelength**, **wave steepness** and **water depth**

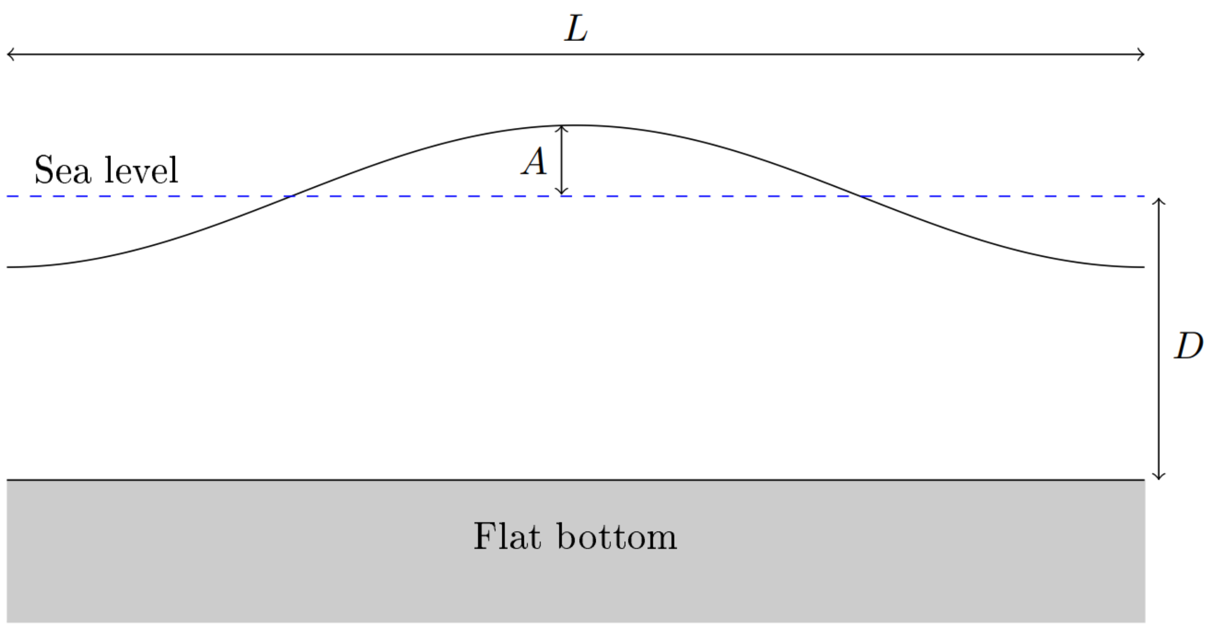
Numerical Tool : Notus CFD

- Notus CFD
  - Developped inside my team
  - Navier-Stokes equation
  - Multiphase flow

- Initial condition
  - First order Stokes wave – Periodic sinusoidal wave
  - Flat bottom
  - 2D
  - Wavelength from 5 cm to 35 cm – Capillary-Gravity wave

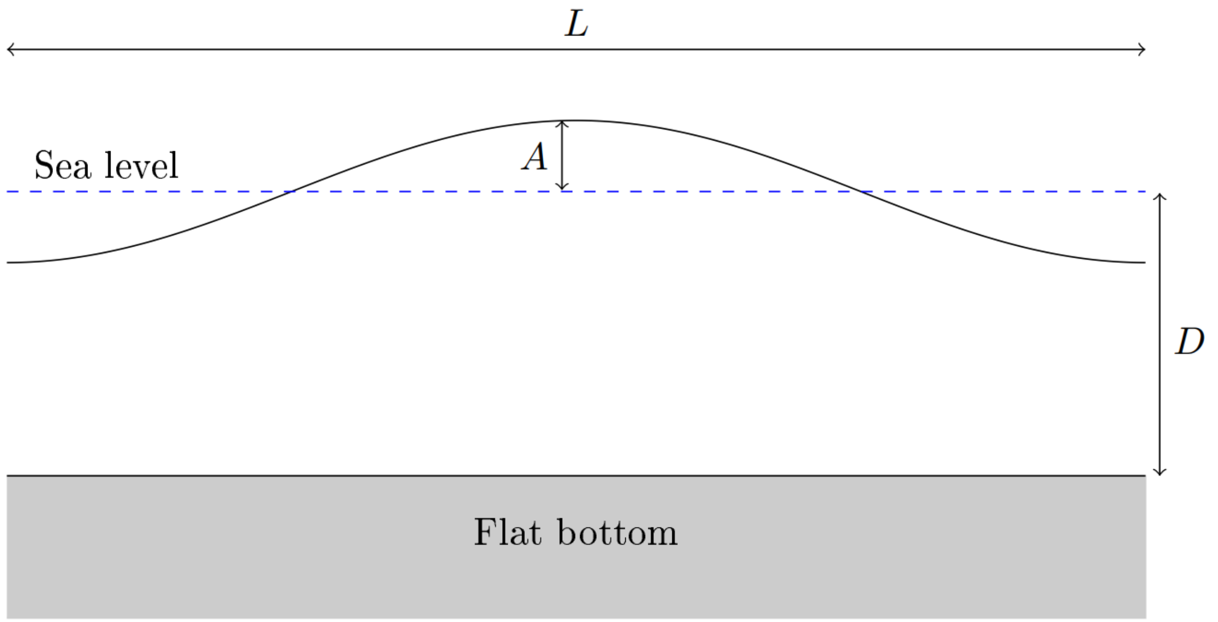
- Simulations
  - More than 150 simulations
  - 2,5 millions of hours on supercomputers

Wave characteristics



Scheme of an initial wave characteristics

Wave characteristics

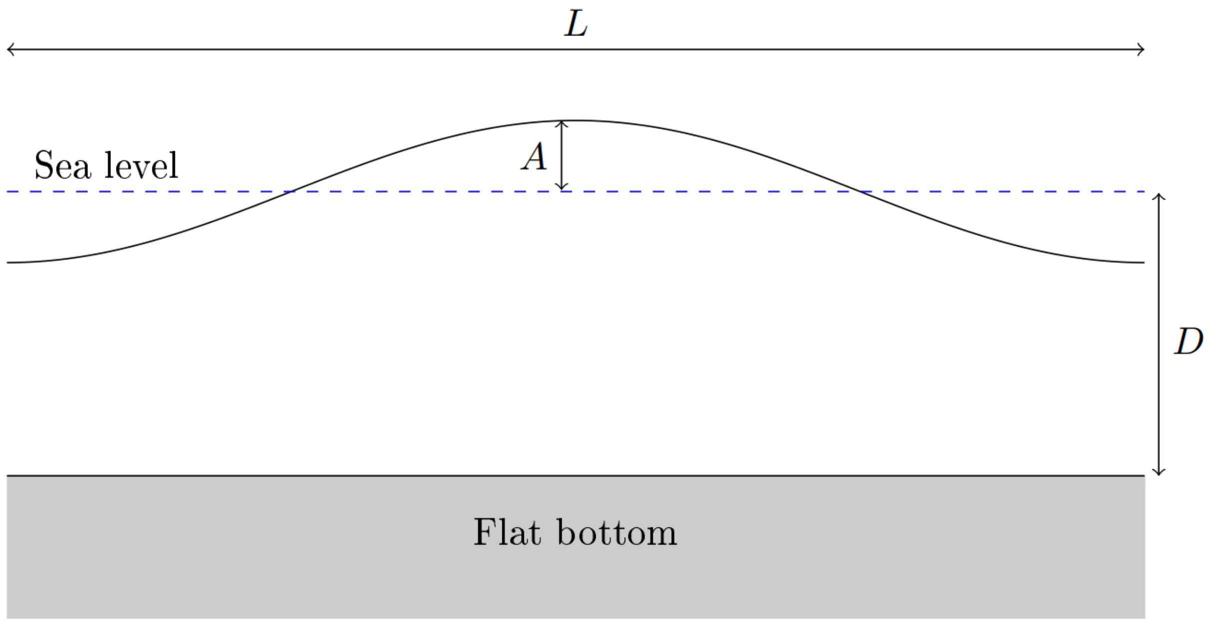


Scheme of an initial wave characteristics

Characteristics:

- Wavelength : L
- Wave amplitude : A
- Wave depth : D

Wave characteristics



Scheme of an initial wave characteristics

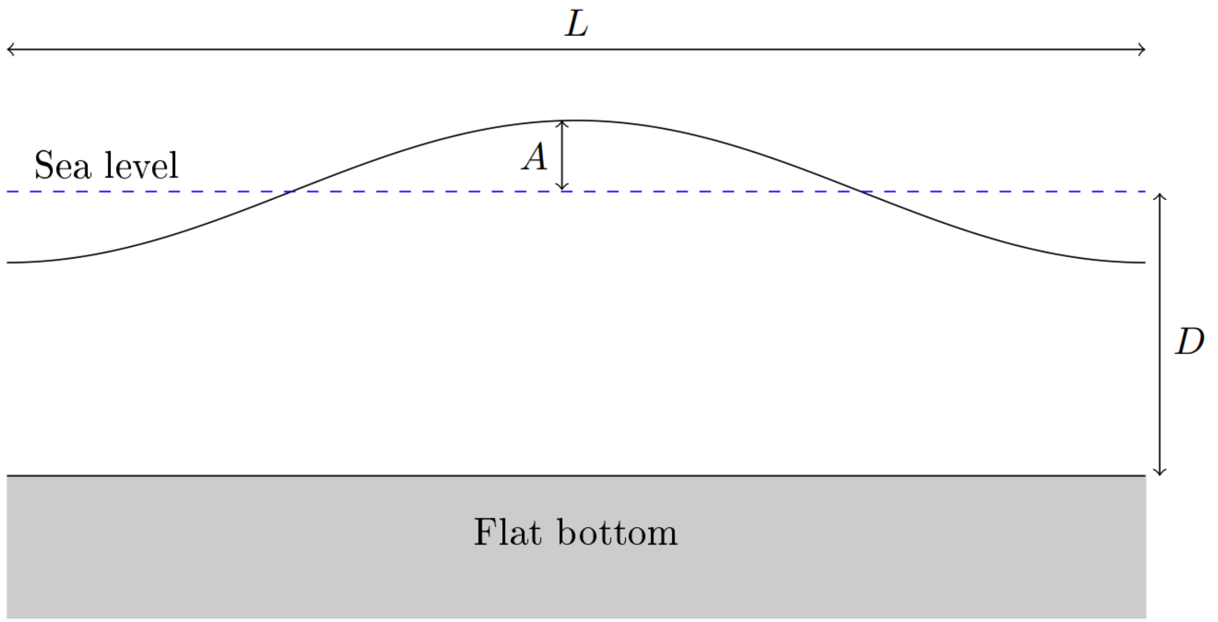
Characteristics:

- Wavelength : L
- Wave amplitude : A
- Wave depth : D

Relations:

- Wave steepness : $\varepsilon = \frac{2\pi A}{L}$
- Water depth : $\frac{D}{L}$

Wave characteristics



Scheme of an initial wave characteristics

Characteristics:

- **Wavelength : L**
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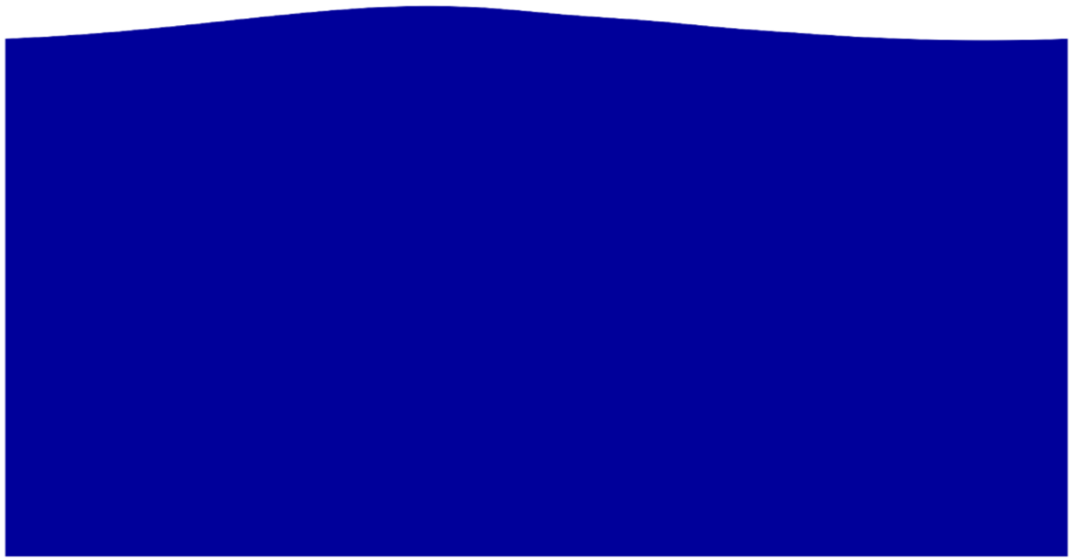
Relations:

- **Wave steepness** : $\varepsilon = \frac{2\pi A}{L}$
- **Water depth** : $\frac{D}{L}$

Different type of breaking waves

- Non Breaking (NB)
- Parasitic Capillary Waves (PCW)
- Spilling Breaker – High surface tension (SB)
- Plunging Breaker (PB)



Non breaking wave simulation

Different type of breaking waves

- Non Breaking (NB)
- Parasitic Capillary Waves (PCW)
- Spilling Breaker – High surface tension (SB)
- Plunging Breaker (PB)

Only for small waves
L < 50 cm

Parasitic Capillary Waves simulation

Different type of breaking waves

- Non Breaking (NB)
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Only for small waves
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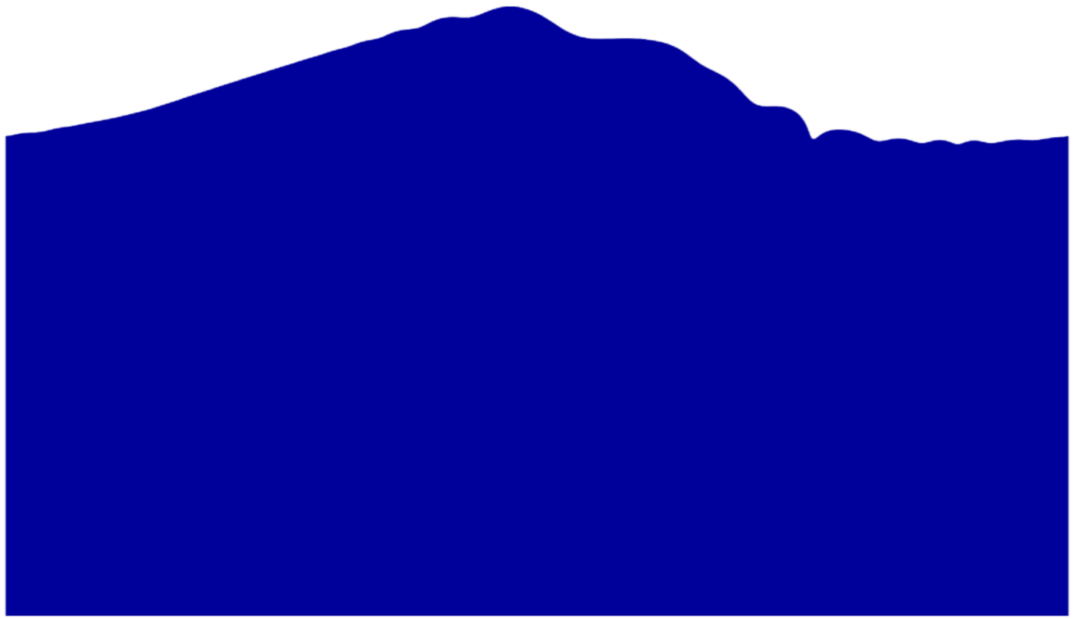

Spilling Breaker simulation

Different type of breaking waves

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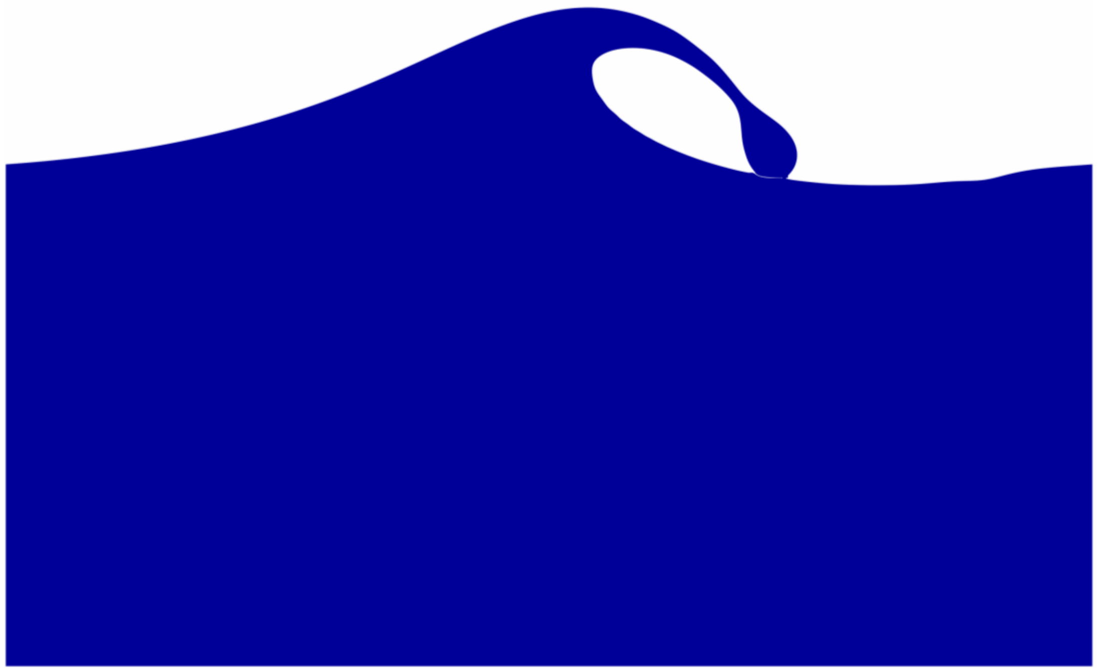
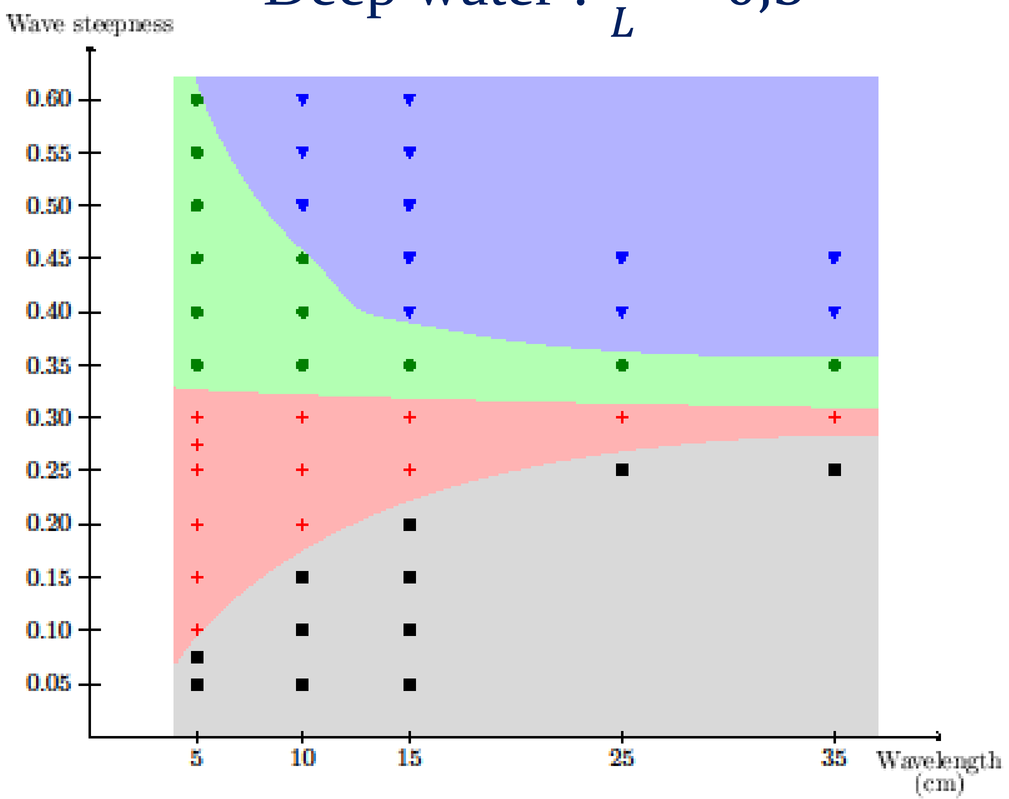


Plunging Breaker simulation

Breaking Maps : Shallow, intermediate and deep

Deep water : $\frac{D}{L} = 0,5$



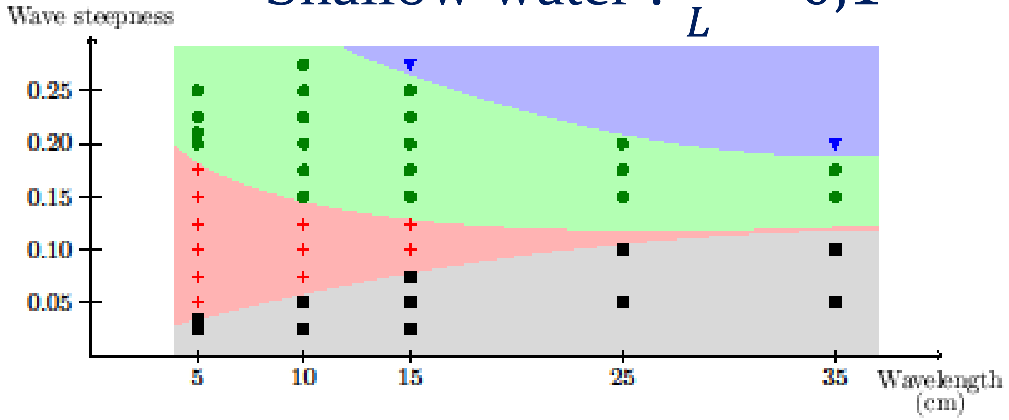
Every symbol is a simulation

Non Breaking – Parasitic Capillary Waves

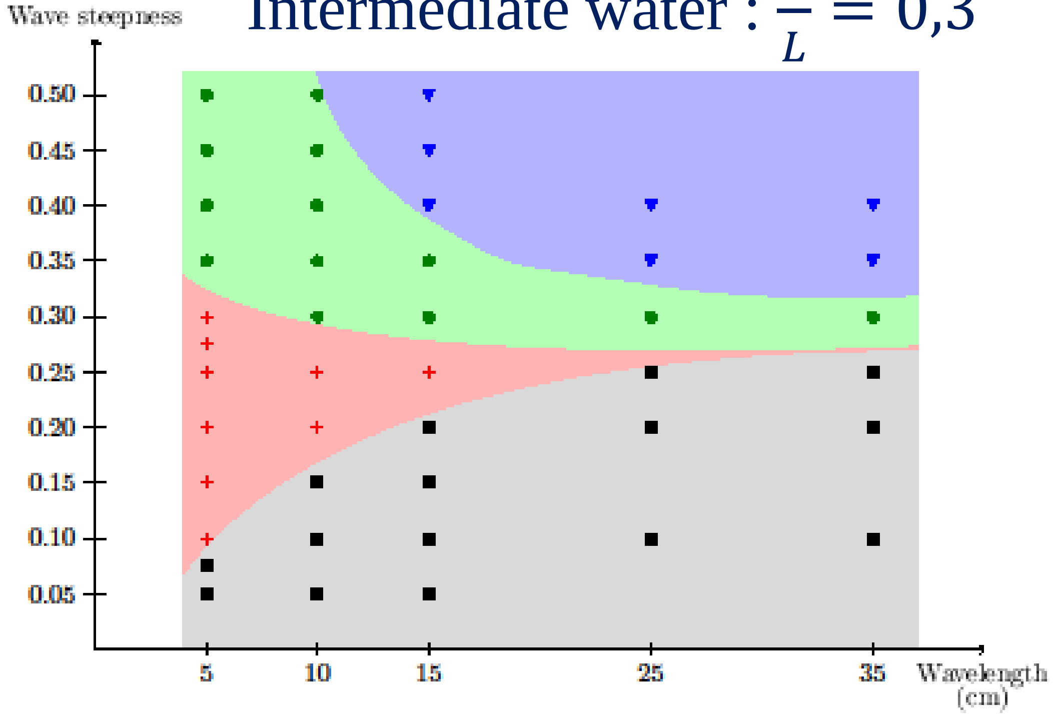
Spilling Breaker – Plunging Breaker

Breaking Maps : Shallow, intermediate and deep

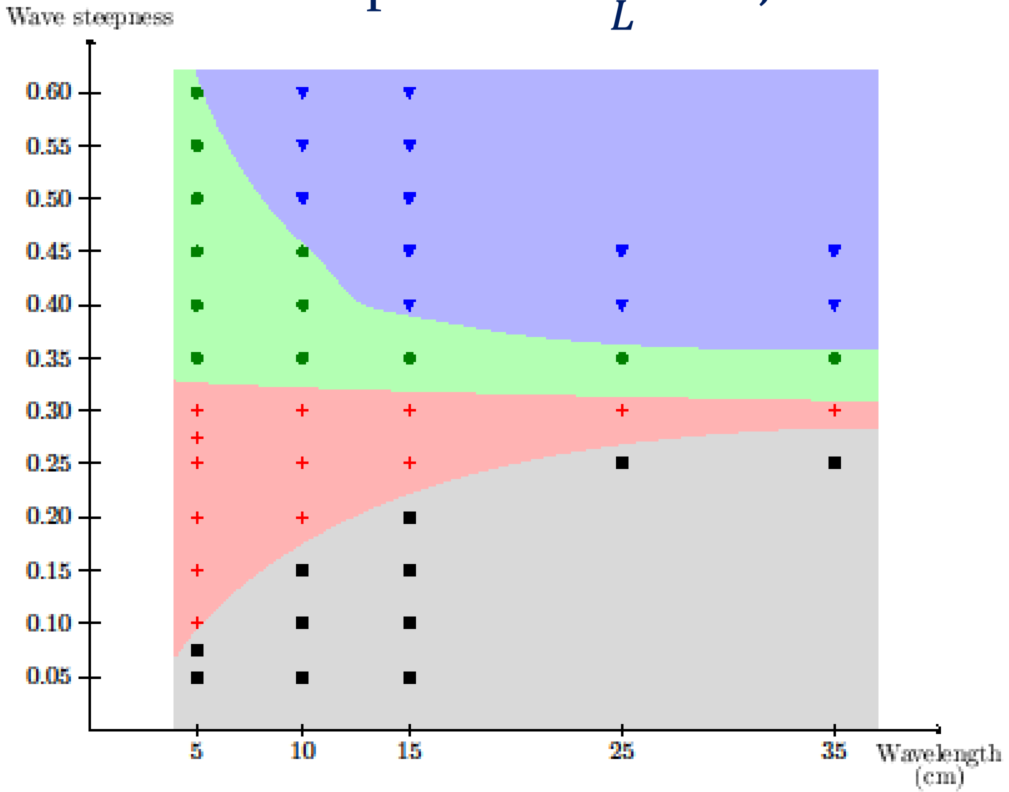
Shallow water : $\frac{D}{L} = 0{,}1$



Intermediate water : $\frac{D}{L} = 0{,}3$



Deep water : $\frac{D}{L} = 0{,}5$



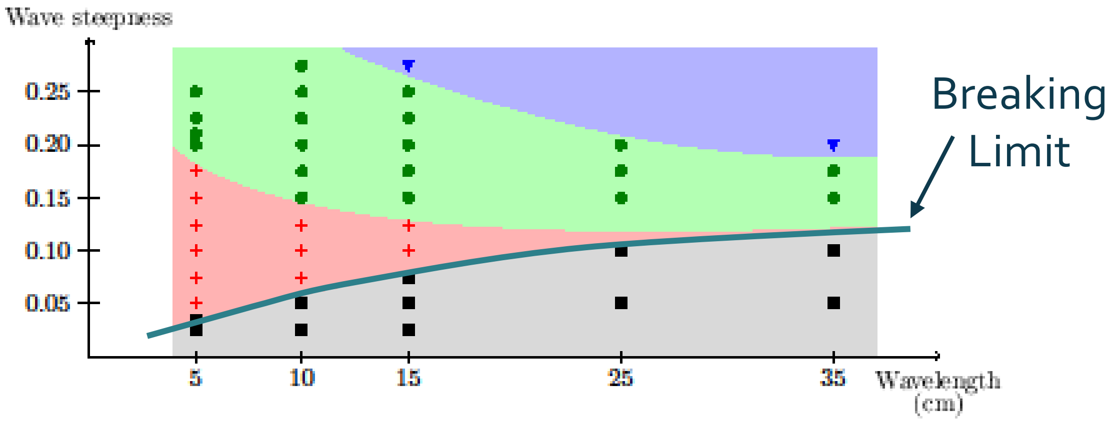
Every symbol is a simulation

Non Breaking – Parasitic Capillary Waves

Spilling Breaker – Plunging Breaker

Breaking Maps : Comparison

Shallow water : $\frac{D}{L} = 0{,}1$



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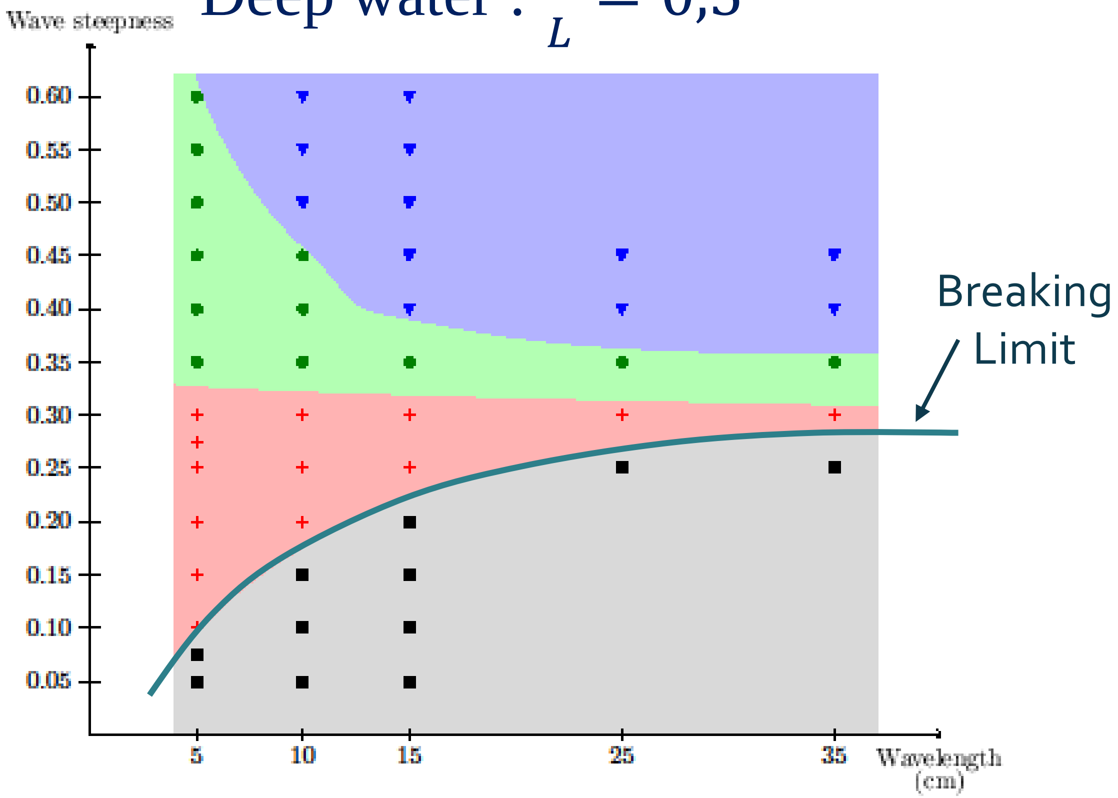


Remarks:

- The breaking limit is lower for the shallow water than the deep water
- Even for a flat bottom, the water depth highly influences the breaking type

Energy dissipation rate ξ

- Total energy E

Sum of : Kinetic Energy, Potential Energy and Surface Energy

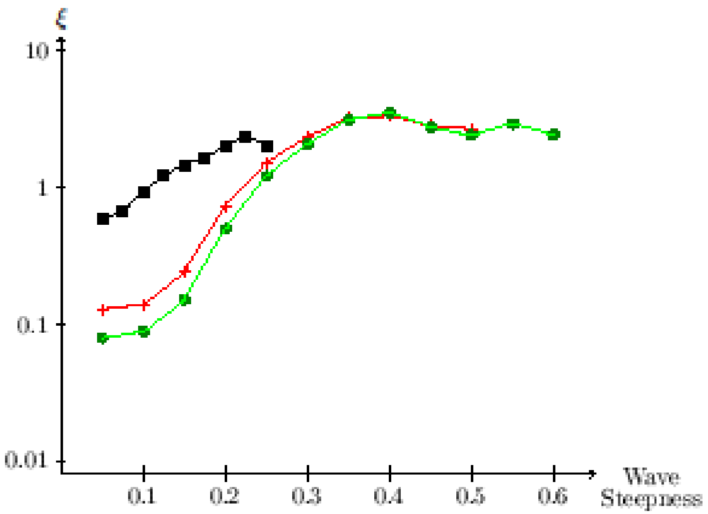
- Energy dissipation rate ξ[1]

$$E(t) = E_0 e^{-\xi t}$$

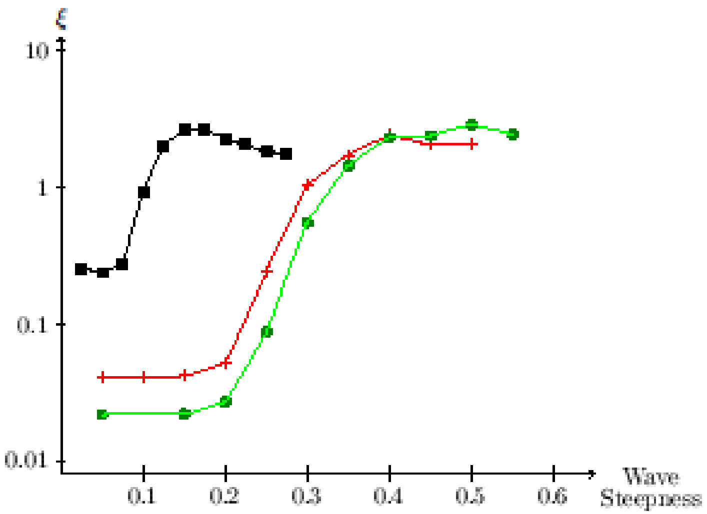
With E_0 the energy just before the breaking

[1] *Capillary effects on wave breaking, Journal of Fluid Mechanics, Luc Deike et al. , 2015*

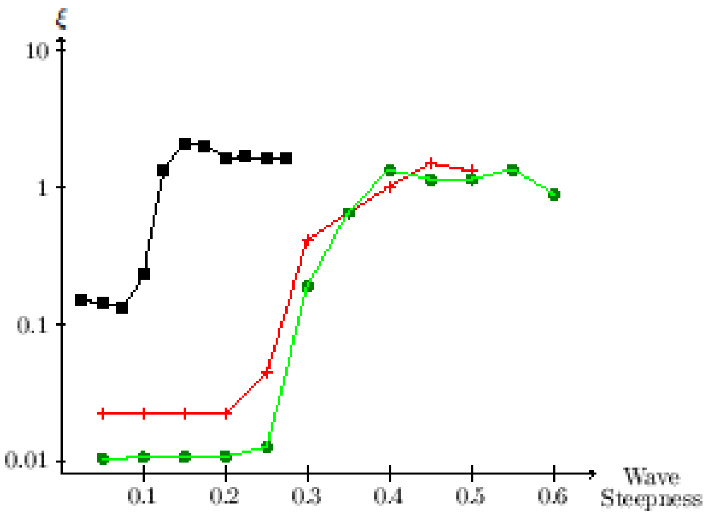
Energy dissipation rate ξ



L = 5 cm



L = 10 cm



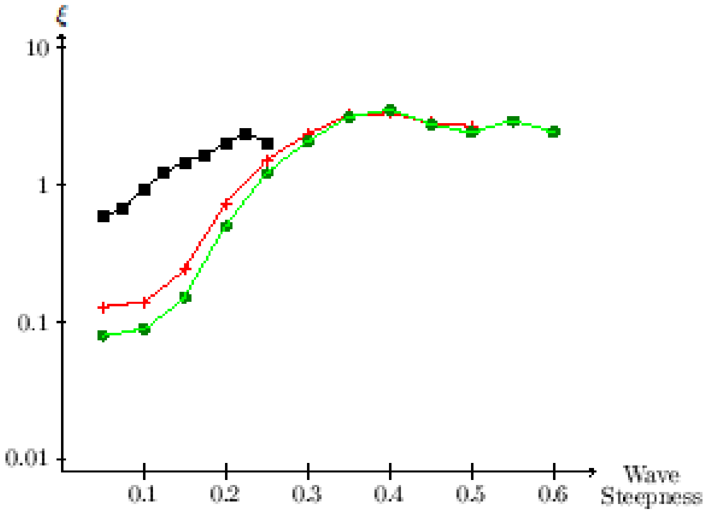
L = 15 cm

$\frac{D}{L} = 0{,}1$

$\frac{D}{L} = 0{,}3$

$\frac{D}{L} = 0{,}5$

Energy dissipation rate ξ



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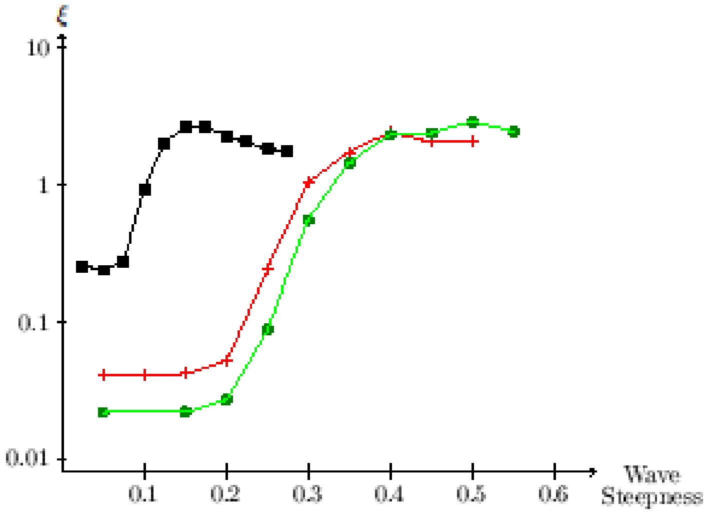

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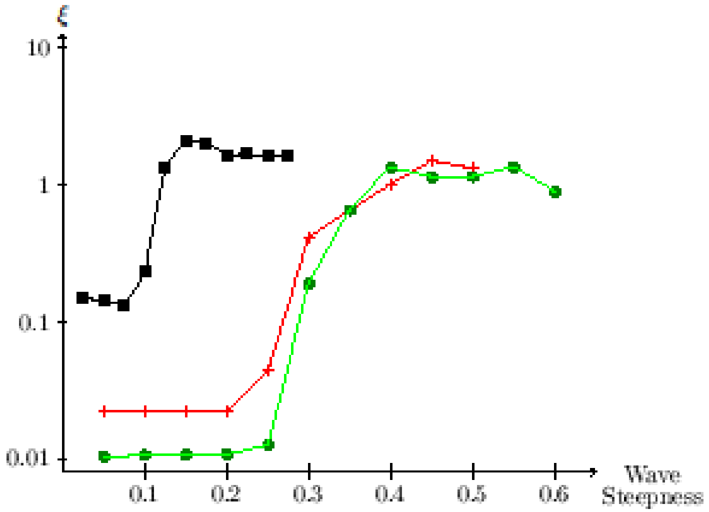

L = 15 cm

$\frac{D}{L} = 0{,}1$

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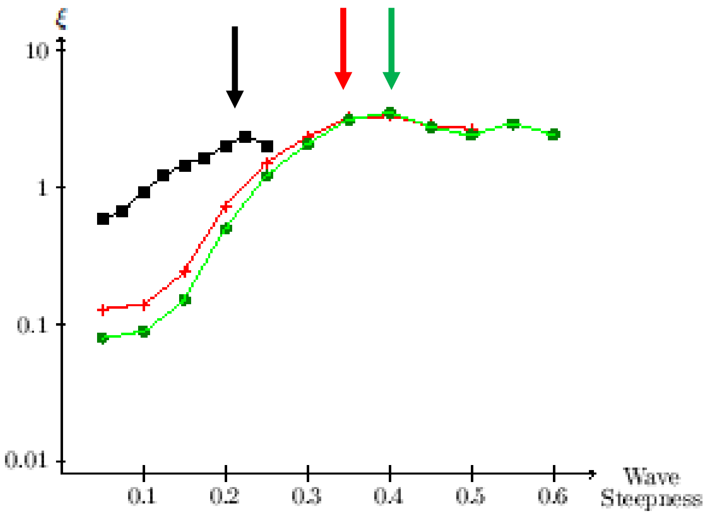
Remarks:

- Shallow water dissipation rate is higher than for deep water

Energy dissipation rate ξ



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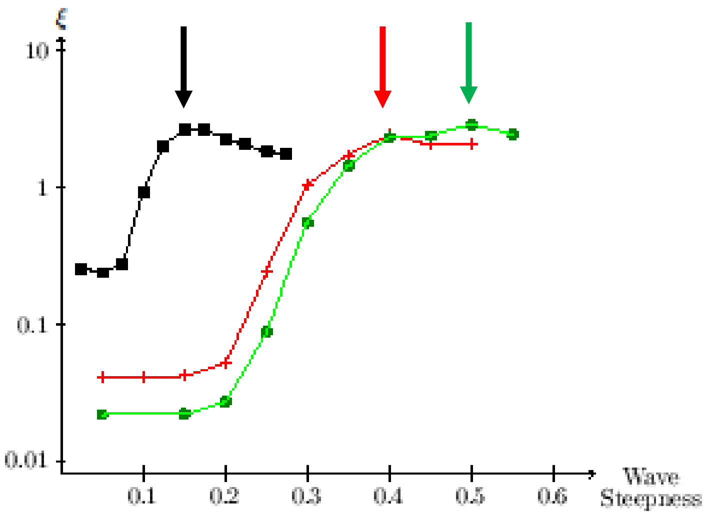
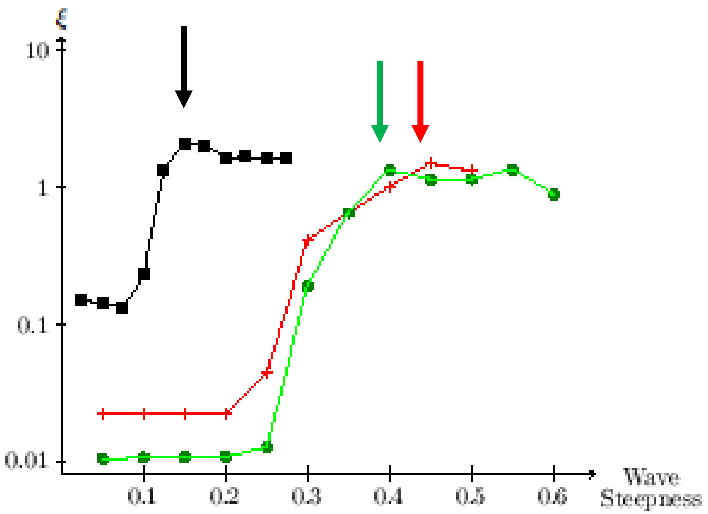


L = 10 cm



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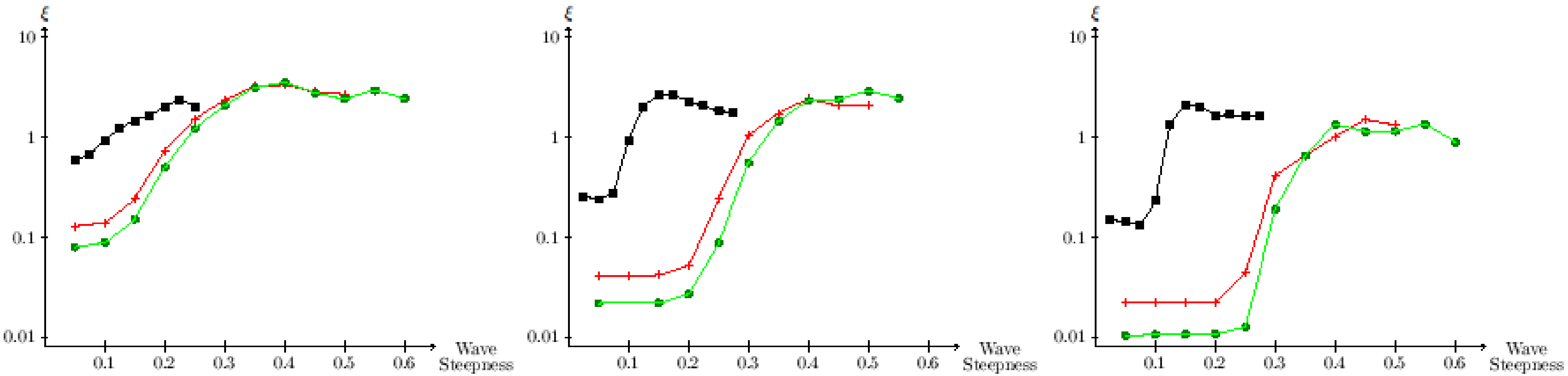
Remarks:

- Shallow water dissipation rate is higher than for deep water
- High dissipation rate is related to Spilling Breaker <u>with surface tension</u>

Energy dissipation rate ξ



L = 5 cm | L = 10 cm | L = 15 cm

$\frac{D}{L} = 0{,}1$

$\frac{D}{L} = 0{,}3$

$\frac{D}{L} = 0{,}5$

Remarks:

- Shallow water dissipation rate is higher than for deep water
- High dissipation rate is related to Spilling Breaker with surface tension
- Small wavelength is better to dissipate the energy

Conclusion and Perspectives

Three types of breaking wave :

- Parasitic Capillary Waves
- Spilling Breaker with Strong surface tension
- Plunging Breaker

More than 150 numerical simulations on 5 – 35 cm breaking wave

Creation of three Breaking Maps (Prediction): Shallow water, Intermediate water, Deep water

Characterization of the energy dissipation rate for shallow water:

- Small wavelength tends to dissipate faster the energy
- Shallow water dissipation rate is higher than for deep water

« Breaking wave is when it becomes interesting » (Marc Buckley, 2018)