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Development of a hybrid oscillating water column-overtopping device: Preliminary results of laboratory tests at scale 1:25 on the O^2WC WEC

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AM3 SPIN-OFF
ADVANCED MODELS AND METHODS IN MARITIME ENGINEERING

FRAMEWORK AND AIMS

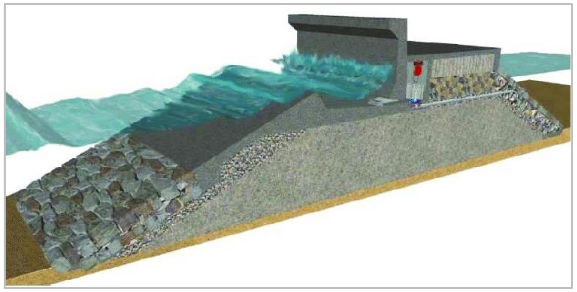
Oscillating Water Column
(air turbine)

CONSOLIDATED BUT….

Oscillating body
(hydraulic motor, hydraulic turbine, linear electric generator)

(*Classification as in Falcão, 2010*)

Overtopping
(low head water turbine)



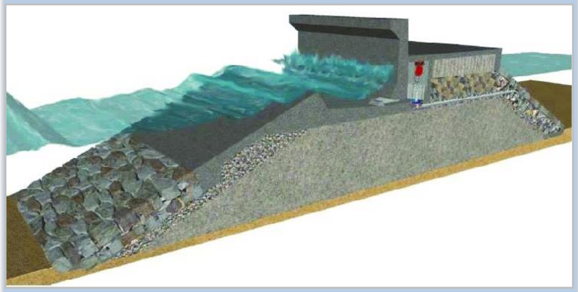
Research is still needed to maximize **conversion efficiency** & **survivability/operability** in severe wave conditions

OWC could have limited operability in energetic sea-states (efficiency loss/ **damage at air turbine** for excessive air pressure).

Relief valve are sometimes used to regulate excessive air chamber pressure (*Falcão & Justino, 1999; Falcão et al., 2003*).

FRAMEWORK AND AIMS

Oscillating Water Column *(air turbine)*	Oscillating body *(hydraulic motor, hydraulic turbine, linear electric generator)*	Overtopping *(low head water turbine)*



(Classification as in Falcão, 2010)

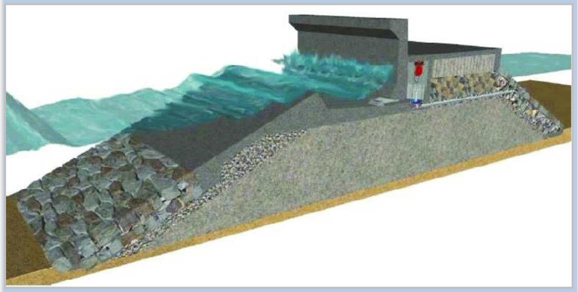
- The stored potential energy is used to activate a low head hydraulic turbine.
- Recognized advantages: (i) **possibility to store the wave energy;** (ii) the low **head hydraulic turbine** is a consolidated technology.
- **BUT…** Wave overtopping takes place just in case of relatively high energetic sea-states.

FRAMEWORK AND AIMS

Oscillating Water Column
(air turbine)

+

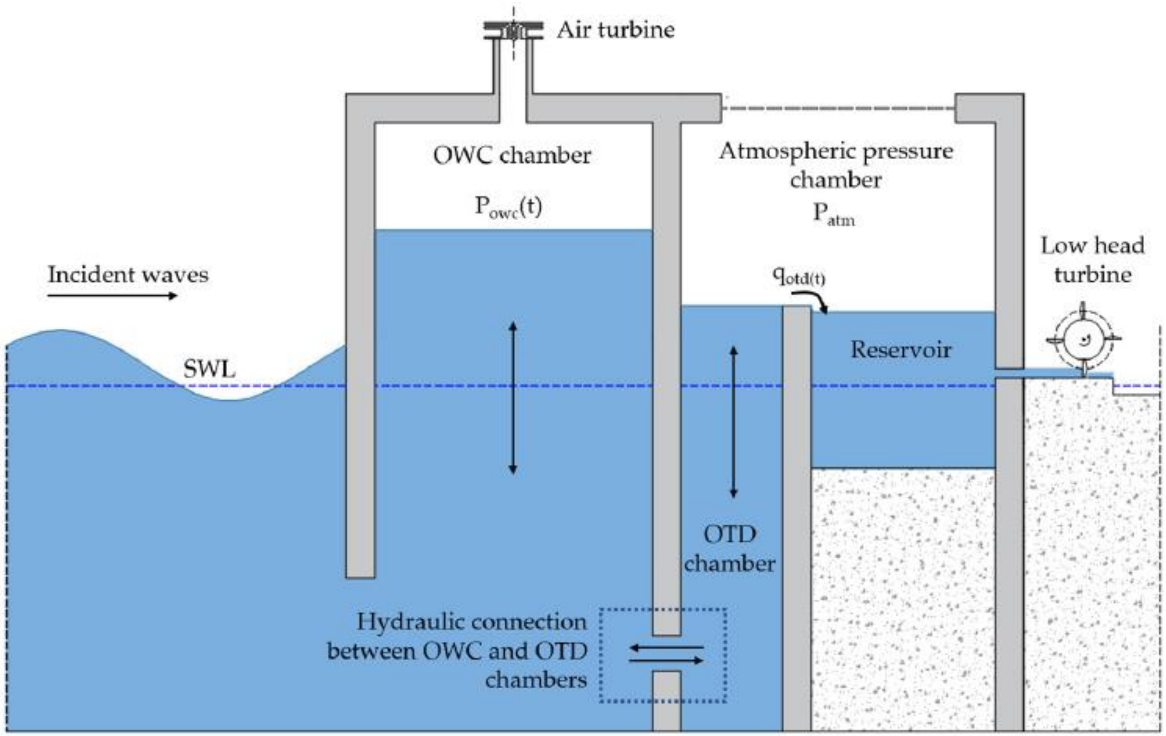
Overtopping
(low head water turbine)



- A **Hybrid OWC-OTD** device referred to as **Oscillating and Overtopping Water Column (O^{2}WC)** wave energy is proposed
- Particularly suitable for breakwater integration
- Its functioning is studied by means of laboratory tests

THE O-OWC CONCEPT

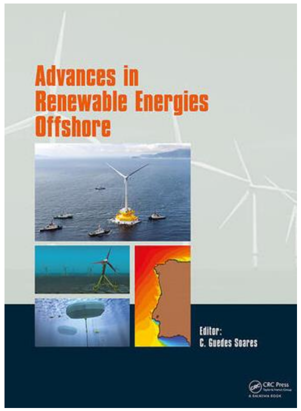
- **First chamber**: OWC chamber equipped with an air turbine for PTO, connected to the second chamber through underwater apertures
- **Second chamber** at atmospheric pressure: when the free surface exceeds the freeboard, water overtops into a reservoir (**potential energy storage**)



To **reduce** the maximum air pressure in the fist chamber (**AVOID DAMAGE**)

To **STORE THE EXCESS OF ENERGY** as potential energy

THE O-OWC CONCEPT



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Laboratory tests on an original wave energy converter combining oscillating water column and overtopping devices

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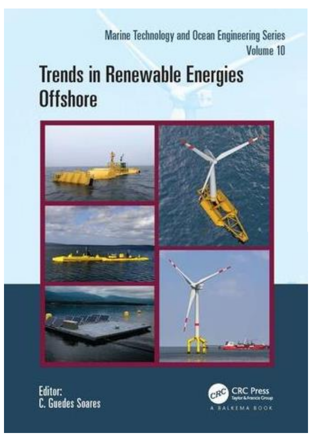

Chapter

Development of a hybrid oscillating water column-overtopping device: Preliminary results of laboratory tests at scale 1:25 on the O2WC WEC

By I. Simonetti, A. Esposito, L. Cappietti

energies MDPI

Article

Experimental Proof-of-Concept of a Hybrid Wave Energy Converter Based on Oscillating Water Column and Overtopping Mechanisms

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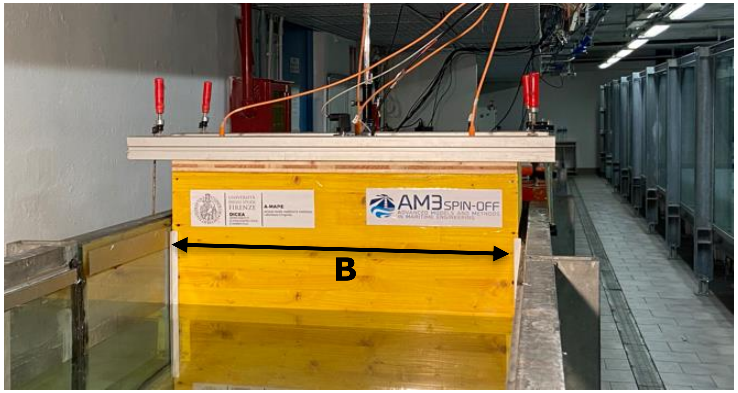
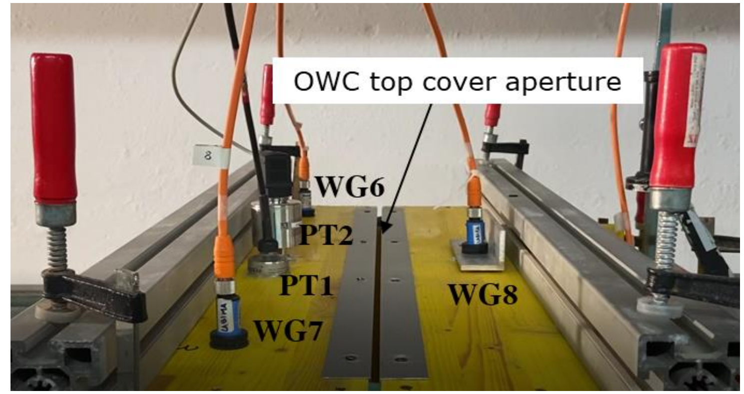
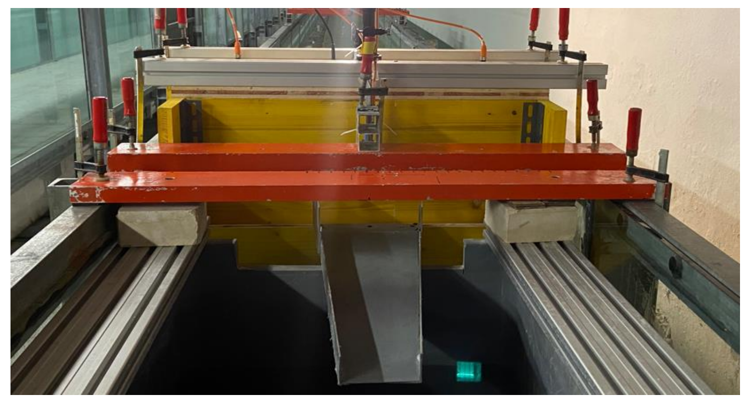
THE SMALL-SCALE MODEL OF THE DEVICE







2D model

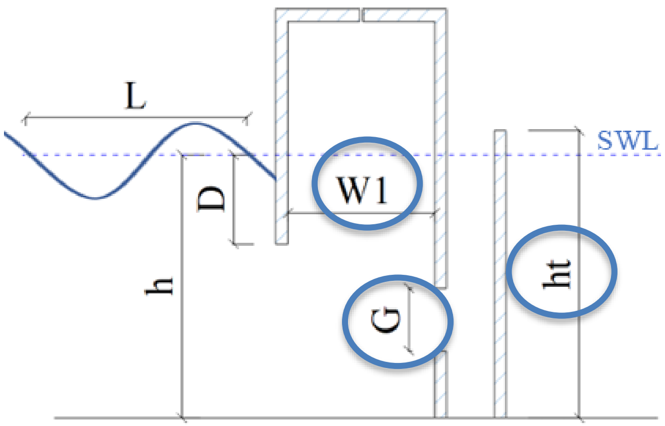
Froude scaling
Scale 1:25

- **Width of the model: B** =79cm
- Slot to reproduce the PTO damping
- Submerged opening connecting OWC and overtopping chambers: variable size **G**
- Overtopping into a reservoir → measured

THE SMALL-SCALE MODEL OF THE DEVICE

Geometry parameters tested:

- OWC chamber width **W1**=0.33 m → **W1/L** between 0.068 and 0.22
- Submerged opening of variable size (**G**=0-10 cm, with a step of 2 cm).
- 3 values of the overtopping threshold in the second chamber (**ht**=0.61 - 0.65 cm)
- Top cover slot: 1.6% of top cover area

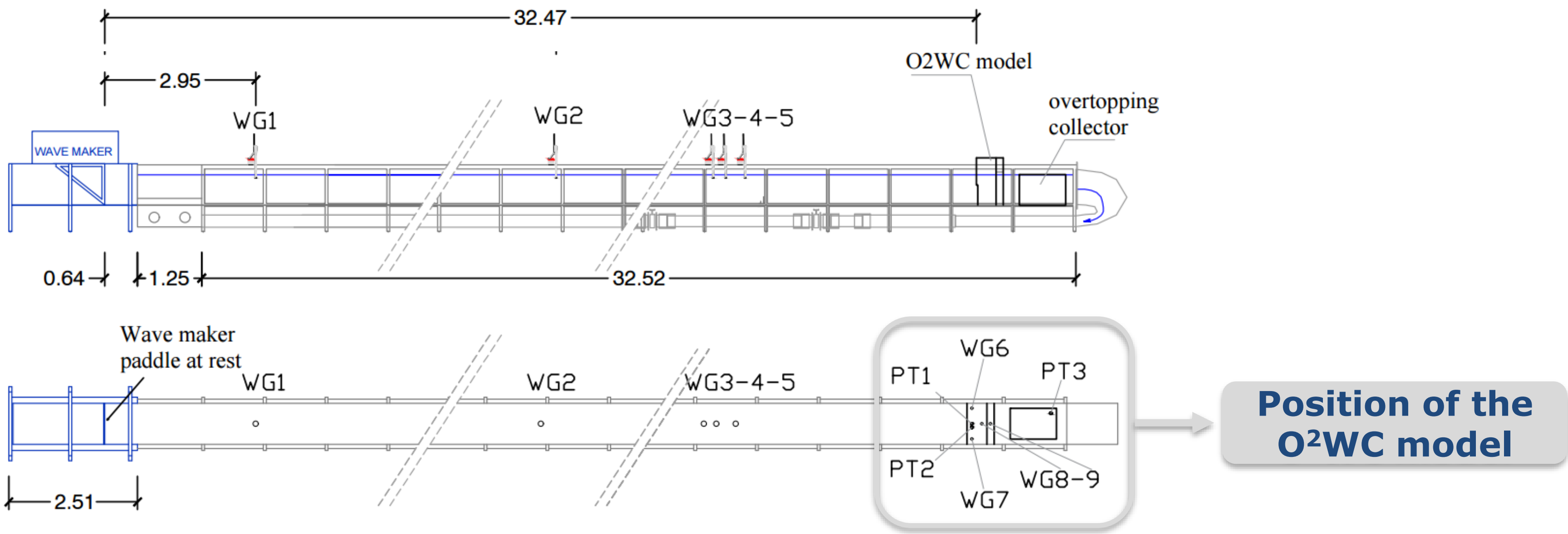


Wave code	scale 1:25			
	H	**T**	**L**	**steepnes**
H01	0.08	1	1.54	0.078
H02	0.08	1.2	2.12	0.057
H03	0.08	1.4	2.33	0.052
H04	0.08	1.6	3.25	0.037
…	…	…	…	…
H16	0.16	1.8	3.79	0.042
H17	0.16	2	4.33	0.037

Test conditions:

- regular waves only
- Wave heights varying between 0.08 and 0.16 m (**2-4 m** at full scale) and periods in the range 1-2 s (5-10 s at full scale)
- water depth **h**=0.59m

CURRENT-WAVE FLUME SET-UP



- 9 **ultrasonic distance sensors** WG, accuracy ±1mm
- **WG6, WG7, WG8** to measure the water level in the OWC chamber, **WG9** to measure the level in the overtopping chamber
- 2 **Pressure Transducer PT** (full scale 100mBar & accuracy ±0.1%FS) for pressure variations in the OWC chamber
- 1 **PT** to measure the water level in the overtopping reservoir
- 200 Hz acquisition frequency

ESTIMATION OF THE CAPTURE WIDTH

$$P_{wave} = \frac{1}{16}\rho g H^2 \frac{\omega}{k}\left(1 + \frac{2kh}{\sinh(2kh)}\right)$$

Period averaged incident wave power [W/m]

$$CW = \frac{P_{extracted}}{P_{wave} \cdot B} = \frac{\left(P_{owc} + P_{otd}\right)}{P_{wave} \cdot B} = CW_I + CW_{II}$$

B → Device width

Power extracted as pneumatic power (air flux) in the first chamber:

$$P_{owc=} \frac{1}{T_{test}} \int_0^{T_{test}} p(t) \frac{d\eta_{owc}}{dt} \cdot S_{owc} dt$$

$p(t)$ → Differential pressure in the OWC air chamber

$\frac{d\eta_{owc}}{dt}$ → Water level

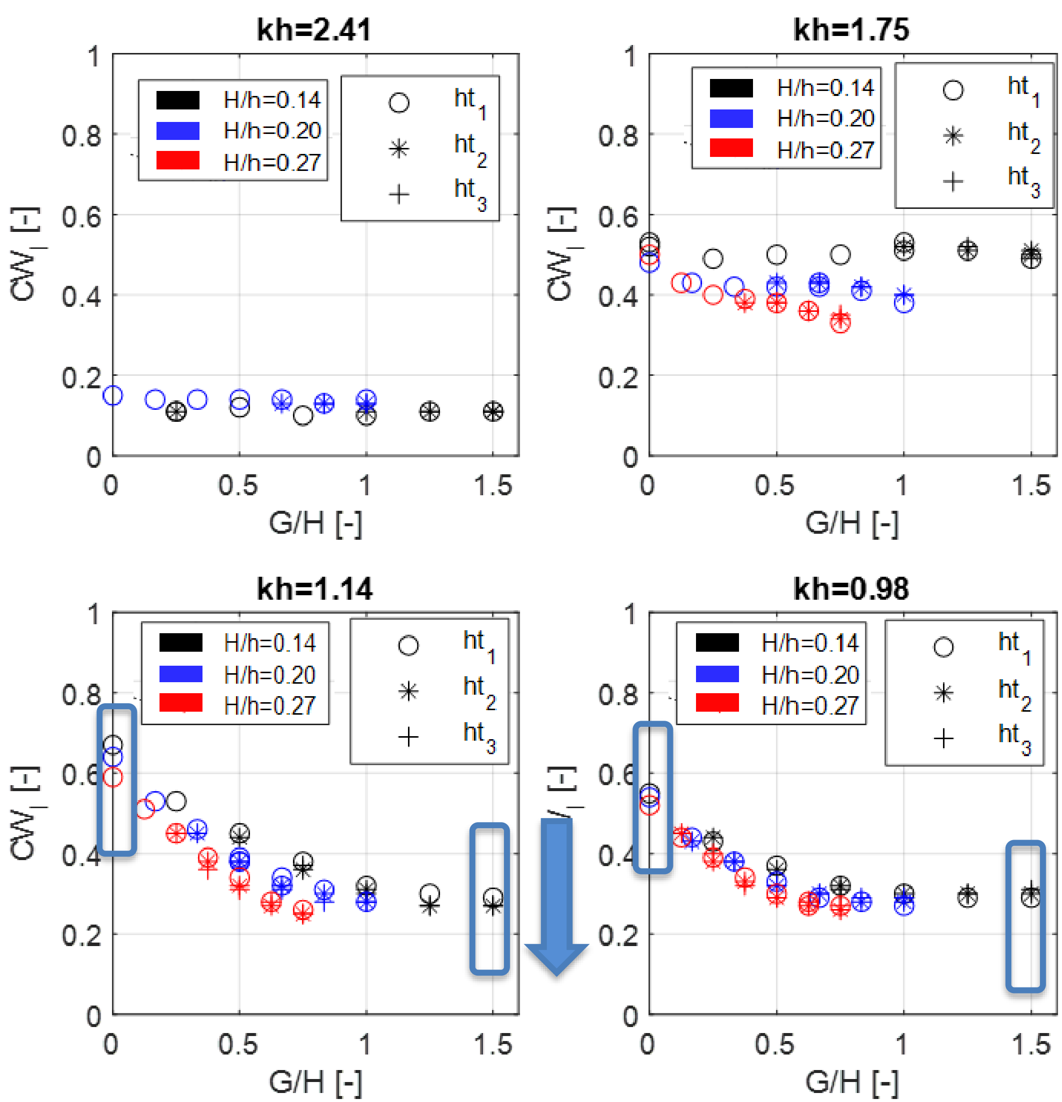
Hydraulic power of the flow overtopped from the second chamber

$$P_{odt=} q_{otd} \cdot \Delta h_{otd} \cdot \rho \cdot g$$

Δh_{otd} → Hydraulic head

q_{otd} → Average flow discharge from the second chamber

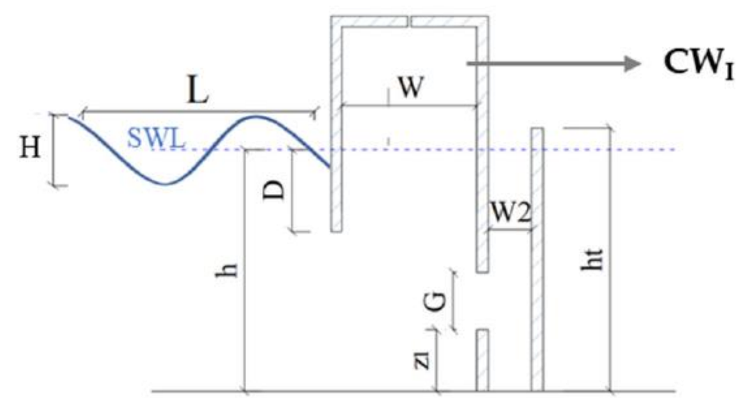
RESULTS



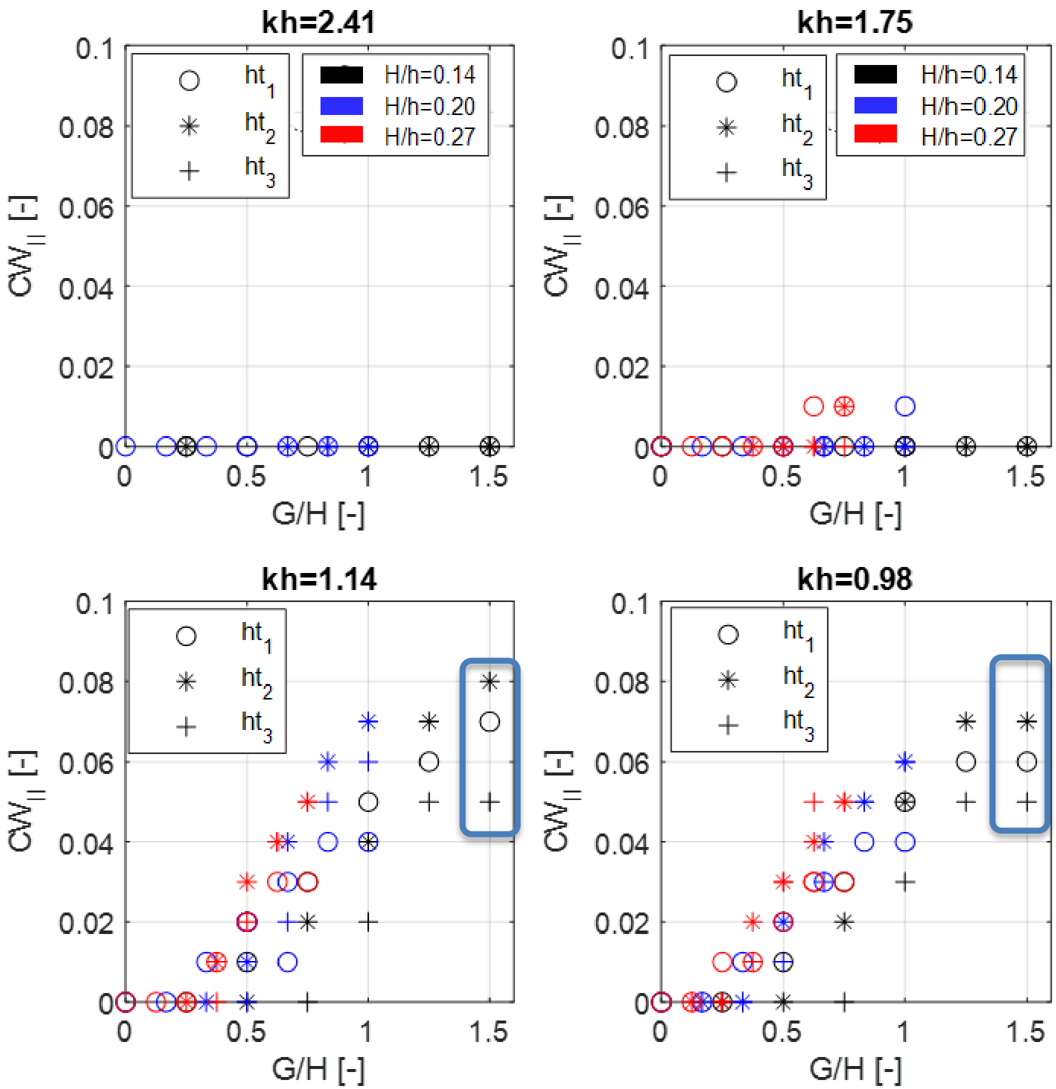
CW_I

First Chamber (OWC chamber)

- For the pure OWC case (G/H=0), **CW_I** has a maximum of **0.7** (for W/L=0.1, H/h=0.14)
- For **kh>1.75, CW_I** remarkably decreases when increasing G/H
- For kh=1.14, **CW_I** decrease from 0.7 to 0.3 for G/H increasing from 0 to 1.5



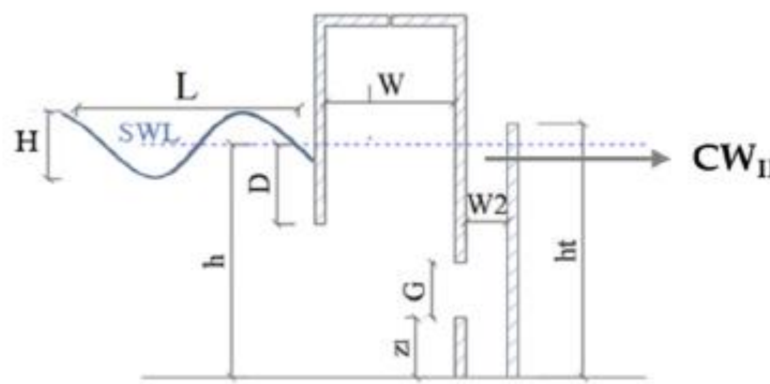
RESULTS



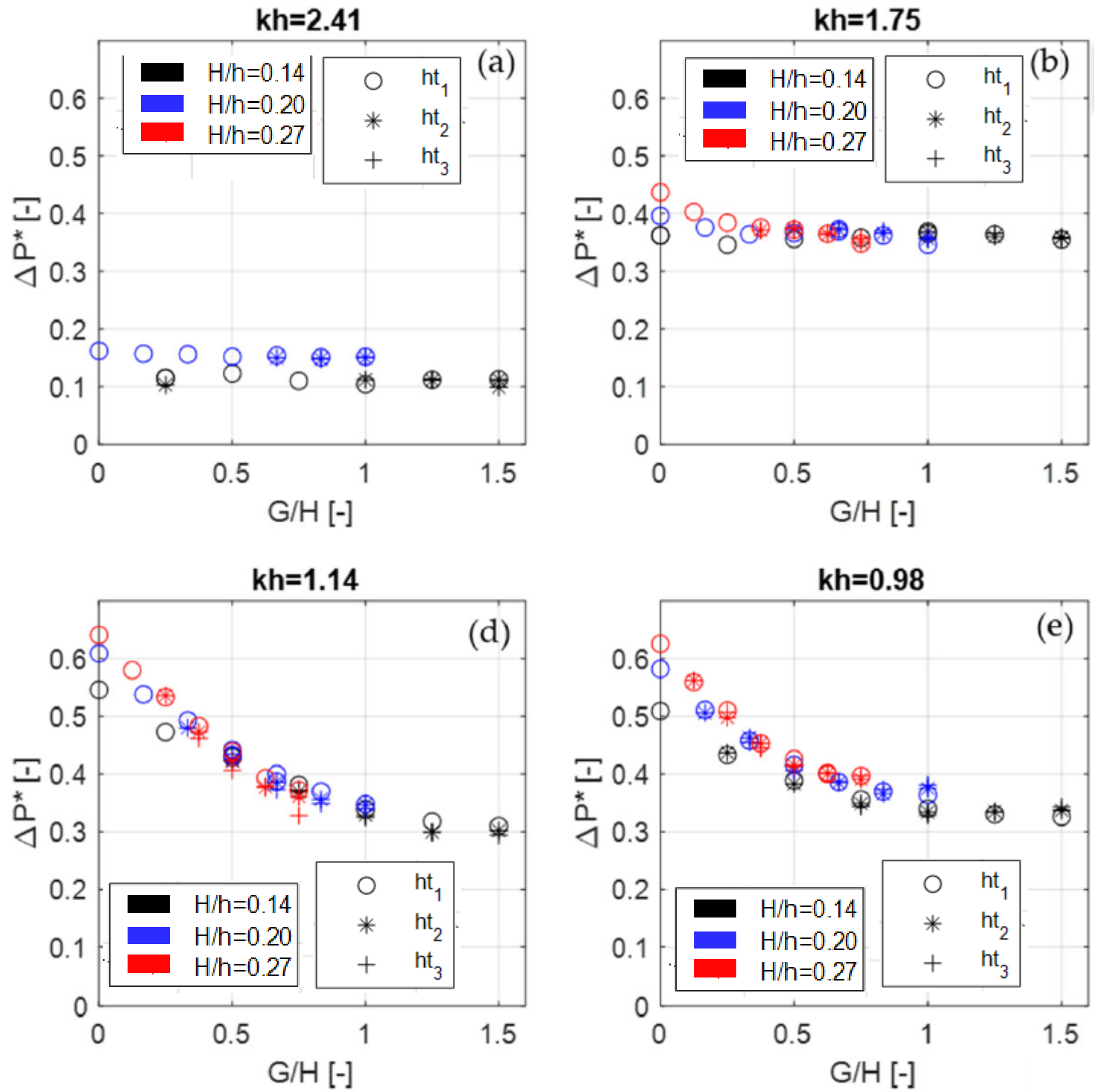
CW_{II}

Second Chamber (overtopping)

- Maximum CW_{II} of 0.08
- Remarkable increase with G/H for G/H < 1
- Highest CW_{II} values for ht_2 → the explored range contains the optimum!



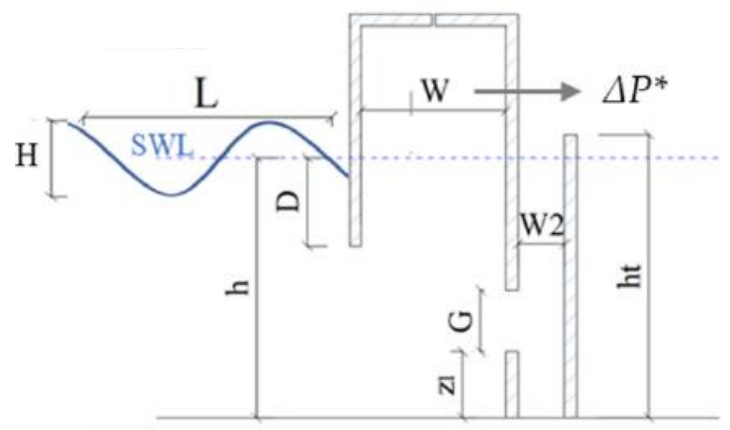
RESULTS



Air chamber pressure

$$\Delta P^* = \frac{\Delta P}{\rho g H}$$

For kh > 1.75, maximum air pressure oscillation amplitude up to 50% lower are obtained



CONCLUSIONS

Laboratory tests

Adding the OTD device to the OWC device can be useful to **limit the maximum air pressure in the OWC chamber,** aiding to implement strategies for **safe functioning of the air turbine**

The decrease of CW_{I} resulting from the lower air pressure **can be only partially recovered** by the additional CW_{II} in the OTD chamber

Outlooks

Results can be used for calibration/validation of **numerical models** for further optimization of the concept

The present results are limited to the primary efficiency, to fully asses the potentiality of the device in terms of energy extraction, further studies including the PTO are fundamental (e.g. the maximum air pressure/air flowrates are strongly turbine-specific) → **wave-to-wire models**

THANKS FOR YOUR ATTENTION

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