On-line workshop:

Avanzamento Delle Energie Rinnovabili Marine: Strategia Europea, Attività In Corso In Italia, e Aggiornamento Del Piano D'azione Nazionale Del Cluster-Big

24-25 Febbraio 2022

‘CFD Modelling of Floating Bodies Interaction Under Waves Using OpenFOAM®’

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Università di Bologna

On-line workshop, 24-25 Febbraio 2022

Presentation Outline

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ACTIONS

02
RESEARCH IDEA

03
LABORATORY EXPERIMENTS AND CFD MODELLING

04
RESULTS

05
CONCLUSIONS

1

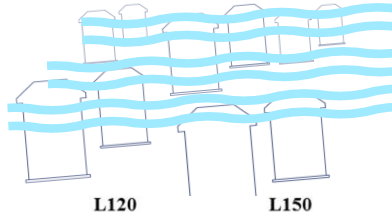
ACTIONS

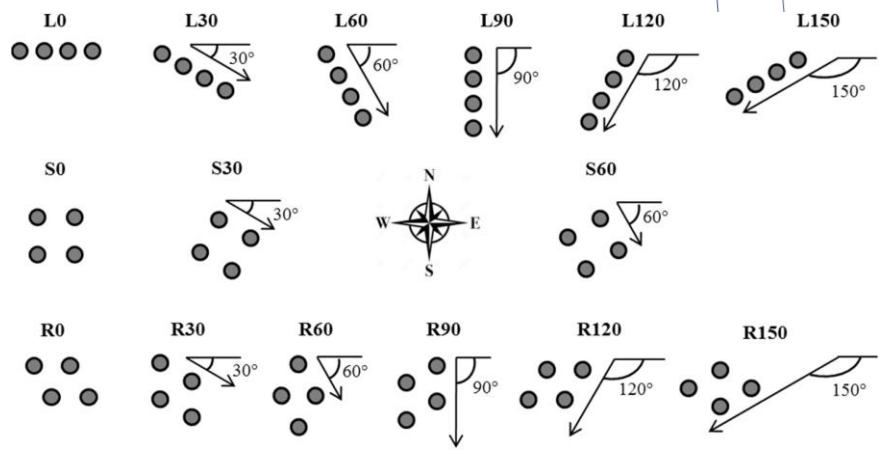
Renewable Energy from Seas

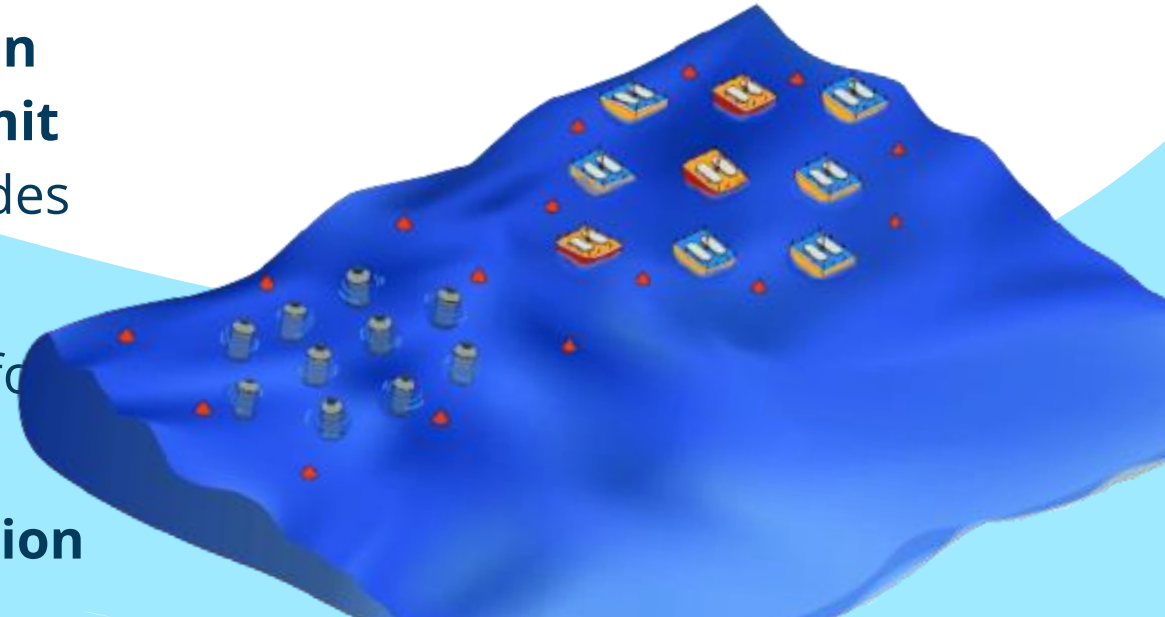
- RICERCA Modelling(CFD e Modelli a potenziale WEC-SIM) e Test in lab
- https://site.unibo.it/vasca-marittima/it
- Offshore Engineering - Laurea Magistrale - Ravenna (unibo.it)

WEC Farms

- A **WEC farm** can count hundreds of units and extend over kilometres, making **full-scale experiments** nearly impossible
- To **simulate** multiple **interacting WECs** and the **farm impact** on the **surrounding** environment is a very challenging task
- **Experimental tests on WEC array are very rare in literature** and the lack of experiments is now a **limit** in the development and validation of simplified codes of WEC Array interaction
- To provide innovative **numerical methodologies** fo the **WEC array design**
- To provide an **experimental database** for **validation** of numerical models

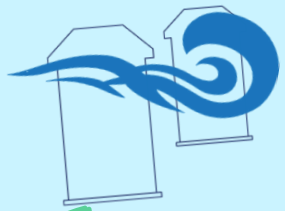




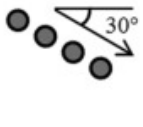
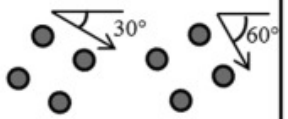
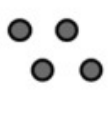
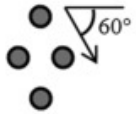
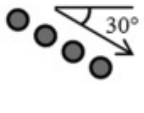
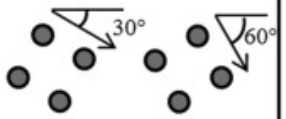
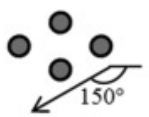
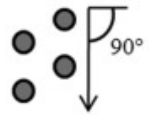
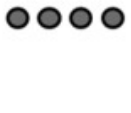
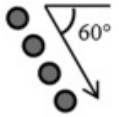
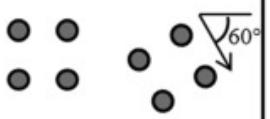
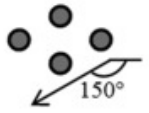
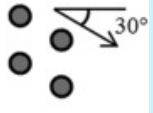
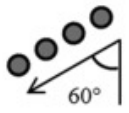
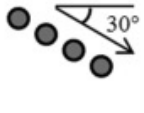
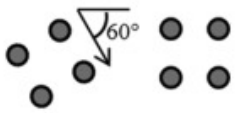
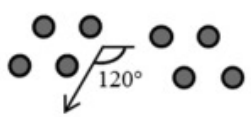


2

RESEARCH



2.1 Array

Alghero	-5.8%	+1.3%	-3.2%	+1%	-5.1%	+1.5%
						
	d = 5D	d = 10D	d = 5D	d = 20D	d = 5D	d = 20D
Mazara	-5.5%	+3.4%	-2.1%	+1.3%	-3.9%	+1.7%
						
	d = 5D	d = 5D	d = 5D	d = 20D	d = 5D	d = 20D
Ponza	-5.7%	+3.2%	-1.5%	+1.5%	-3.6%	+2.1%
						
	d = 5D	d = 5D	d = 5D	d = 20D	d = 5D	d = 10D
La Spezia	-5.1%	+3.3%	-2.1%	+1.3%	-3.8%	+1.6%
						
	d = 5D	d = 5D	d = 5D	d = 20D	d = 5D	d = 20D

WEC lines should stay at 30° with respect to wave fronts, square arrays should avoid the alignment between wave direction and square sides and rhombus layout should be oriented so that the two rows are parallel to wave fronts.

The distance among the units plays a key role in array performance. Too close or too spaced units can hardly benefit of constructive wave interferences]. The optimum distance is between 10 and 20 buoy diameters.

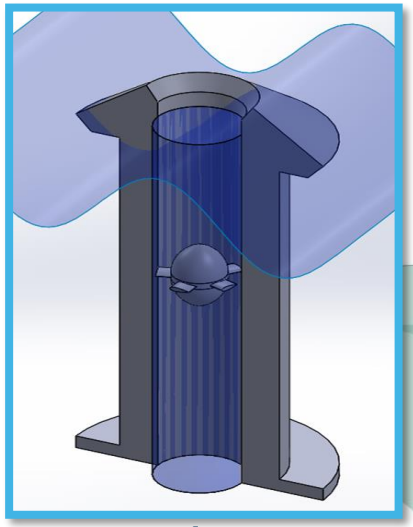
The optimum array designs are: a rhombus layout with WEC distance equal to 20D at Alghero and a linear layout with 5D spacing at the other locations.
the optimum array orientation can be assessed as if the waves were coming by one direction, equal to the prevailing one.

The optimum wave farm designs lead to power gains from 1.5% (at Alghero) to 3.4% (at Mazara del Vallo).

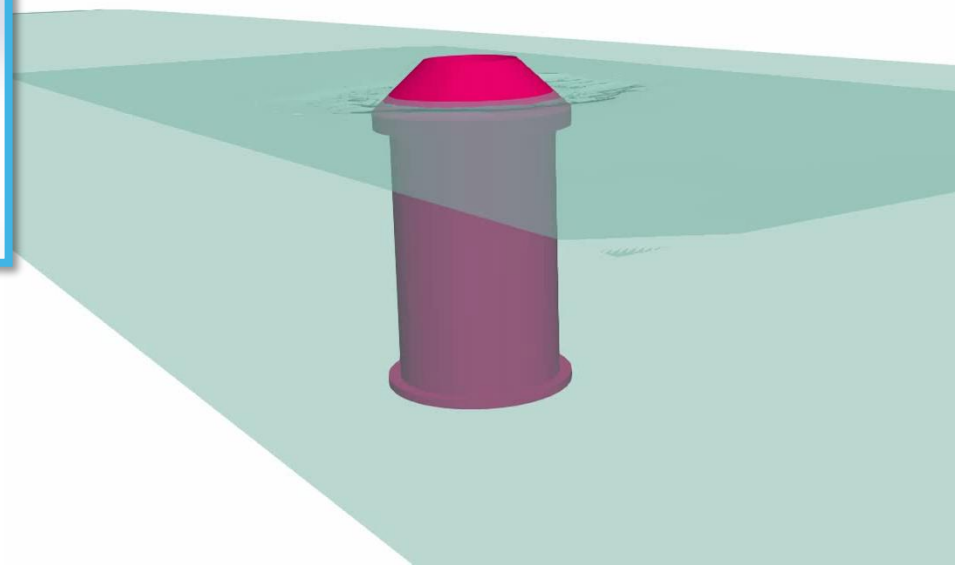
Bozzi S., Giassi M., Moreno Miquel A., Antonini A., Bizzozero F., Gruosso G., Archetti R., Passoni G.. (2017). Wave energy farm design in real wave climates: the Italian offshore. ENERGY. vol.122, p. 378-389. ISSN: 0360-5442.

2.2 MoonWEC Device

- MoonWEC – Invented by **Dr. Adrià Moreno Miquel** and **Prof. Dr. Renata Archetti** – patented by the University of Bologna
- Composed of → **cylindrical floater** + **bottom disc** (+ wells turbine for the power generation)
- Placed in water → forms a virtual body, i.e., **moonpool**
- **Under the action of waves** → both the **floater and moonpool get excited**
- Power generation → by **relative motion between floater and moonpool**



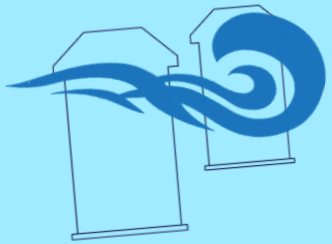
MoonWEC layout (NTS)



3

LABORATORY EXPERIMENTS AND CFD MODELLING

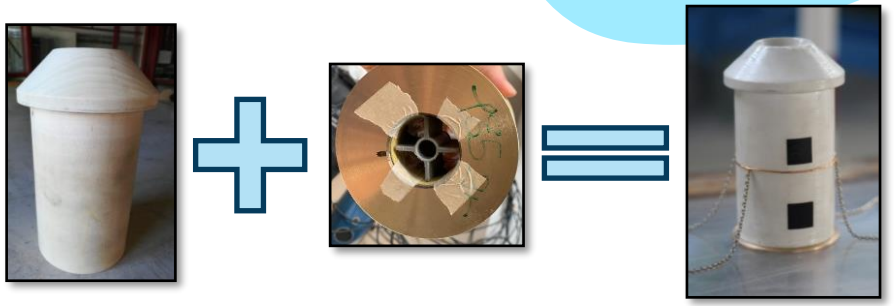
3.1 CFD Model and Experiments



- **Computational Fluid Dynamics (CFD) modelling** and **laboratory experiments** for the MoonWEC in **Wave Flume**
  - Prototype **A** → scale of **1:64**
  - Numerical Wave Tank (**NWT**) → **Simulates Experimental Wave Flume**
- **CFD modelling** and **laboratory experiments** for the MoonWEC in **Wave Basin**
  - Prototype **B** → scale of **1:40**
  - Numerical Wave Tank (**NWT**) → **Simulates a PART of Experimental Wave Basin**
- Open-source CFD software **OpenFOAM®**

3.2 MoonWEC Prototypes

- The floater was made from **wood**
- The **brass disc** was attached at the bottom to control the buoyancy
- All the dimensions (masses) were designed to achieve the required draft
- Total height of the **Prototype A** for **Wave Flume** experiments → **156 mm**
- Total height of the **Prototype B** for **Wave Basin** experiments → **250 mm**



Single MoonWEC Prototype (A) for Wave Flume

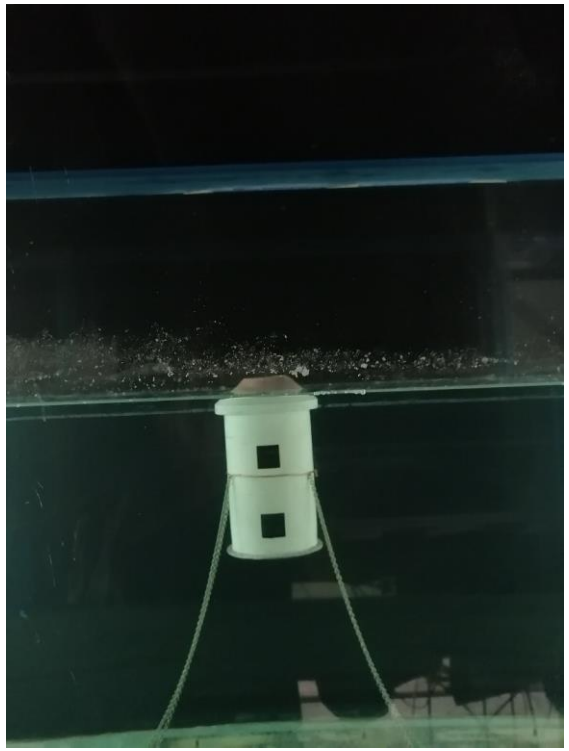
4 MoonWEC Prototypes (B) for Wave Basin

3.3 Experiments in Wave Flume

- **Experimental Wave Flume** → 12 m long x 0.5 m wide x 0.7 m deep (**0.4 m water depth** for the current study)

- Wave generation → cuneiform-shaped **piston-type wave-maker** on the L.H.S.

Wave Flume Experimental Setup with a Single MoonWEC Prototype

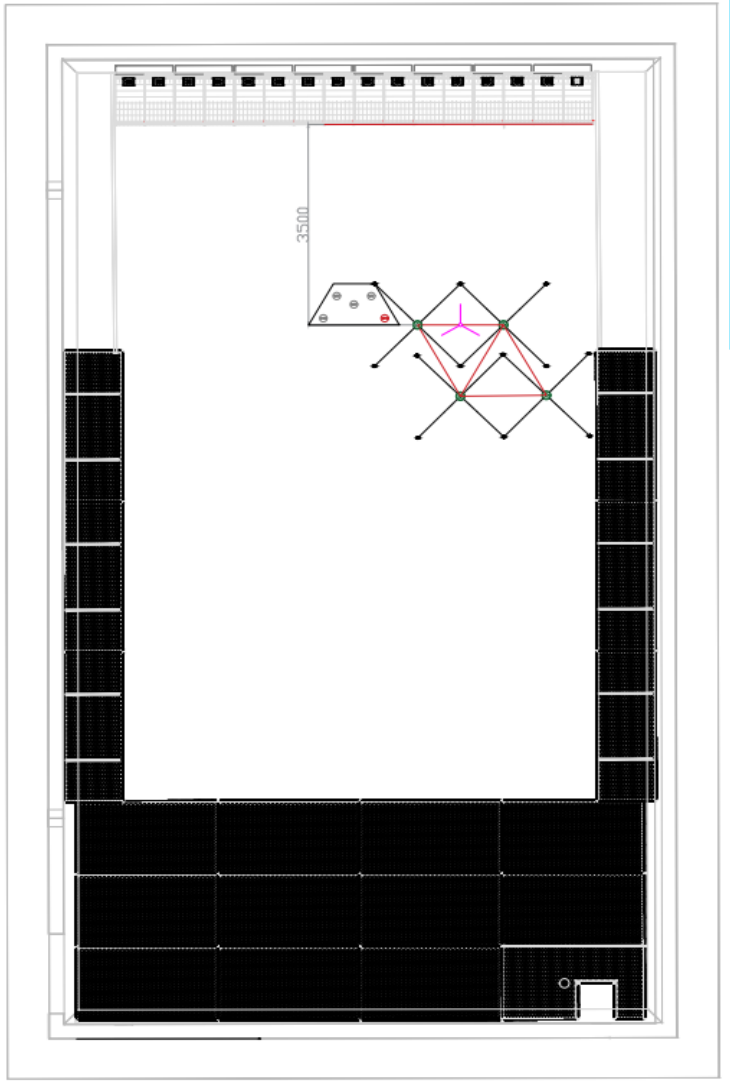


MoonWEC Prototype as Seen from the GoPro Camera Outside Flume

3.4 Experiments in Wave Basin

- **Laboratory of Hydraulics Engineering**, UniBO
- **Experimental Wave Basin** → 20 m long x 10 m wide x 1.2 m deep (**0.7 m water depth** for the current study)
- Wave generation → cuneiform-shaped **piston-type wave-makers in series**
- Data recording → **GoPro camera** (inside the basin, underwater)

Wave Basin (Side View)



Wave Basin Plan (Top View)

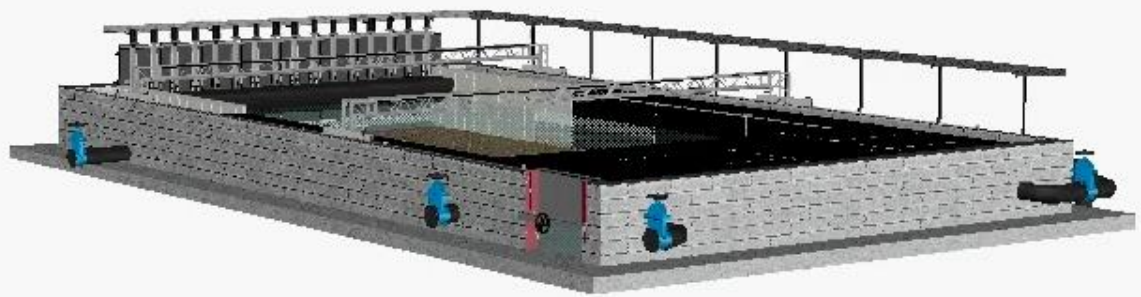
VASCA MARITTIMA | WAVE BASIN

LABORATORY OF HYDRAULIC ENGINEERING

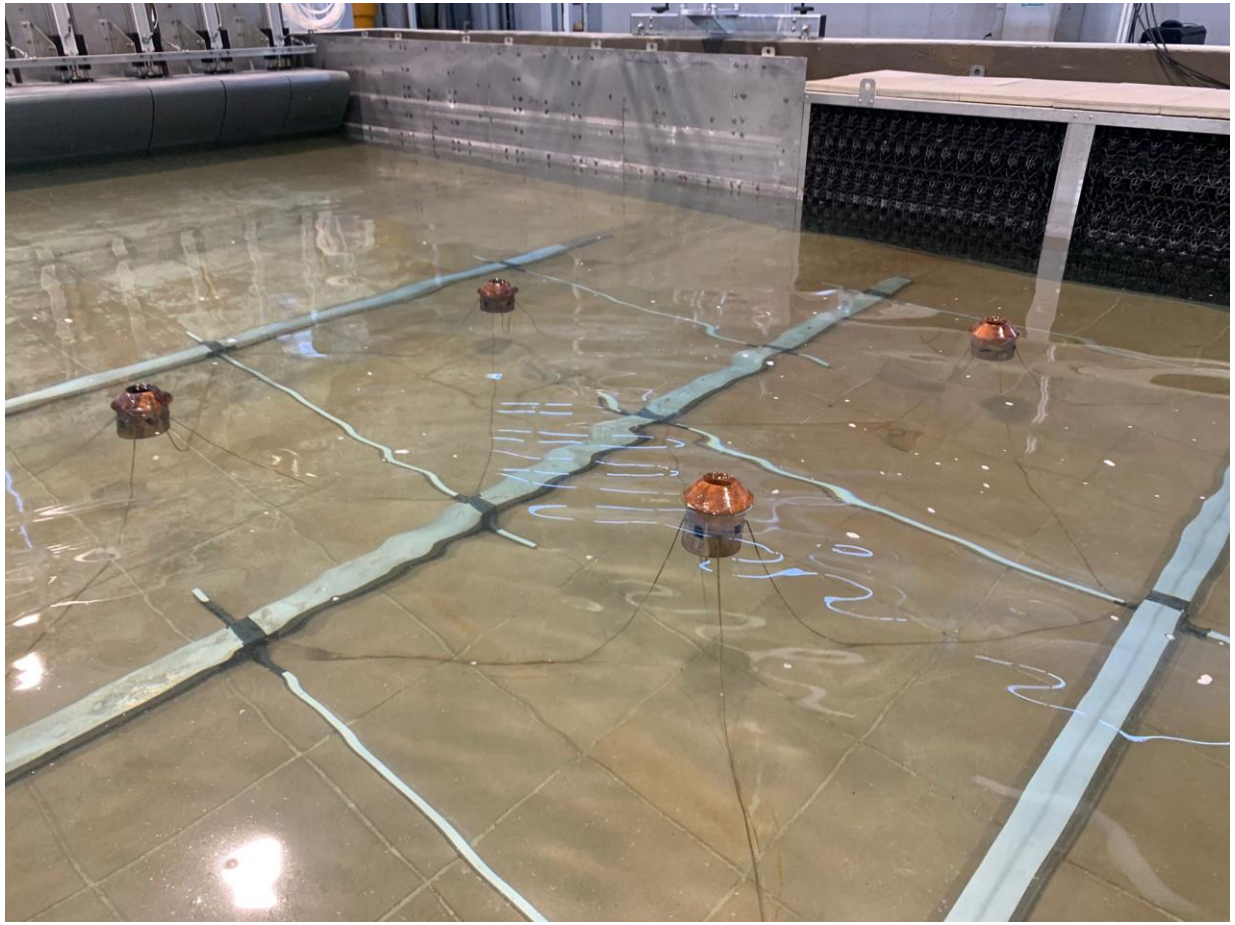
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

DIPARTIMENTO DI
INGEGNERIA CIVILE, CHIMICA,
AMBIENTALE E DEI MATERIALI

CENTRO
INTERDIPARTIMENTALE
DI RICERCA INDUSTRIALE
EDILIZIA E COSTRUZIONI



3.4 Experiments in Wave Basin



Wave Basin Experimental Setup with 4 MoonWEC Prototypes

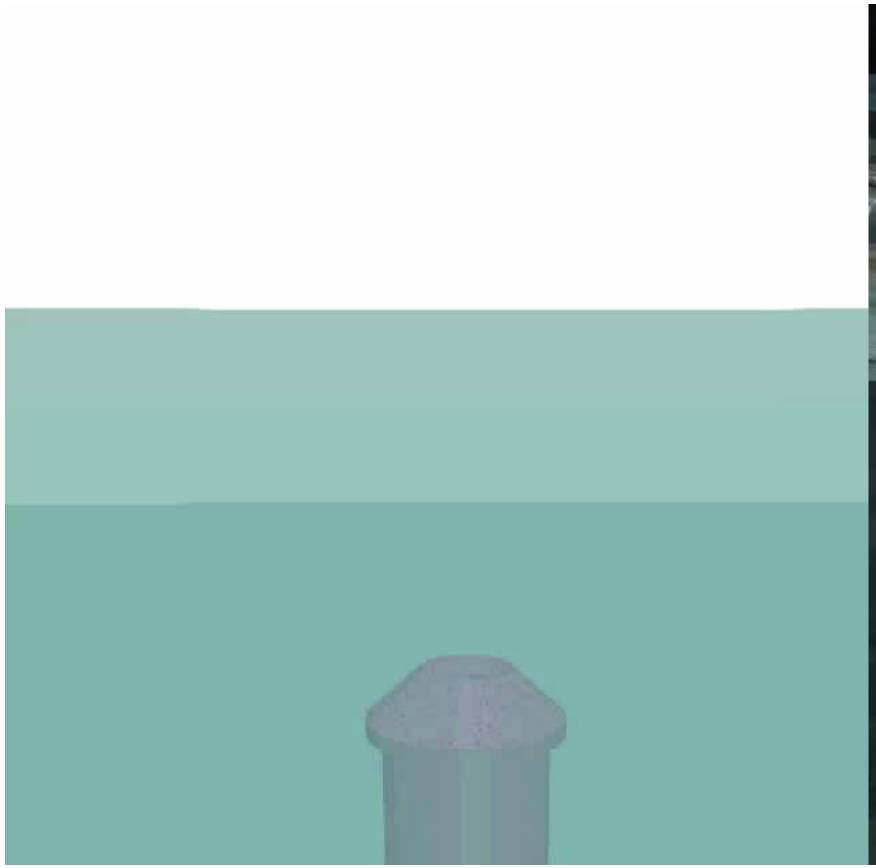
MoonWEC Prototype as Seen from Underwater GoPro Camera

4

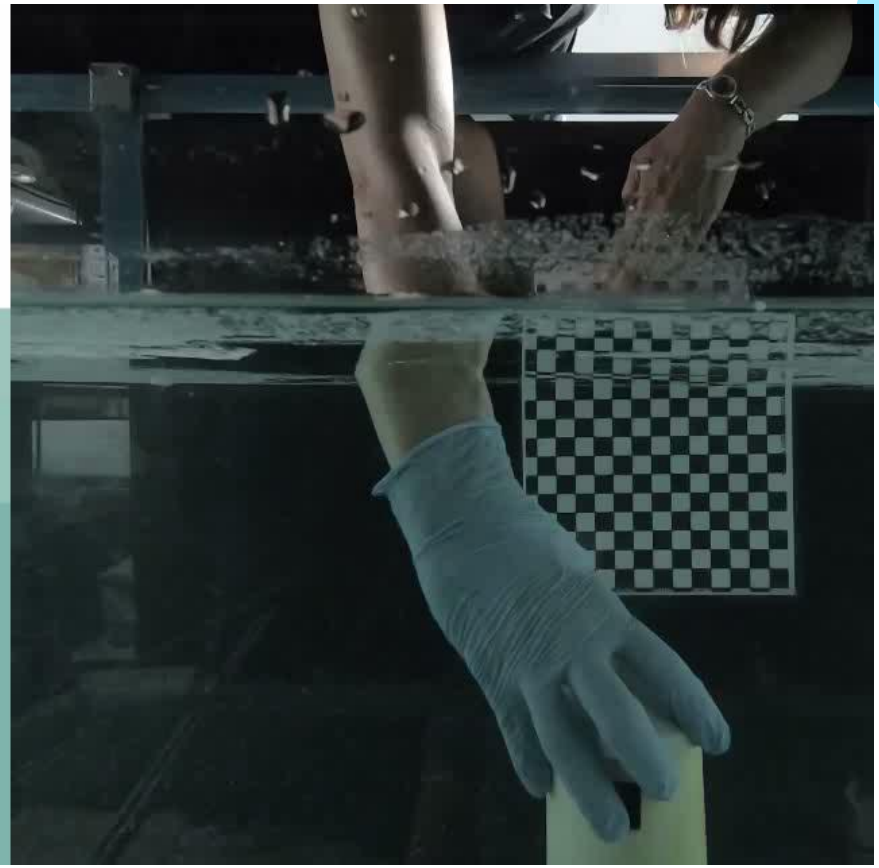
RESULTS

4.1 Prototype A Initial Results

Free Decay Test → calculation of natural period



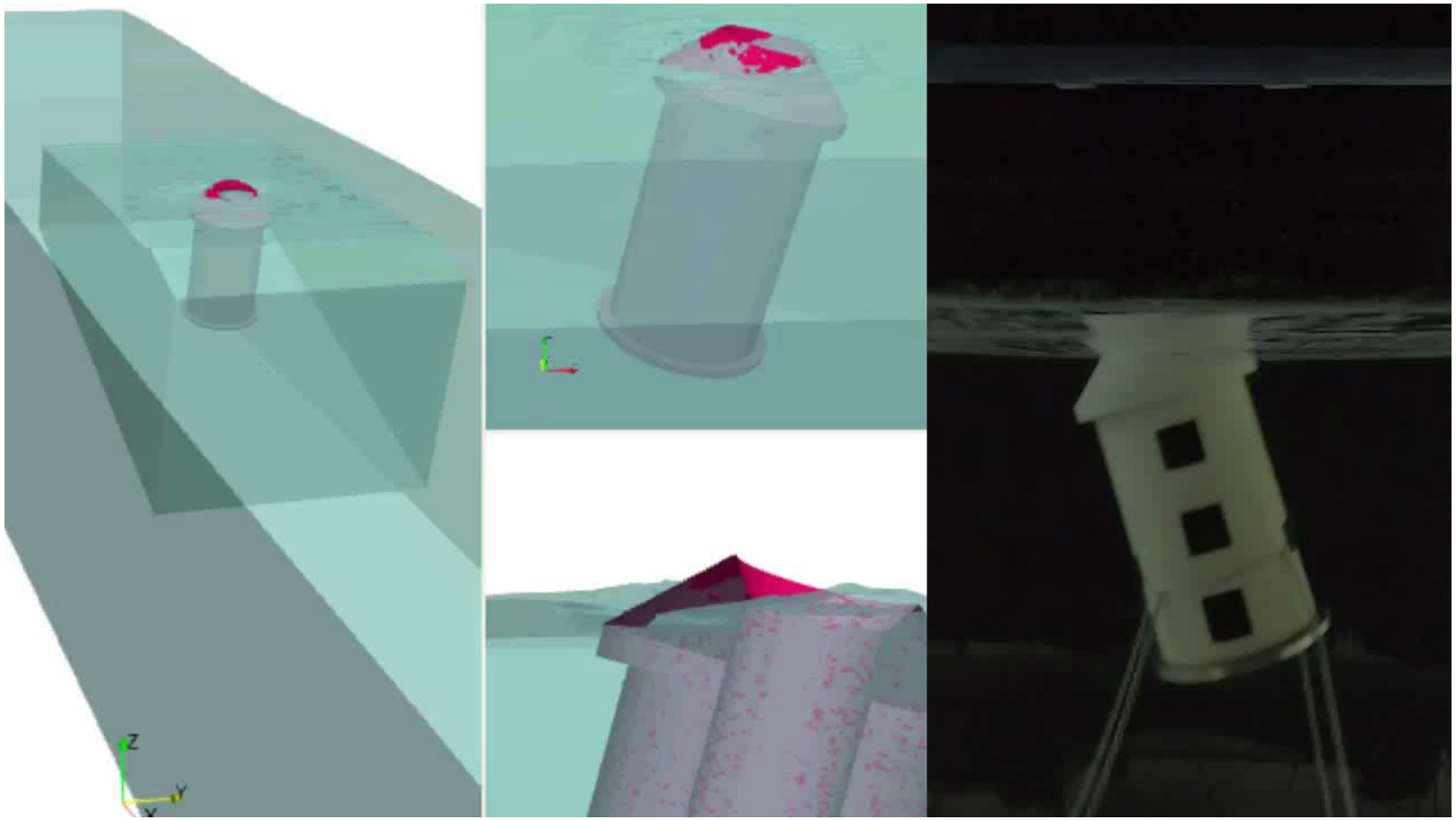
OpenFOAM



Experiment

4.1 Prototype A Initial Results

Wave-Interaction Test → Wave Height of 10 mm and Period of 0.935 s

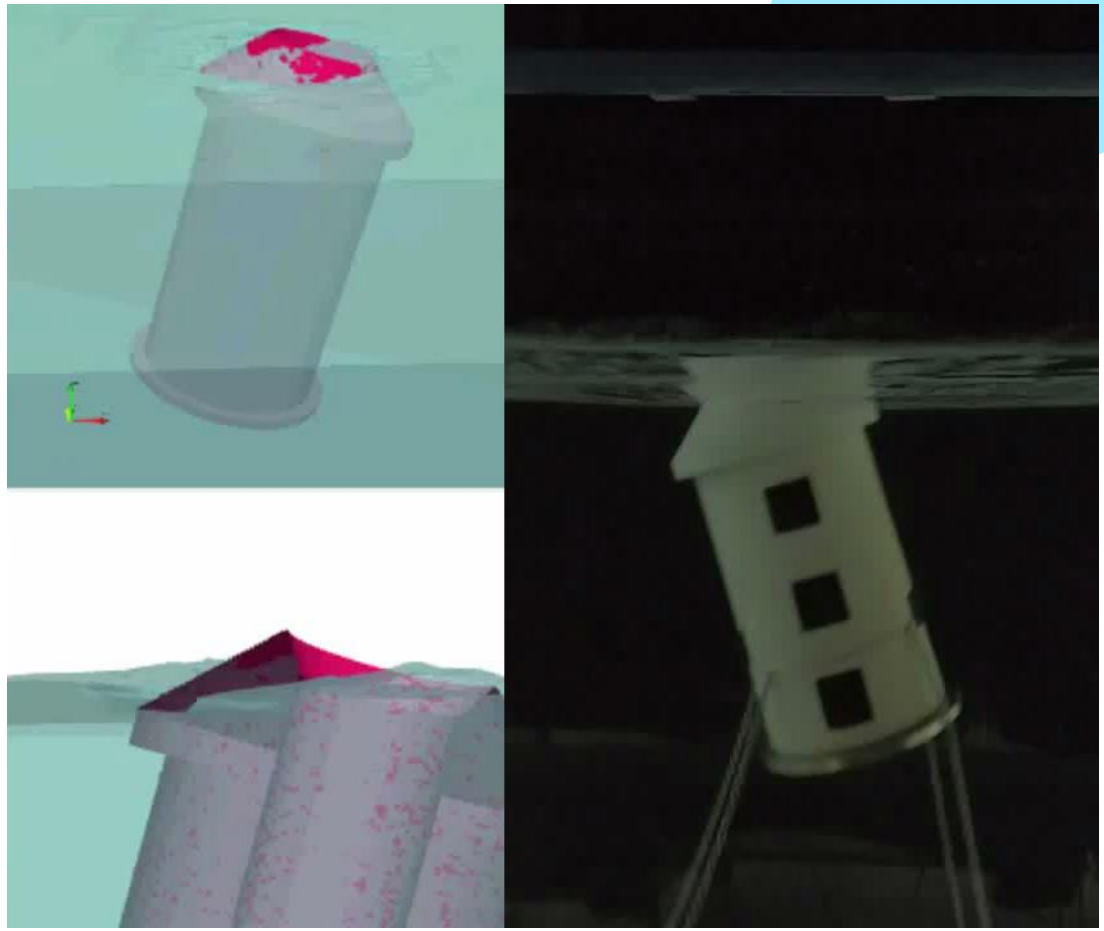


OpenFOAM

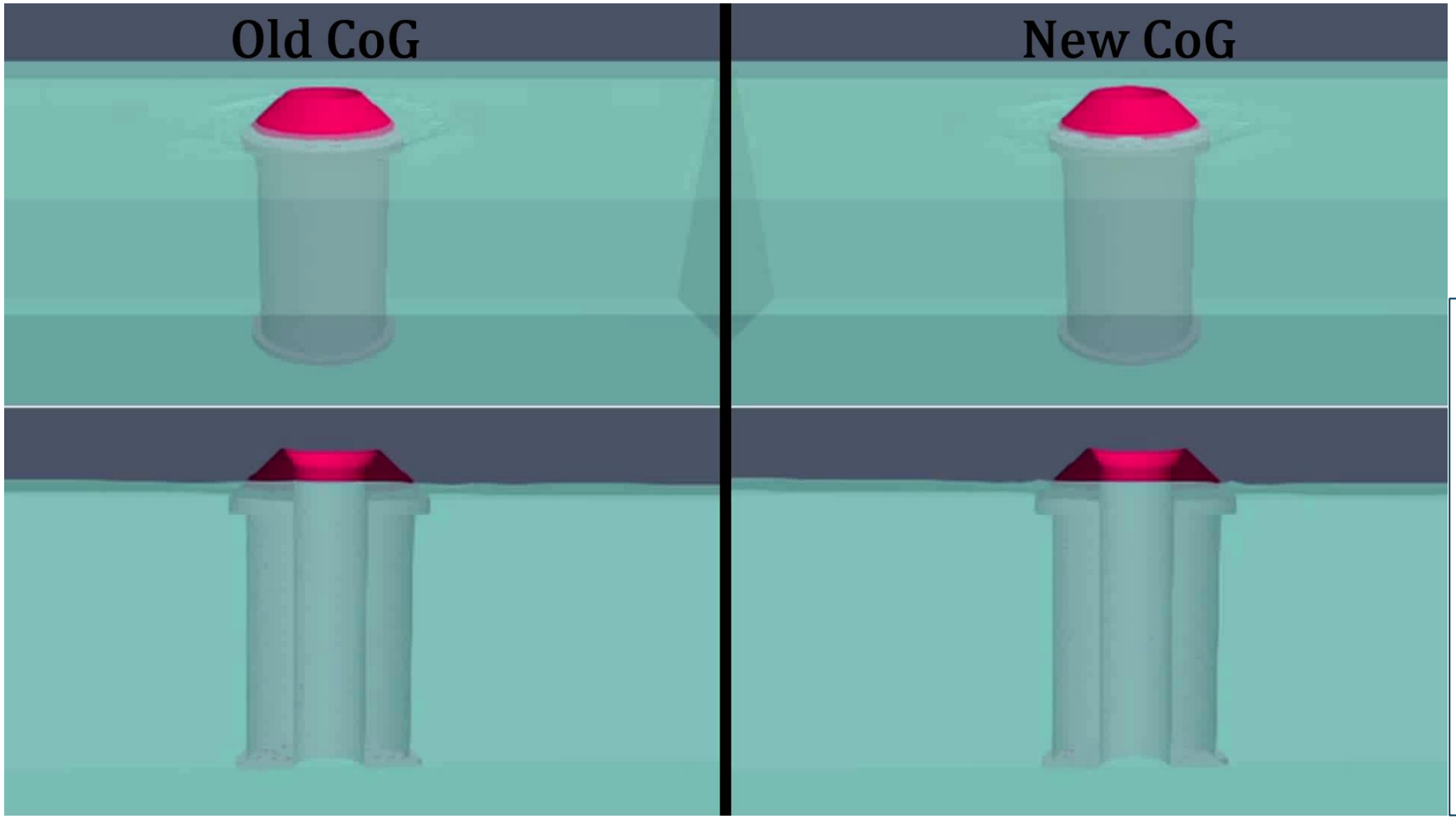
Experiment

4.2 Resolving Pitch Problem for Prototype A

- **Pitch** observed to be **higher than expected** for the prototype
- Current center of gravity **(CoG) → 51.92 mm** (with the origin at the bottom-center of the MoonWEC)
- The center of buoyancy **(CoB)** is around **72 mm**
- **Shifting the CoG towards the CoB**, making it 67 mm and 71.5 mm in CFD Model



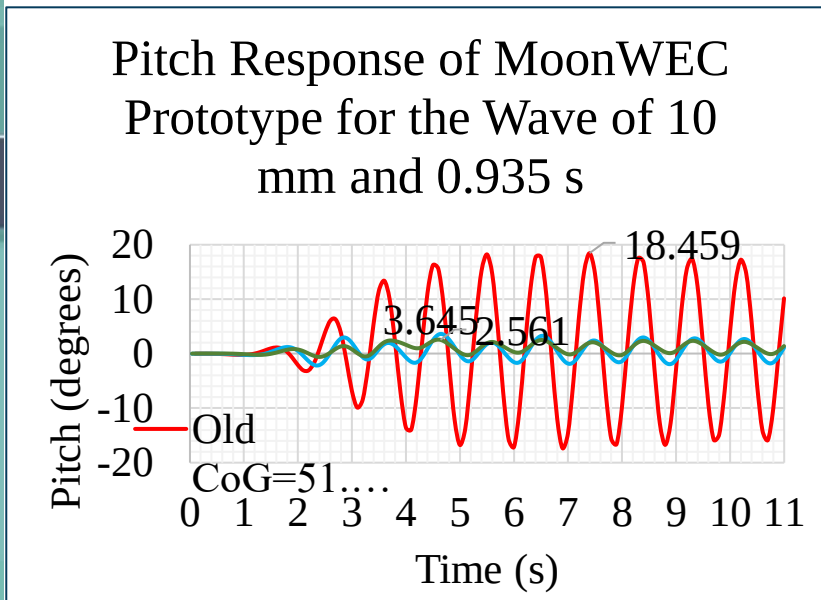
4.4 Resolving Pitch – CFD Wave Test Results



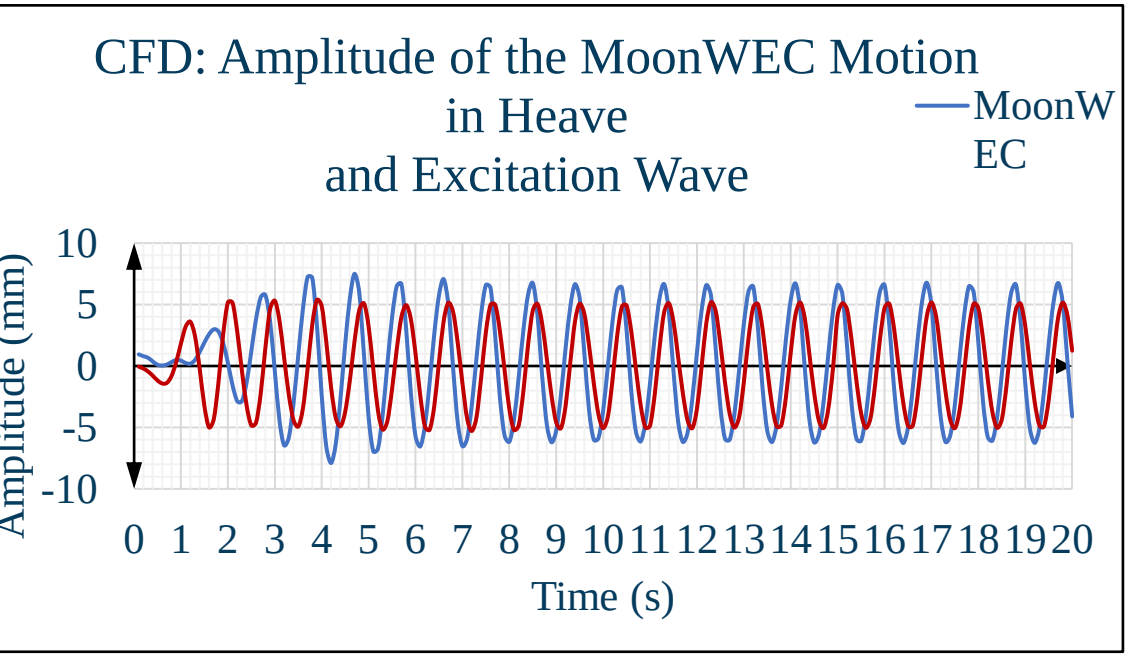
CoG at 51.92 mm

CoG at 67 mm

$$RAO\ in\ Pitch\ = \frac{6.523}{5.068} = 1.287$$



4.5 Prototype Results



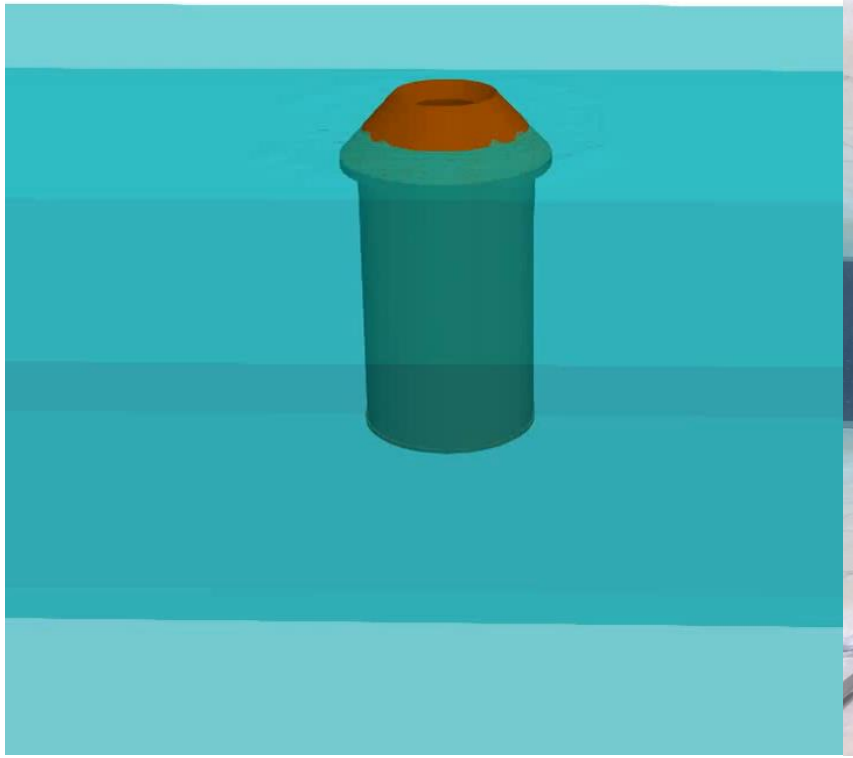
$$RAO = \frac{6.523}{5.068} = 1.287$$

4.5 Prototype B Initial Results

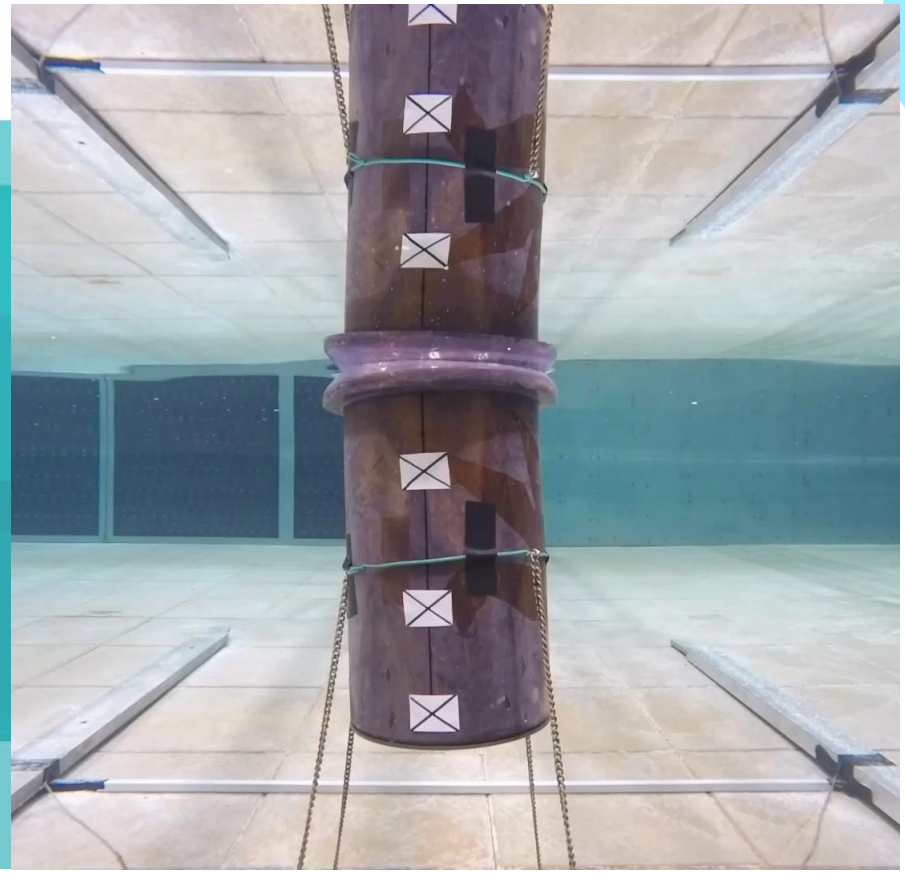
Wave Basin Experiments, Laboratory of Hydraulics Engineering, UniBO

4.5 Prototype B Initial Results

Wave-Interaction Test → Wave Height of 55 mm and Period of 1.4 s

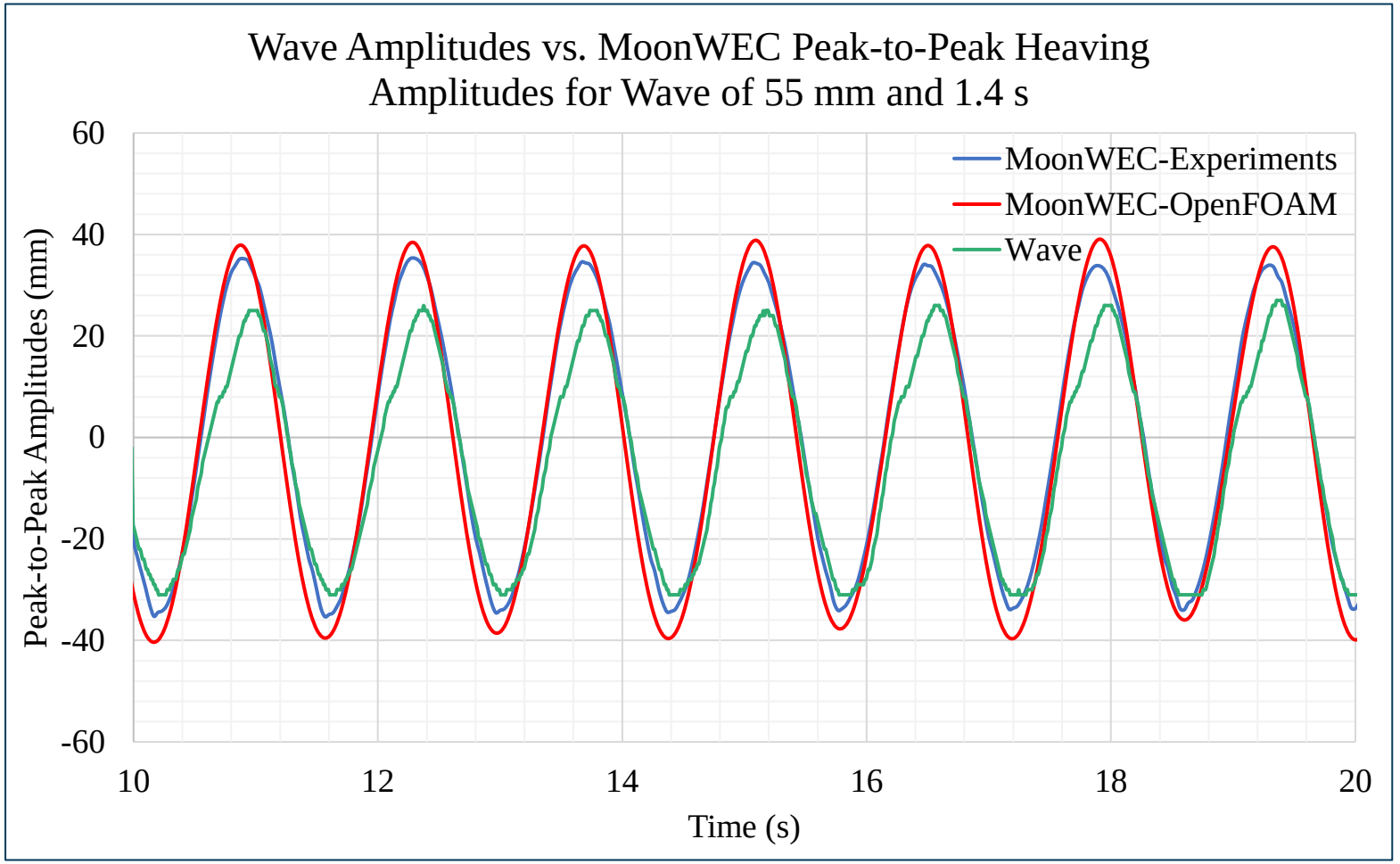


OpenFOAM



Experiment

4.5 Prototype B Initial Results



$$RAO = \frac{36.6}{27.5} = 1.33$$

5

CONCLUSIONS

5.1 Conclusions

- **CFD model** provides **good results** in relation to the laboratory experiments
- **MoonWEC** Prototype shows **positive results** for the PTO motion → the higher **RAO** and the **relative motion**
- **TRL of 3-4**, i.e., the small-scale prototype validation in laboratory environment
- CFD model → an **additional tool** to cross-check the physical experiments and to verify for any **physical model changes**
- **Access to internal dynamics** – Point details → in space + in time

5.2 Future Work

- **WEC array** testing
- **CFD model to be revised** to incorporate the mooring lines, wells turbine and multiple WECs
- **PTO**
- **Complementarity** considering other sources of renewable energy **(Wave energy,** with **solar** and **wind** energy**)**
- **Power production** and **survivability** of the proposed systems

THANK YOU