Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

MORE LAB

Politecnico di Torino

Progettazione e prototipazione del PeWEC 2

Torino, 14/12/2021

Sergej Antonello Sirigu, Giovanni Bracco, Giuliana Mattiazzo

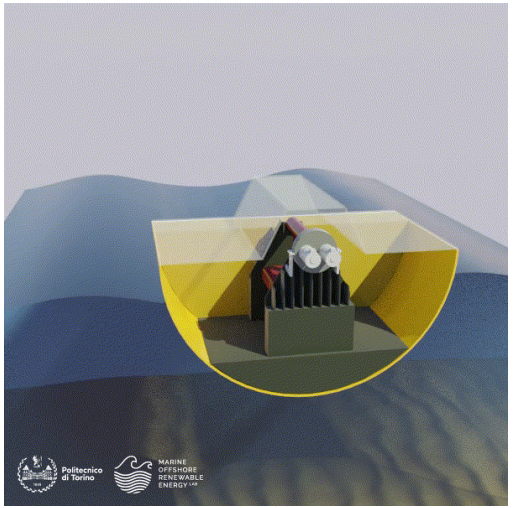
Summary

- The PeWEC device
- Technology roadmap
- Optimization and design process
- Mooring system
- Prototyping of the device
- Experimental campaign
- Next steps

The PeWEC device

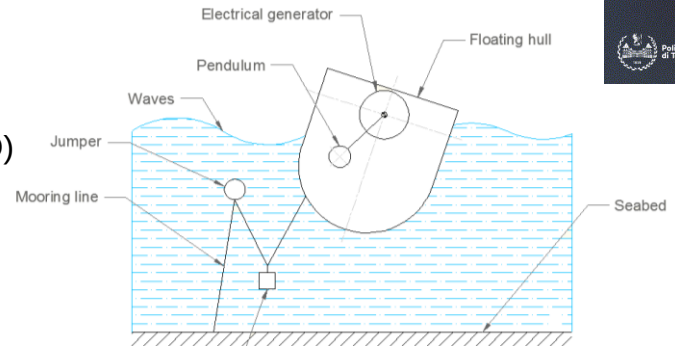
Highlights

- Pendulum Wave Energy Converter
- All energy conversion systems are inside a watertight hull
- Designed to work in the Mediterranean Sea



Subsystems

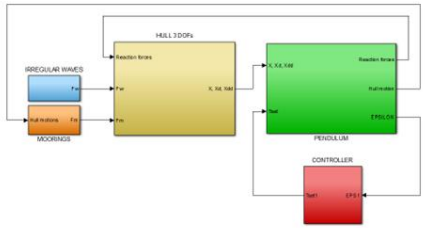
- Hull
- Pendulum
- Electro-mechanical Power Take Off (PTO)
- Mooring system



Technology roadmap

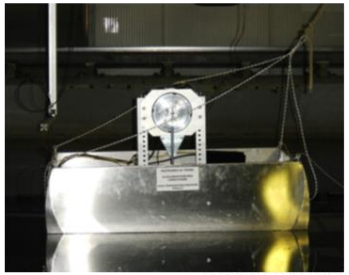
2012
Numerical model
Politecnico di Torino

- TRL 1
- Conceptualization of PeWEC
- Development of the numerical model



2014
1:45 PeWEC
INSEAN

- TRL 3
- Concept Demonstration
- Preliminary model validation

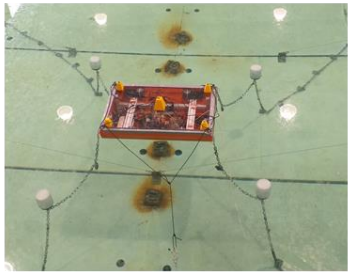


2015
PeWEC 1:12
INSEAN

- TRL 4
- Numerical model validation

2021
PeWEC 1:20
UNINA

- TRL 5
- Device optimization
- Design metodology
- Focus on mooring system



ENEA MORE LAB Politecnico di Torino

Project brief

Goals

- Reduction of the PeWEC Cost of Energy
- Design procedure of full-scale device
- Experimental campaign focused on mooring system

1 year WP1

- Resource Analysis
- Development of PeWEC optimization tool
- Design guidelines of the device

2 year WP2

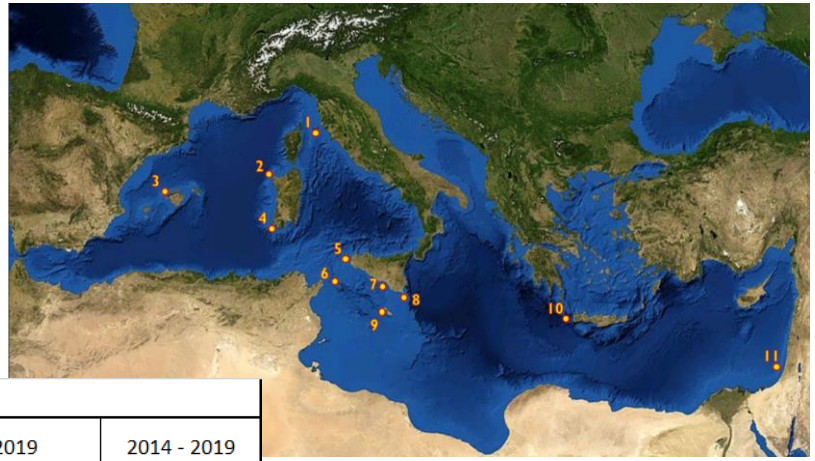
- Prototyping of the scaled model
- CFD model of PeWEC
- Execution of the experimental campaign

3 year WP3

- Validation of the PeWEC models
- Preliminary design of PeWEC full-scale

Resource analysis

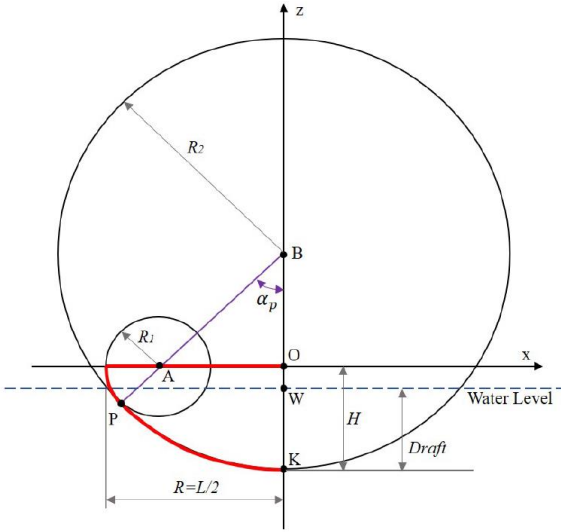
- 11 sites in Mediterranean Sea
- Data simulated with validated ENEA model WAM and SWAN models
- Two spatial resolutions: 3.5 and 0.7 km

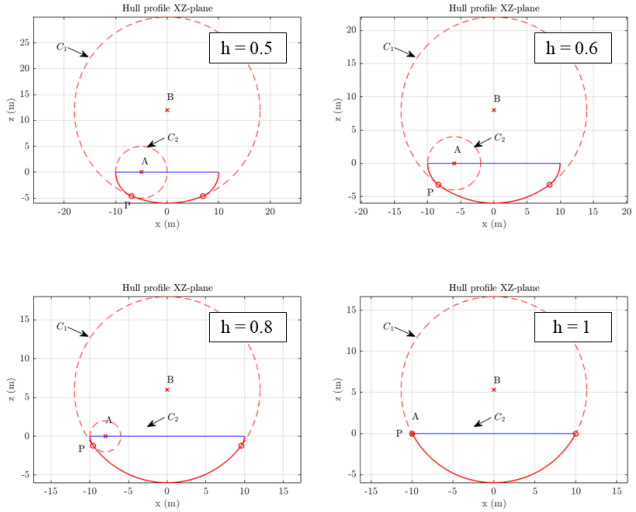


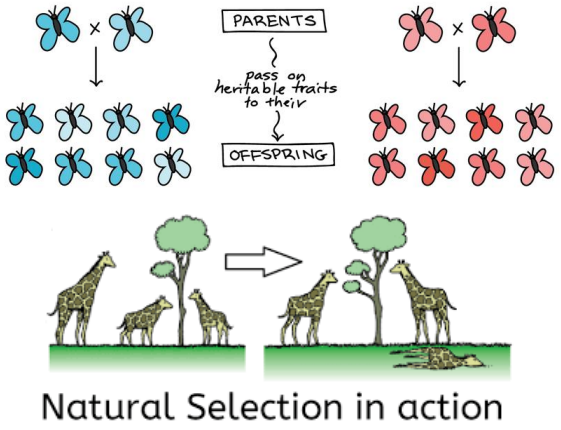
Power density kW/m							
Anno	2014	2015	2016	2017	2018	2019	2014 - 2019
P01 Isola D Elba	0.94	0.66	1.03	0.90	1.10	1.19	0.97
P02 N O Sardegna	6.15	6.83	6.50	8.36	6.23	9.10	7.20
P03 N Baleari	1.52	2.03	1.60	2.25	1.68	2.19	1.88
P04 S O Sardegna	4.54	5.70	4.62	6.18	4.48	7.26	5.46
P05 N O Sicilia	2.70	2.79	2.82	2.56	3.20	3.63	2.95
P06 Pantelleria	4.12	5.42	3.88	4.40	4.46	5.96	4.71
P07 S O Sicilia	2.09	2.40	2.19	1.97	2.48	2.74	2.31
P08 S Sicilia	2.69	2.86	3.00	2.26	2.92	3.56	2.89
P09 Malta	3.98	5.08	4.15	4.31	4.84	5.84	4.71
P10 O Creta	2.55	3.75	3.60	2.91	4.11	5.23	3.70
P11 Israele	1.24	2.35	2.61	1.73	2.48	2.43	2.15

PeWEC optimization tool

1. Detailed parametrization of the PeWEC
2. Development of genetic algorithm optimization tool
3. Techno-economic assessment: costs and productivity



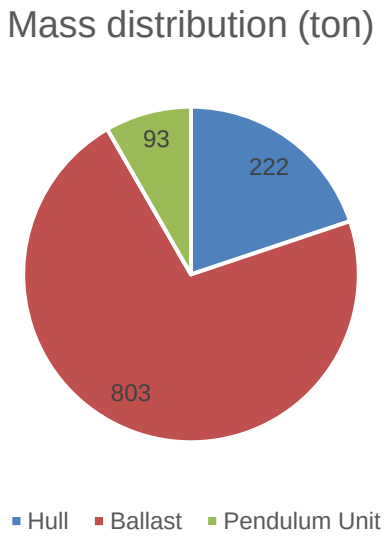


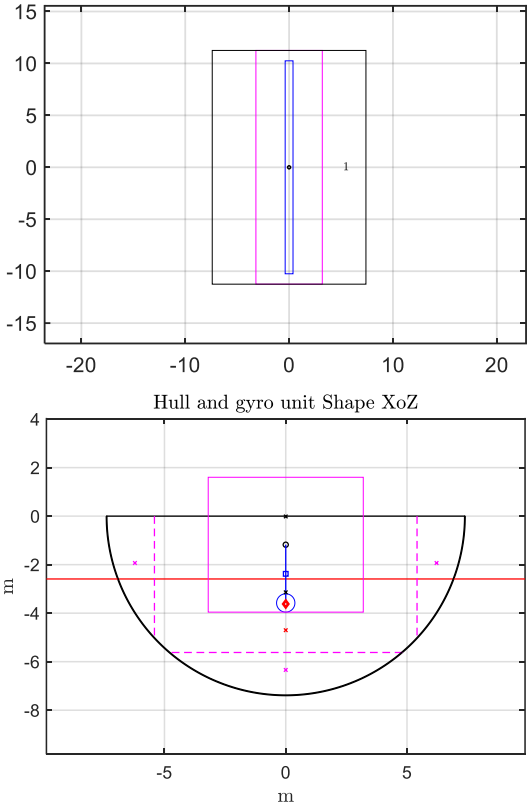


PeWEC device

1. Deployment site: Pantelleria
2. Tradeoff between CoE and Productivity
3. Hull and pendulum made in steel

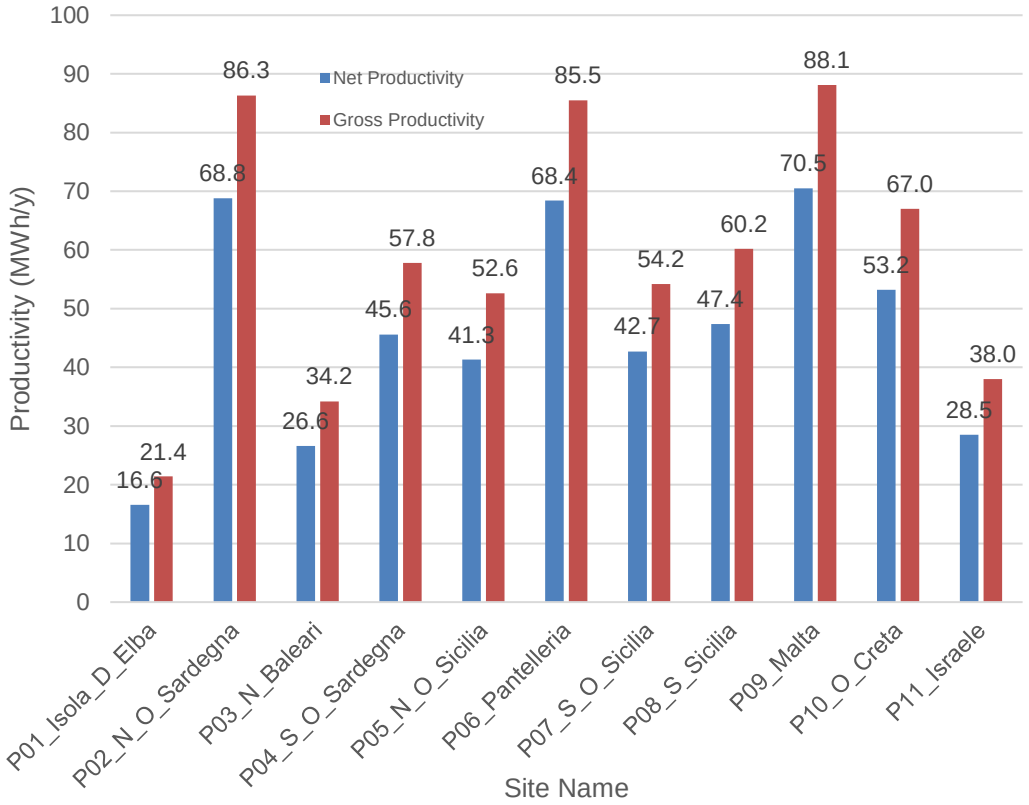
property	Unit	Value
Hull length	m	14.8
Hull width	m	22.5
Hull height	m	7.4
Hull draft	m	4.8
Displacement mass	ton	1118
Installed power	kW	523
Resonance period	s	6





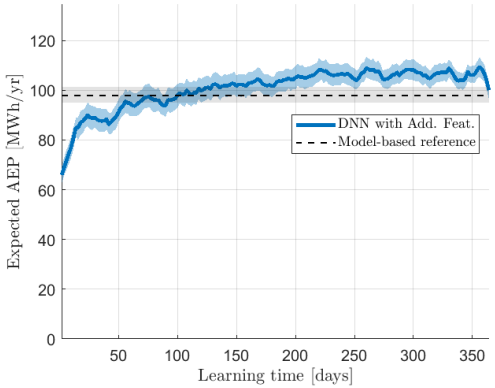
Productivity analysis

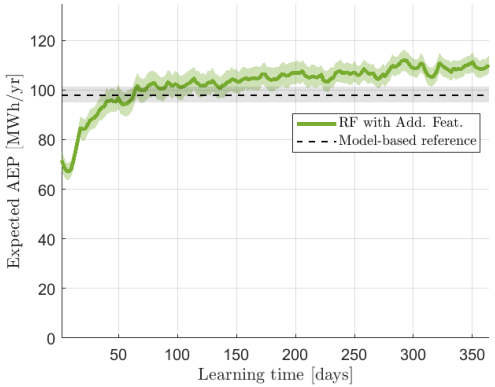
Site Name	Site Power Density (kW/m)	Net productivity (MWh/y)	Gross productivity (MWh/y)
P01_Isola_D_Elba	0.974	16.6	21.4
P02_N_O_Sardegna	7.2	68.8	86.3
P03_N_Baleari	1.88	26.6	34.2
P04_S_O_Sardegna	5.46	45.6	57.8
P05_N_O_Sicilia	2.95	41.3	52.6
P06_Pantelleria	4.7	68.4	85.5
P07_S_O_Sicilia	2.3	42.7	54.2
P08_S_Sicilia	2.89	47.4	60.2
P09_Malta	4.7	70.5	88.1
P10_O_Creta	3.7	53.2	67.0
P11_Israele	2.15	28.5	38.0

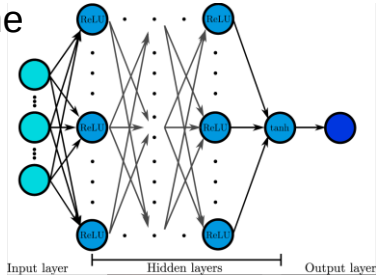


Control strategies – Data driven approach

- Proposed approach: evolve the actual control on which the device is designed, letting it learn only from data the best actions to be taken
- The real data are gathered, processed, and used to train Deep Neural Networks and Random Forests models
- Optimize the control action on the basis of these data-driven models
- In less than 3 months → data-driven overcome the model-based reference.

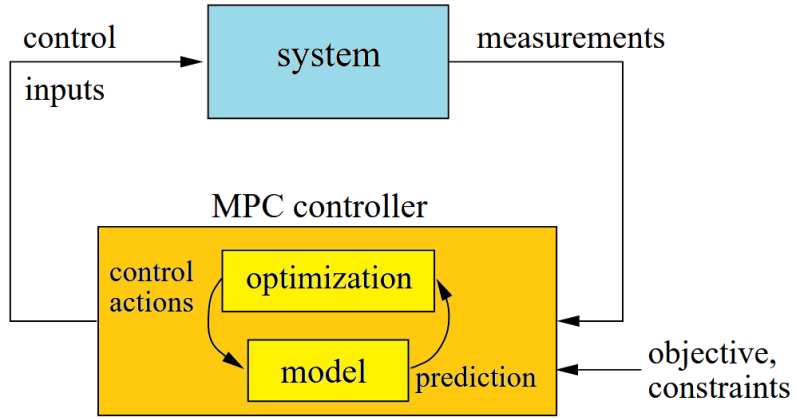


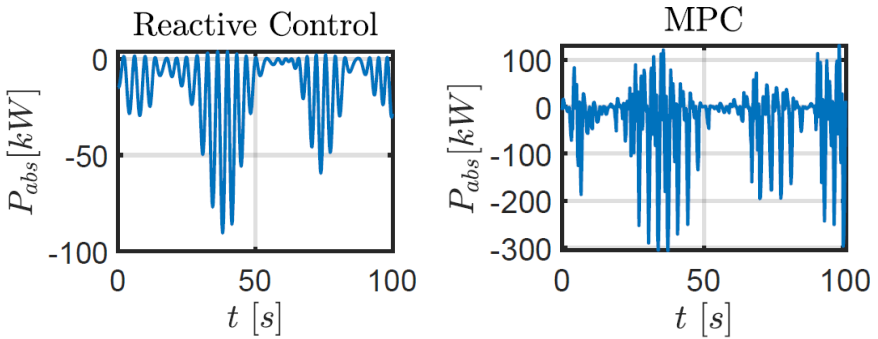




Control strategies – Model Predictive Control

- A different approach could be used: the model-based Model Predictive Control (MPC).
- MPC allows PeWEC to adopt the control action that maximize the energy absorbed respecting the technological constraints.
- The knowledge of the future allows actions that would permit additional absorption in more energetic scenarios.





Mooring system design procedure

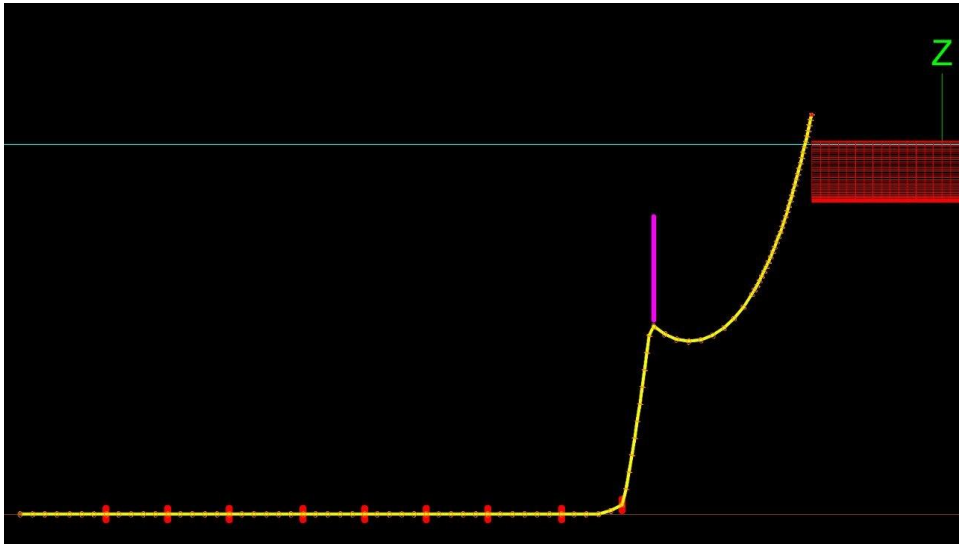
A mooring system shall withstand in several meteocean condition and a design shall be accomplished according to standards.
We are going to analyse the following rule from DNV

- **DNV-OS-E301**

The withstanding capability shall be verified in the Limit States exposed besised.

Mooring system pre-design procedure

- **Goals**:
  - Low influence in operative waves
  - Ultimate limit state verification
- **parametric model**
- **Catenary mooring layout**
- **Orcaflex model**

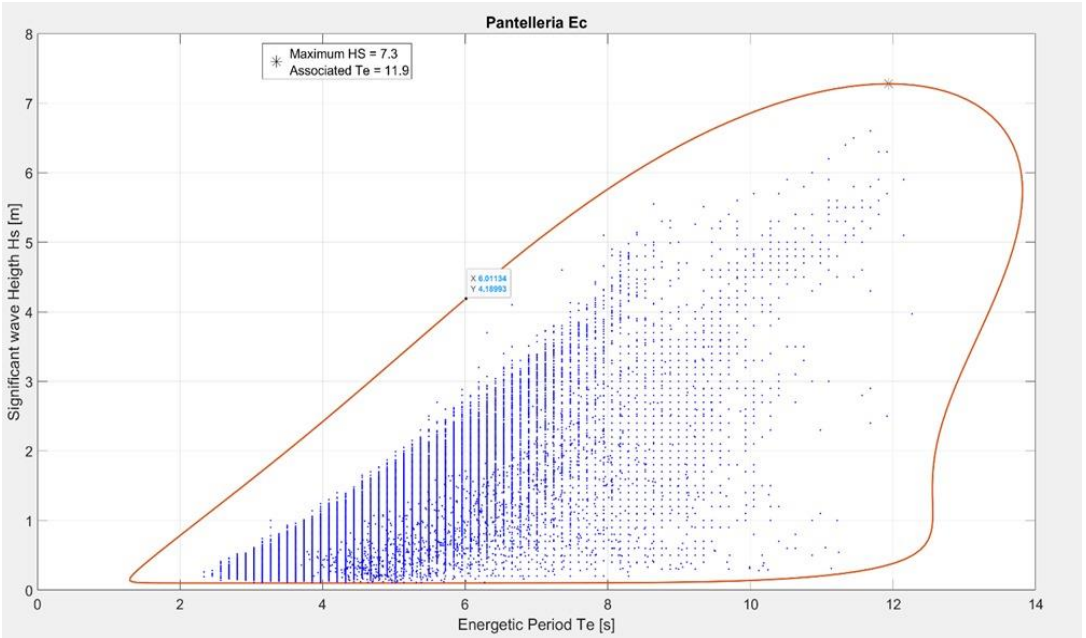


	d [mm]	w [kg/m]	d_eq [mm]	EA [kN]
Chain_080mm_studless	80	140	0.1512	646.4e3
Chain_100mm_studless	100	199	0.18	854.0e3
Chain_125mm_studless	125	310	0.225	1334.4e3
Chain_150mm_studless	150	448	0.27	1921.5e3

Mooring system pre-design procedure

Each mooring configuration has been tested (according to DNV standards) with the **Environmental Contour** (100yrp) waves.

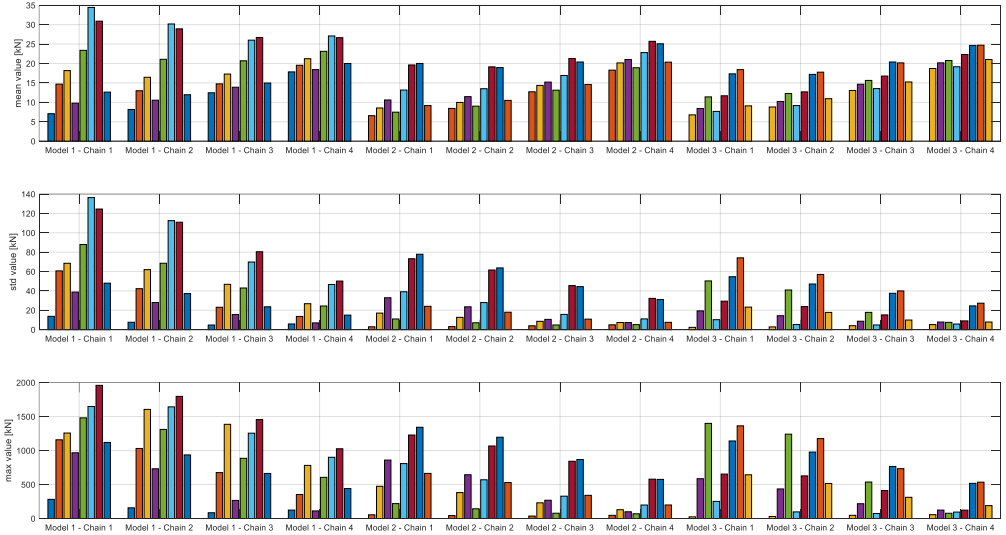
The waves have been considered also in different directions (0,45,90 deg from PeWEC bow).



Mooring system pre-design procedure

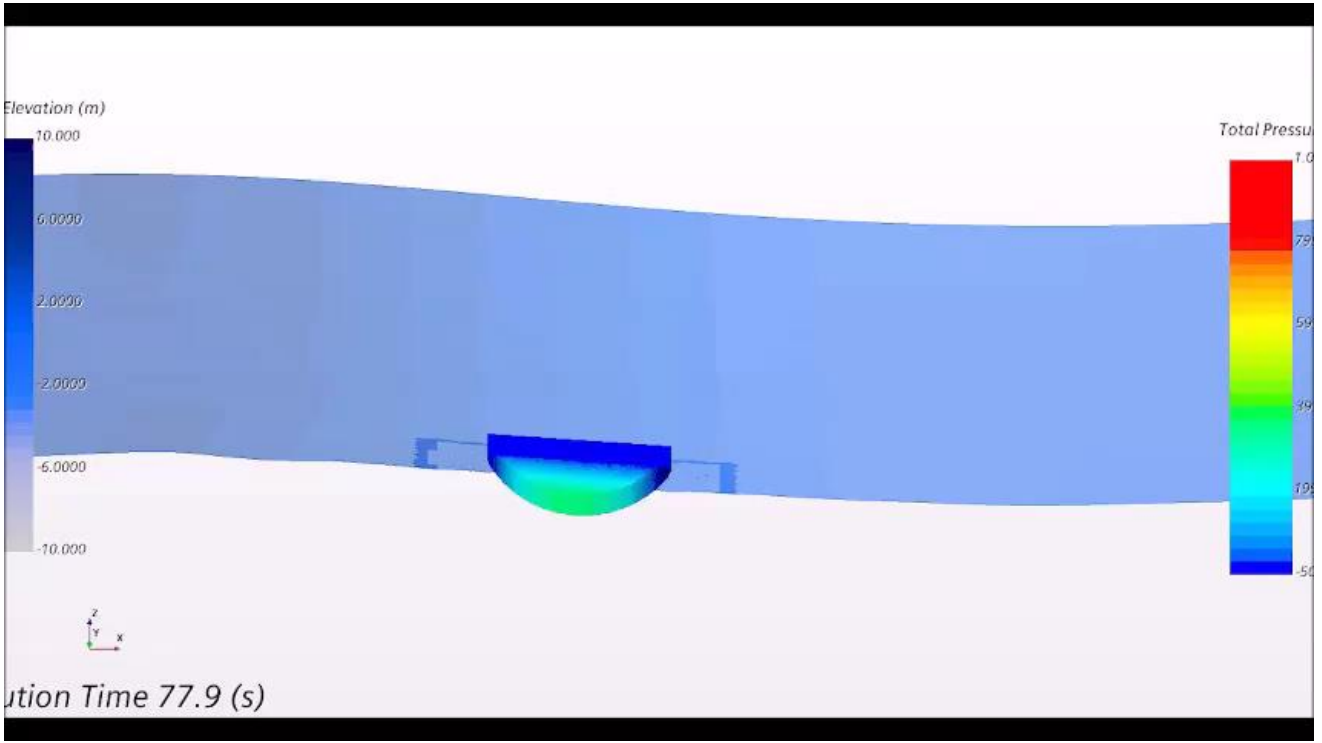
The mooring configurations have been evaluated considering several parameters:

1. **Anchors uplift tension**
   influences the anchor type choice
2. **Fairleads tension**
   Influences hull structural design
3. **Device offset**
   Influences the electrical cable design



CFD model: virtual wave tank

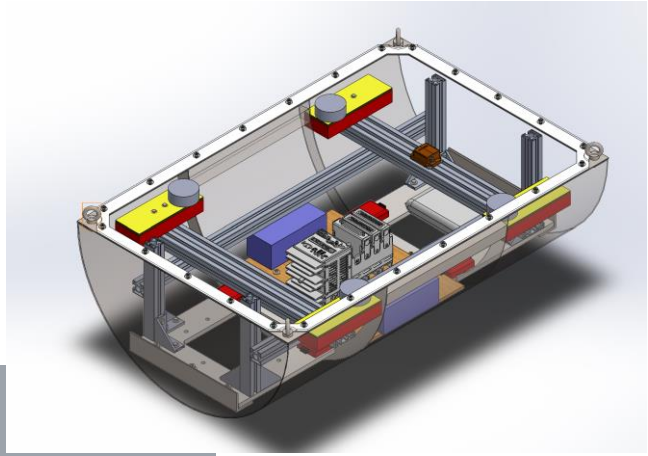
1. **Star CCM+**
2. **Moordyn for mooring dynamics**



Experimental campaign

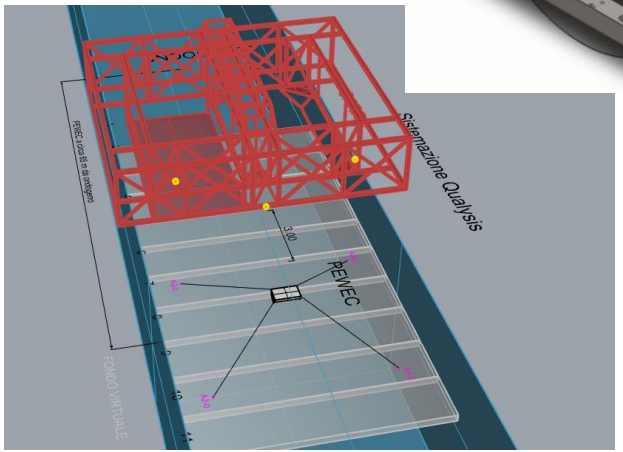
Goal

- Test the **1:25 device** in operative and extreme conditions
- Evaluate loads on mooring system
- Validation of numerical and design tools



Features

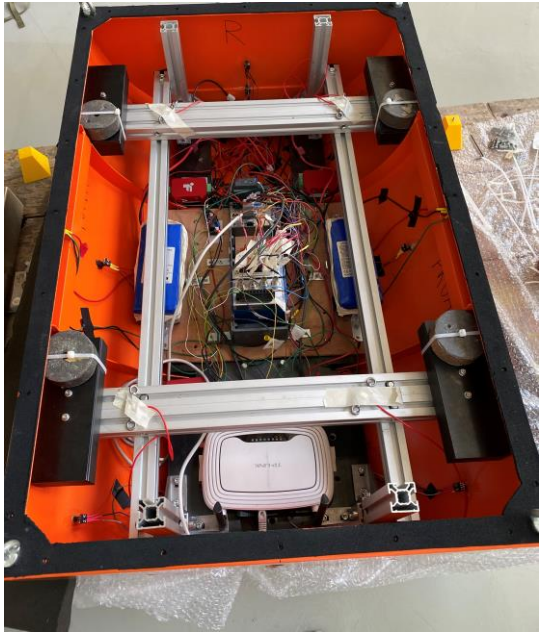
- UNINA Towing Tank facility
- National Instrument DAQ
- Load cells at fairleads
- 27 pressure sensors on hull
- On-board IMU
- Qualisys Motion capture system (Wave tank)
- 7 capacitive wave probles



Prototipe

Inertial Measurements

Prototype



DATI Modello Full-Scale	MSU	Design Value	Misura Sprimentale	err perc(%)
Lunghezza	[m]	0,592	0,592	0,0%
Larghezza	[m]	0,900	0,900	0,0%
Altezza	[m]	0,296	0,296	0,0%
Massa	[kg]	71,552	72,360	1,1%
COG (from deck)	[m]	-0,145	-0,139	4,1%
Linea di gallegg. (from deck)	[m]	-0,104	-0,100	3,7%
Pitch Inertia	[kg*m^2]	5,668	5,827	2,8%
Roll Inertia	[kg*m^2]	3,070	3,334	8,6%
Yaw Inertia	[kg*m^2]	7,388	7,388	0,0%
Draft	[m]	0,192	0,196	2,0%
COG(from waterline)		-0,041	-0,039	5,0%

Experimental Setup

Model

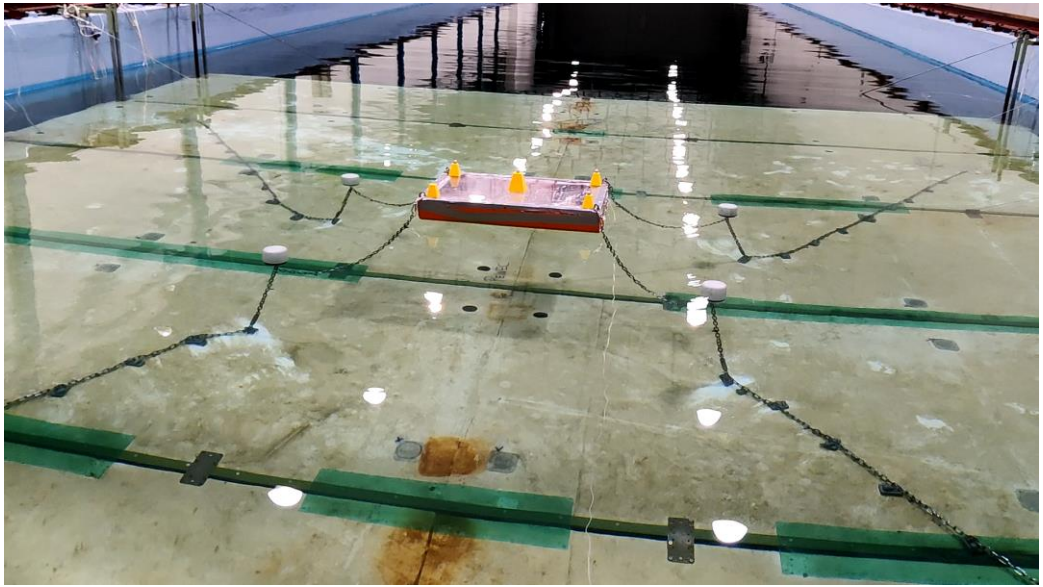
- Orcaflex environment
- Full Scale model
- Pantelleria is the site of installation

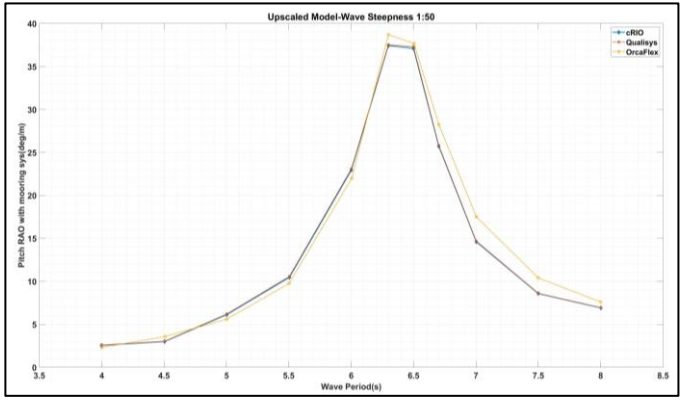
Experimental layout

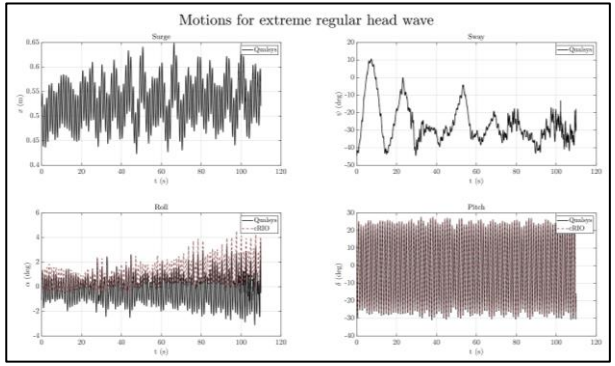
- Tank tests built to reproduce the real condition
- Scaled model (1:25)
- Artificial sea bed
- Motion capture system

Experimental Tests

Test in regular waves



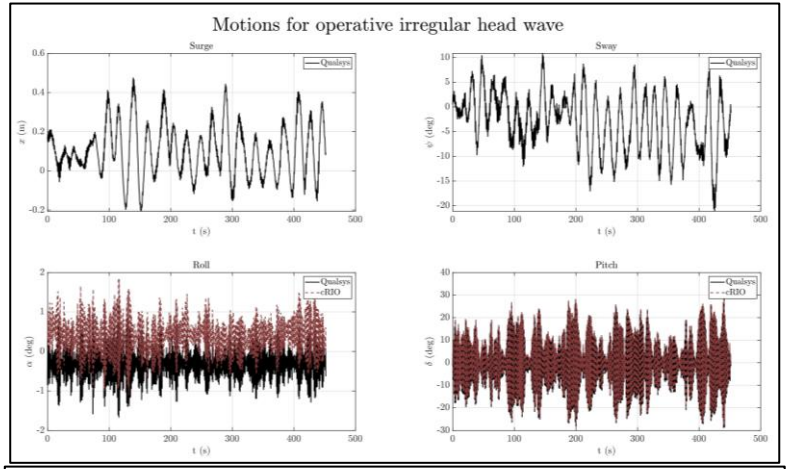


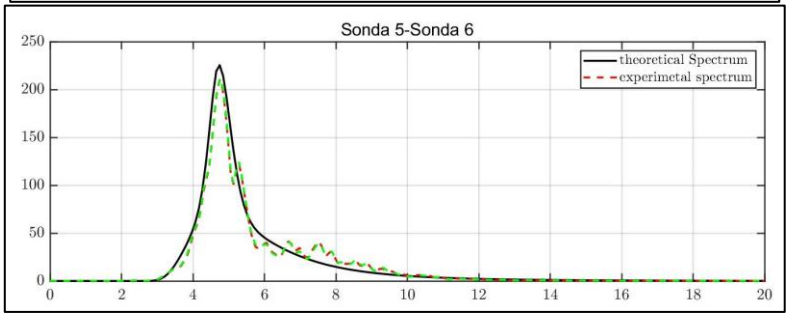


Experimental Tests

Test in irregular waves

Irregular (Tp=1.33s, Hs=7.42 cm)



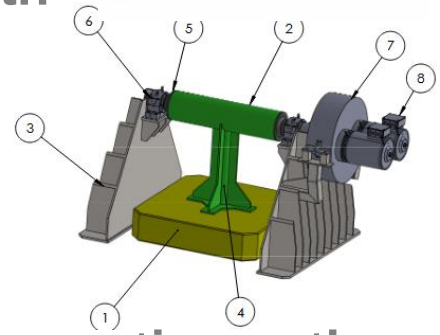


Next steps

Full-scale design

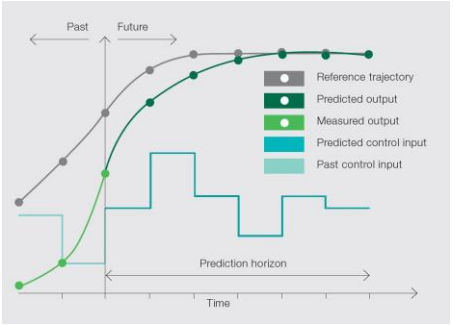
Cost reduction - innovation path

- Mooring system with polyester rope
- Concrete hull
- Cast iron or concrete pendulum
- Hydraulic Power Take off



Performance enhancement - innovation path

- Model Predictive Control (MPC)
- Optimized mooring system
- Robust optimization of the system
- Photovoltaic Panels on deck



Sergej Antonello Sirigu
Giovanni Bracco
Giuliana Mattiazzo
Sergej.sirigu@polito.it

ENEA MORE LAB Politecnico di Torino