Specialist Committee on Hydrodynamic Modelling of Marine Renewable Energy Devices

2017-2021

Chairman : Petter Andreas Berthelsen
Members : Maurizio Collu, Hyun Kyong Shin, Ye Li, William M. Batten, William A. Straka, Giuseppina Colicchio, Keyyong Hong, Jean-Roch Nader, Sylvain Bourdier

Committe Members

Offshore wind turbines (OWT):

Dr. Petter Andreas Berthelsen (chair)	SINTEF Ocean, Norway
Dr. Maurizio Collu (Committee Secretary)	University of Strathclyde, UK
Prof. Hyun Kyoung Shin	University of Ulsan, South Korea

Current turbines (CT):

Prof. Ye Li	Shanghai Jiaotong University, China
Dr. William M. Batten	QinetiQ, UK
Mr. Willam A. Straka	Pennsylvania State University, USA

Wave energy converters (WEC):

Dr. Giuseppina Colicchio	CNR, Italy
Dr. Keyyong Hong	KRISO, South Korea
Dr. Jean-Roch Nader	AMC, University of Tasmania, Australia
Dr. Sylvain Bourdier	LHEEA, Centrale Nantes, France

Committee Meetings

The committe met four times:

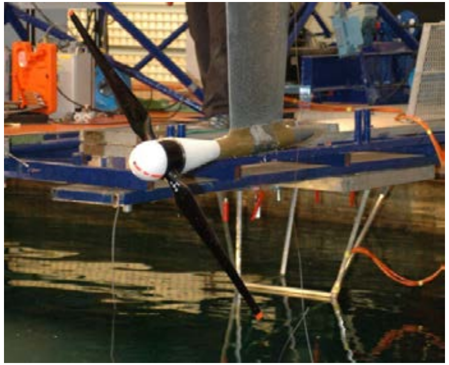
- SINTEF Ocean, Trondheim, Norway, 24-26 January 2018.
- AMC, UTAS, Launceston, Australia, 12-14 February 2019.
- University of Strathclyde, Glasgow, UK,   4-7 June 2019.
- University of Ulsan, Ulsan, South-Korea, 11-13 February 2020.

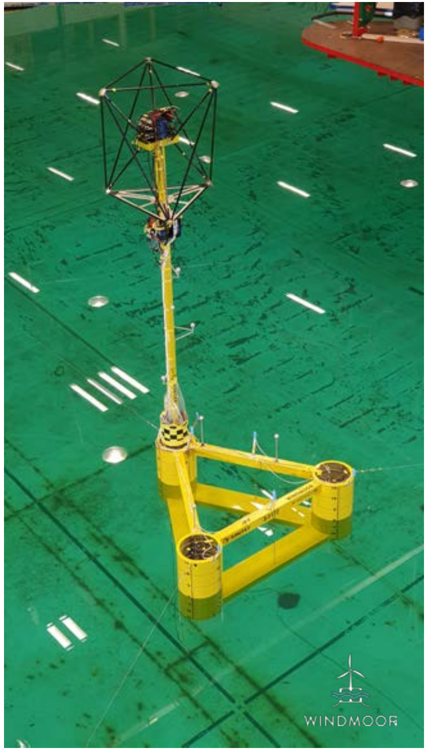

University of Strathclyde, 2019


AMC, 2019

Committee's Tasks

1. Guideline development
2. Report on state-of-the-art on:
    i. Wave Energy Converters (WEC)
    ii. Current Turbines (CT)
    iii. Offshore Wind Turbines (OWT)





Committee's Tasks – Terms of reference

1. **Report on full scale installations**

a. Type of device

b. Problems in installation

c. Success of energy extraction

d. Survivability

2. **Wave Energy Converters (WEC)**

a. Monitor and report on new concepts for WEC’s (focus on new WEC's with high TRL)

b. Develop guidelines for physical and numerical modelling of WEC’s

c. Review and report on the progress made on the modelling of arrays

d. Continue to monitor developments in PTO modelling both for physical and numerical prediction of power capture

e. Investigate Survivability for WEC

3. **Current Turbines**

a. Develop specifications for benchmark tests (EFD and CFD) for current turbines

b. Investigate effects and reproduction at model scale of inflow turbulence and unsteadiness to the turbine

c. Review and report on the progress made on the modelling of arrays elaborating on wake interactions and impact on performance

4. **Offshore Wind Turbines**

a. Monitor and report on recent developments of testing methodology for offshore wind turbines.

b. Report on other existing regulations related to model tests of offshore wind turbines (e.g. IEC, classification societies, DoE) and draw on these regulations if considered relevant.

c. Develop a guideline for uncertainty analysis for model testing of offshore wind turbines.

Cooperations with other Committees

Cooperation with others generating guidelines include:

- International Electrotechnical Commission (IEC)
  - TC88 (Wind Turbines) & TC114 (Marine Energy)

- DNV-GL
  - JIP - Coupled Analysis Of Floating Wind Turbines

Guidelines

The committee is responsible for maintaining the following ITTC procedures and guidelines:

- 7.5-02-07-03.7 Wave Energy Converter Model Test Experiments
- 7.5-02-07-03.8 Model tests for Offshore Wind Turbines
- 7.5-02-07-03.9 Model tests for Current Turbines
- 7.5-02-07-03.12 Uncertainty Analysis for a Wave Energy Converter
- 7.5-02-07-03.15 Uncertainty Analysis – Example for horizontal axis turbines

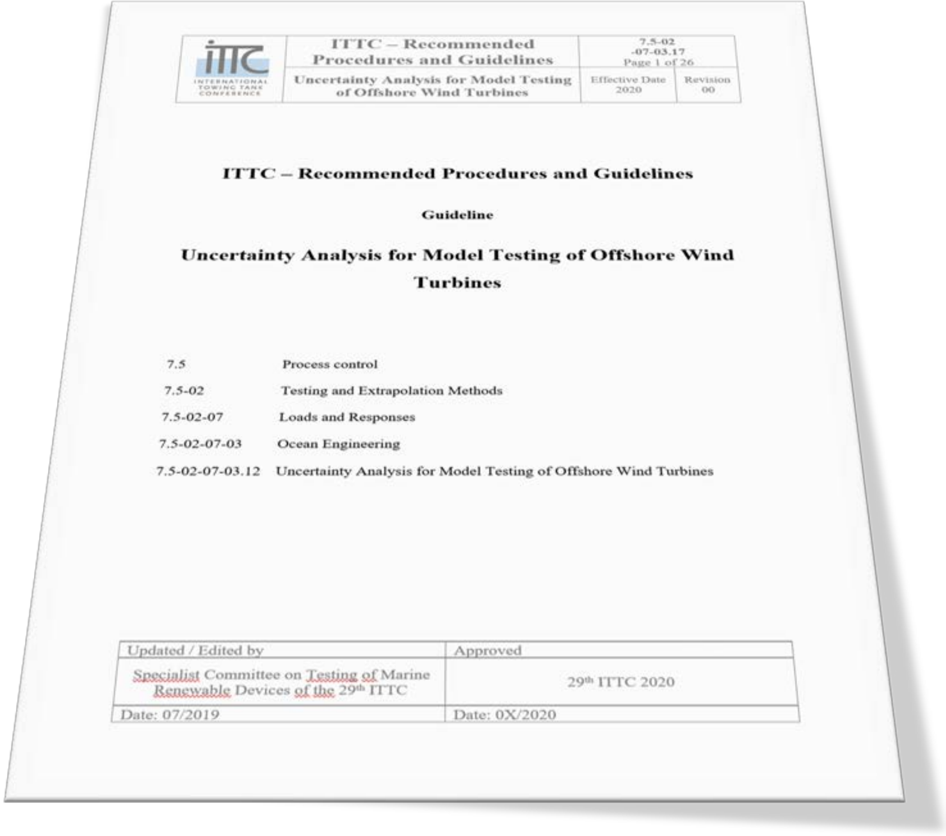
.... and two new guidelines were developed during this term:

- 7.5-02-07-03.17 Uncertainty Analysis for Model Testing of Offshore Wind Turbines
- 7.5-02-07-03.18 Practical Guidelines for Numerical Modelling of Wave Energy Converters

Uncertainty Guideline - OWT

7.5-02-07-03.17 Uncertainty Analysis for Model Testing of Offshore Wind Turbines

- Purpose is to provide guidance on the application of uncertainty analysis of the model scale testing of offshore wind turbines (7.5-02-07-03.8)
- Developed based on ISO (1995)
- Focus on sources of uncertainty
- Including an example of uncertainty analysis of a offshore wind turbine model test



INTERNATIONAL TOWING TANK CONFERENCE	ITTC – Recommended Procedures and Guidelines	7.5-02 -07-03.17 Page 1 of 26	
	Uncertainty Analysis for Model Testing of Offshore Wind Turbines	Effective Date 2020	Revision 00

ITTC – Recommended Procedures and Guidelines

Guideline

Uncertainty Analysis for Model Testing of Offshore Wind Turbines

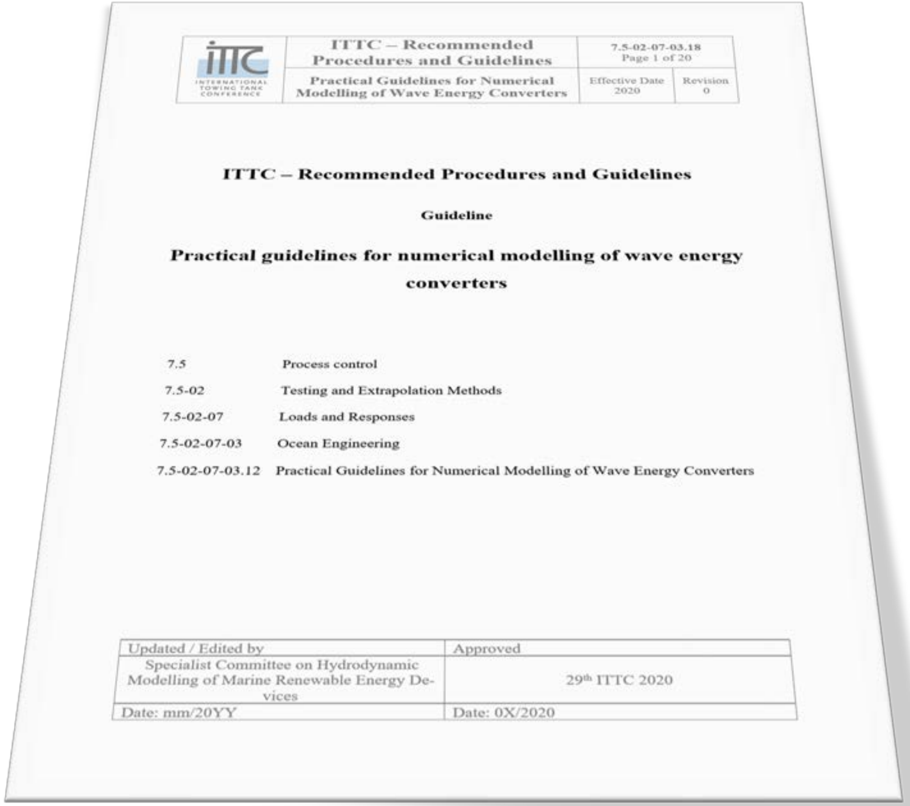
7.5	Process control
7.5-02	Testing and Extrapolation Methods
7.5-02-07	Loads and Responses
7.5-02-07-03	Ocean Engineering
7.5-02-07-03.12	Uncertainty Analysis for Model Testing of Offshore Wind Turbines

Updated / Edited by	Approved
Specialist Committee on Testing of Marine Renewable Devices of the 29th ITTC	29th ITTC 2020
Date: 07/2019	Date: 0X/2020

Guideline – Numerical modelling of WECs

7.5-02-07-03.18 Practical Guidelines for Numerical Modelling of Wave Energy Converters

- Purpose is to provide a methodology to assess the fidelity of the numerical simulation for Wave Energy Converters (WECs) at different stages of development
- Different numerical solvers have been described and range of applicability has been detailed
- Numerical methods have been described and grouped in
  - Analytical
  - potential flow
  - computational fluid-dynamics models
  - ... and coupled with hybrid strategies



	ITTC – Recommended Procedures and Guidelines	7.5-02-07-03.18 Page 1 of 20	
INTERNATIONAL TOWING TANK CONFERENCE	Practical Guidelines for Numerical Modelling of Wave Energy Converters	Effective Date 2020	Revision 0

ITTC – Recommended Procedures and Guidelines

Guideline

Practical guidelines for numerical modelling of wave energy converters

7.5	Process control
7.5-02	Testing and Extrapolation Methods
7.5-02-07	Loads and Responses
7.5-02-07-03	Ocean Engineering
7.5-02-07-03.12	Practical Guidelines for Numerical Modelling of Wave Energy Converters

Updated / Edited by	Approved
Specialist Committee on Hydrodynamic Modelling of Marine Renewable Energy Devices	29th ITTC 2020
Date: mm/20YY	Date: 0X/2020

Full scale installations and new concepts - WEC

Wave energy converter deployment worldwide (2017-2020)

PROJECT NAME	COUNTRY	YEAR ONLINE	DEVELOPMENT STATUS	DEVELOPER	Scale	RATED POWER [MW]	TYPE	REFERENCE
LAMWEC	Belgium	2020/2021	At Sea Prototype	Laminaria	1:7	0.2	Point Absorber	Lamaniria, 2021
Wavepiston	Denmark	2017-2019	Demonstration Scale	Wavepiston A/S	1:9	0.2	Oscillating Wave Surge Converter	WavePiston, 2021
mWave	Wales	2021	Development	Bombora	1:7	1.5	Gravity Based Pressure Differential	Bombora, 2021
King Island Project	Australia	2020	Installed Waiting Connection	Wave Swell Energy	Full Scale	0.2	Oscillating Water Column	WaveSwell, 2021
OE Buoy	Ireland/USA	2020	Arrived at Hawaii Test Site	Ocean Energy (Ireland)	Full Scale	0.5	Oscillating Water Column	Offshore Energy, 2019
PowerBuoy	North Sea	2020	Operational	Ocean Power Technologies	Full Scale	0.003	Point Absorber	Ocean Power Technologies, 2021
NEMOS Wave Energy Converter	Belgium	2019	At Sea Prototype	NEMOS	Large Scale	unknown	Point Absorber	NEMOS, 2021
Tordenskiold	Denmark	2019	Half-Scale Open Sea	Crestwing	1:2	unknown	Attenuator	Crestwing, 2021
WAVEGEM	France	2019	At Sea Prototype	GEPS Techno	Full Scale	0.15	Point Absorber	GEPS Techno, 2021
WaveSub	United Kingdom	2018	At Sea Prototype	Marine Power Systems	1:4	4.5 full scale (Prototype rated power unknown)	Submerged Point Absorber	Marine Power Systems, 2021
WaveRoller	Portugal	2018	At Sea Prototype	AW-Energy	unknown	0.25	Oscillating Wave Surge Converter	AW-Energy, 2019
C3	Sweden	2018	At Sea Prototype	CorPower	1:2	unknown	Point Absorber	CorPower Ocean, 2021
Oneka Buoy	Canada	2018	At Sea Prototype	Oneka	unknown	5/10 cubic meter of fresh water	Point Absorber	Oneka, 2021
Penguin	Finland	2017	Grid Connected Test	Wello Oy	unknown	1	Internal Rotating Mass	Wello, 2021

Full scale installations - CT

- Large CT devices being deployed around world
- Majority of worldwide installation still short lived as demonstrations to increase TRL
- The type of devices have not converged but majority are horizontal-axis turbine
- Other types include kite based system, cross-flow turbines, and tidal fence
- Turbines bottom-mounted, tethered or supported by floating structures

SIMEC ATLANTIS ENERGY (2019)

www.verdantpower.com

Full scale installations - CT

- Success of energy extraction
  - Between 2010-2019 nearly 60 CT devices deployed around Europe
  - 27.7MW total rate power of which
  - By 2019 - 10.4MW still in operation

- Survivability causes

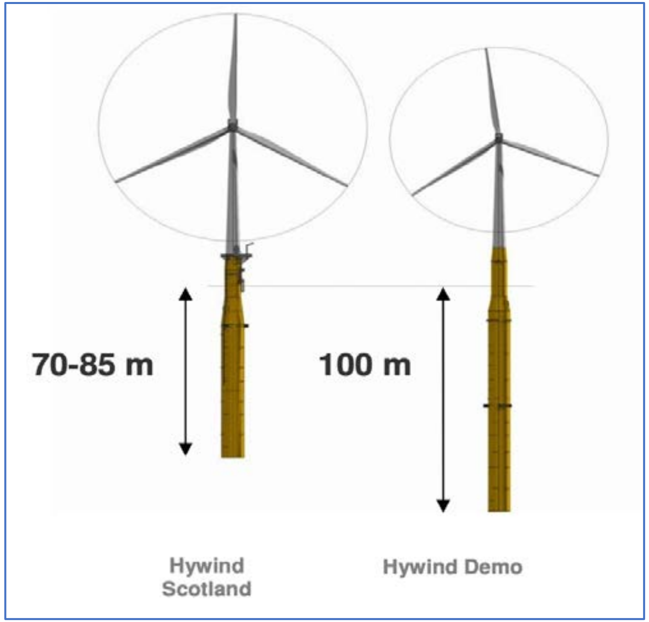
  - Structural and manufacturing issues of rotor blades
  - Financial problems
  - Installation
    - towing issues
    - Complex and unique location specific seabed support
  - Environmental factors such as turbulence and unsteadiness

Full scale installations - OWT

- Since last ITTC (2017):
  - Number of operational floating wind turbines: more than doubled (now 18)
  - Total installed capacity: quadrupled (now ~85MW)

- Configurations:
  - Spar and semisubmersible the most mature
  - New ones emerging (e.g. damping pool barge, ballast-stabilised “pendulum”, advanced spar, and others)

- First step: demonstrators, ~2 MW, connected to the grid
- Second step: pilot wind farm, with 3-5 units, around 30MW



Hywind Scotland (2017) and Hywind Demo (2009) Spar floating offshore wind turbines, by Equinor
[Xodus group, 2013, “Hywind Scotland Pilot Park Project - EIA Scoping Report”, Available at: http://marine.gov.scot/sites/default/files/00435569.pdf , accessed 15 March 2021]

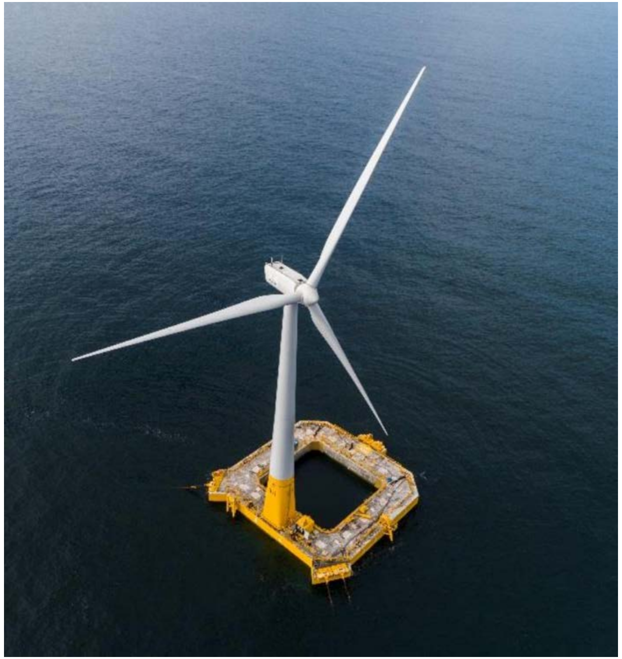
Full scale installations - OWT

- Two floating wind farm operating: ~25-30 MW:
  - Since 2017: Hywind Scotland pilot Park – spar
  - Since 2020: WindFloat Atlantic – semi-submersible
  - Many more under development or approved

- Survivability:
  - Spar and semisub fully proven:
    - Hywind demo in Norway, since 2009
    - WindFloat Atlantic Phase I, 2011-16

  - 3MW demonstrator by Ideol, installed in Japan, managed to survive three category 5 typhoon shortly after its installation.

- To date, there are still no MW-scale Tension Leg Platform (TLP) demonstrators tested in an offshore environment.



Floatgen by Ideol

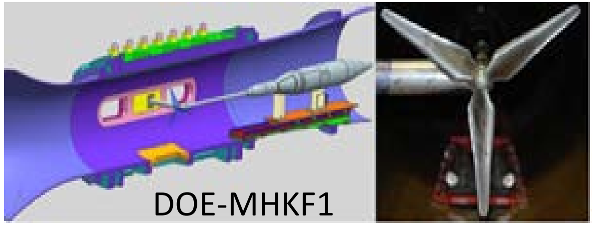
[Ideol, 2019 "Ideol Press Kit", Available at: https://www.ideol-offshore.com/sites/default/files/2019-10/Ideol%20-%20Press%20kit_0.pdf , Accessed 15th March 2021.]

Benchmark data - WEC

- Available databases are all relatively new and very few results have been published until now
- Numerical and experimental test cases have been devised by IEW OES Task 10 "Wave Energy Converters Modelling Verification and Validation:
  - Linear codes
  - Weakly nonlinear codes
  - Fully nonlinear codes
  - Experimental data
- EU H2020 MARINET2 round robin test is still ongoing
  - Focus on uncertainties deriving from the facility bias
- Pan-European WECANET is planning for another round robin test at different model scales

Benchmark data - CT

- A few publicly assessable databases currently exist for CT devices
- US Department of Energy Reference Model Project provides most complete database to date
  - Single horizontal-axis (MHKF1)
  - Dual rotor horizontal-axis (RM1)
  - Cross flow turbine (RM2)
- Lack on non-propriety multi-scale or full-scale comparable datasets



Benchmark data - OWT

- Lack of publicly available experimental results at full scale
- A number of research initiatives have been coordinating code-to-code comparisons and ocean basin scaled tests
- International Energy Agency, Task 23 and 30, "OCx" initiatives – open Access, widely published, results available:
  - OC3: code-to-code (monopile, tripod, spar)
  - OC4: focus on hydrodynamics of jackets and semisub.
  - OC5: focus on validation against experimental data
  - OC6: 3-way verification/validation: engineering modelling tools VS high fidelity tools VS experiments
- A series of experimental campaigns with model ~1:50
  - Range of approaches, including hybrid testing (e.g. Sil/HIL/ReaTHM)

INITIATIVE	LEADING ORGANISATION	YEARS	REPOSITORY WEBSITE/ REFERENCE
IEA OC3	International Energy Agency (IEA)	2004-2009	https://drive.google.com/drive/u/0/folders/0B0KGNSHvXXgCMmVsU3RkZ3FHVlE
IEA OC4	International Energy Agency (IEA)	2010-2013	https://drive.google.com/drive/u/0/folders/0B0KGNSHvXXgCSDBlREZLdDRxX2s
IEA OC5	International Energy Agency (IEA)	2014-2017	https://community.ieawind.org/task30/t30benchmarkproblems
IEA OC6	International Energy Agency (IEA)	2019-2023	Data will be made available upon completion of the project
Experimental Comparison of Three Floating Wind Turbine Concepts	DeepCwind consortium	2012-2014	https://doi.org/10.1115/OMAE2014-24172 https://www.nrel.gov/docs/fy13osti/58076.pdf https://doi.org/10.1115/1.4024711
INNWIND.EU Task 4.2	CENER	2014-2015	http://www.innwind.eu/publications/deliverable-reports
NOWITECH Semisubmersible	MARINTEK (SINTEF Ocean)/NTNU	2015	https://doi.org/10.1115/OMAE2016-54435 https://doi.org/10.1115/OMAE2016-54437 https://doi.org/10.1115/OMAE2016-54640
NOWITECH Monopile	SINTEF Ocean/NTNU	2017	https://doi.org/10.1016/j.apor.2019.05.002
Mexico	Energy Research Centre of the Netherlands (ECN)	2006-2007	http://iopscience.iop.org/1742-6596/75/1/012014
Mexnext (IEA Wind Task 29)	International Energy Agency (IEA)	2012-2018	https://www.mexnext.org/resultsstatus/

Modelling of WEC arrays

To be really appetible for electric utilities:

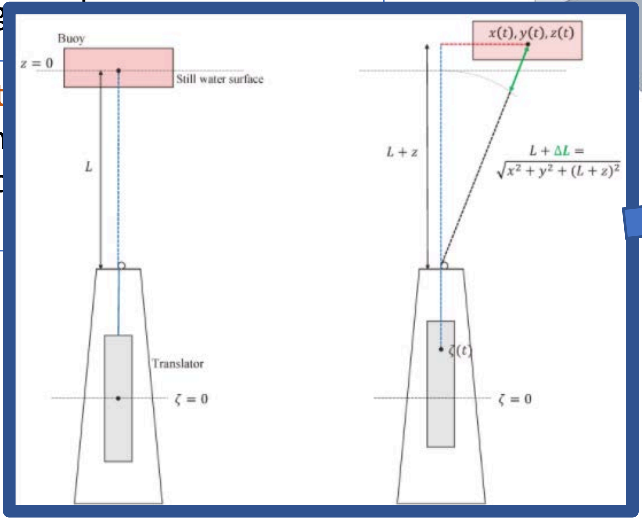
- Either WECs are built during the revamping of breakwaters
- Or they have to be deployed in farms with a cumulative production of the order of MW.

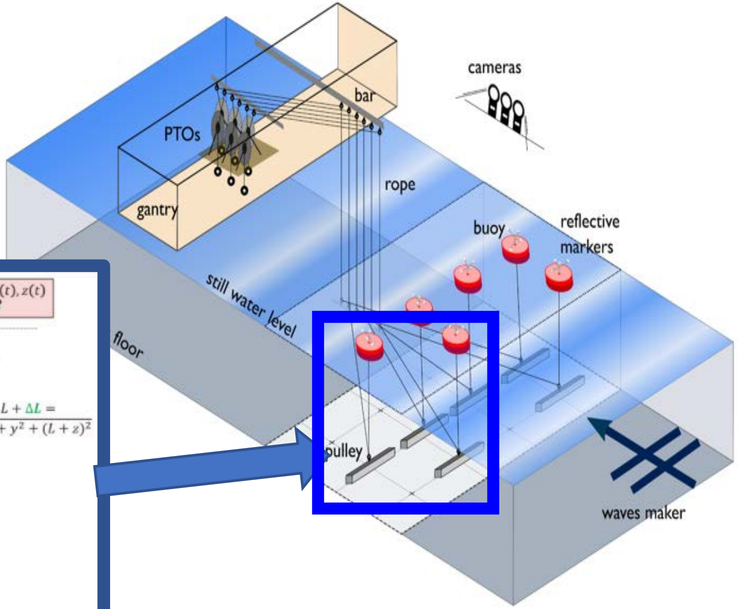
When arranged in arrays, the interaction among the WECs and and surrounding environment has to be studied.

	Experimental approach	Numerical approach
Advantages	Model test in wave tanks: controlled environment At sea: large scales	Possibility to model a virtually infinite number of conditions theoretically
Drawbacks	Model test in wave tanks: interaction with the tank walls At sea: uncertainty of the work conditions	Large computational times and lack of codes validations

Modelling of WEC arrays (experimental analysis)

	Experimental approach
Advantages	Model test in wave tanks: controlled environment At sea: larg
Drawbacks	Model test interaction At sea: unc conditions

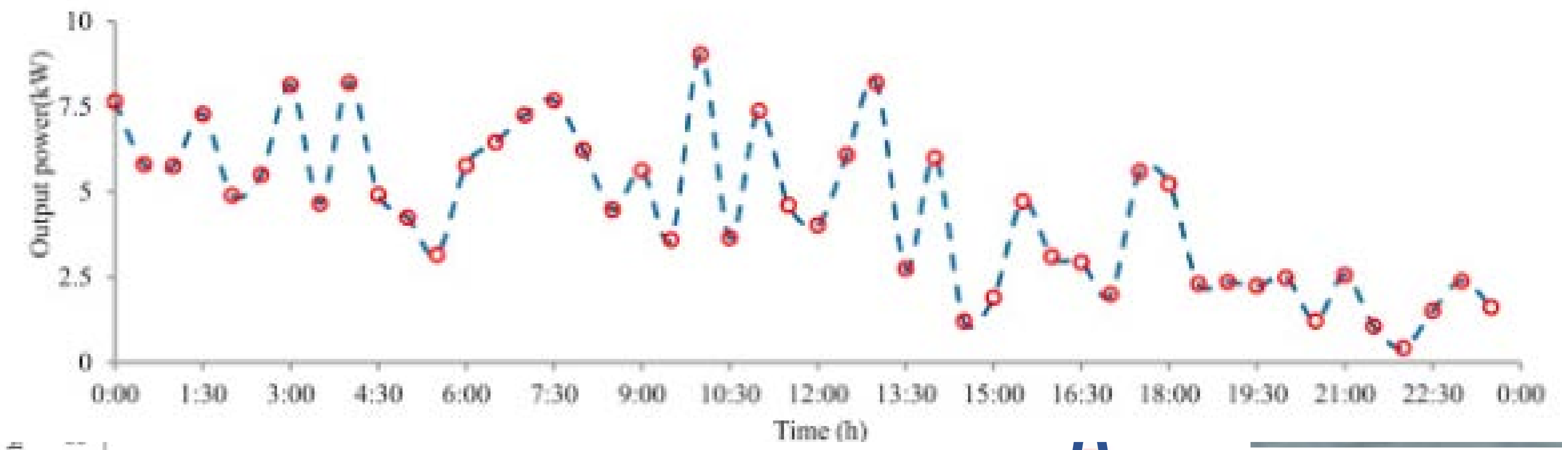




Giassi, 2020

Modelling of WEC arrays (experimental analysis)

(Yang, 2020)



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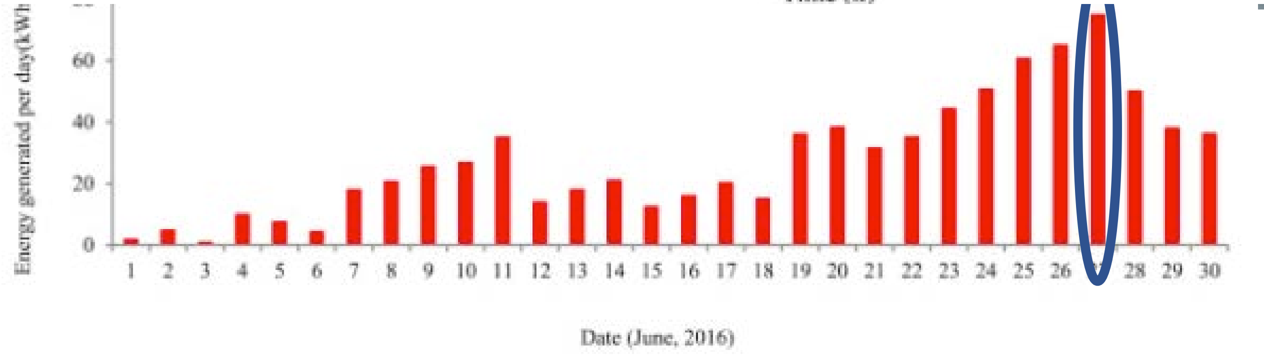
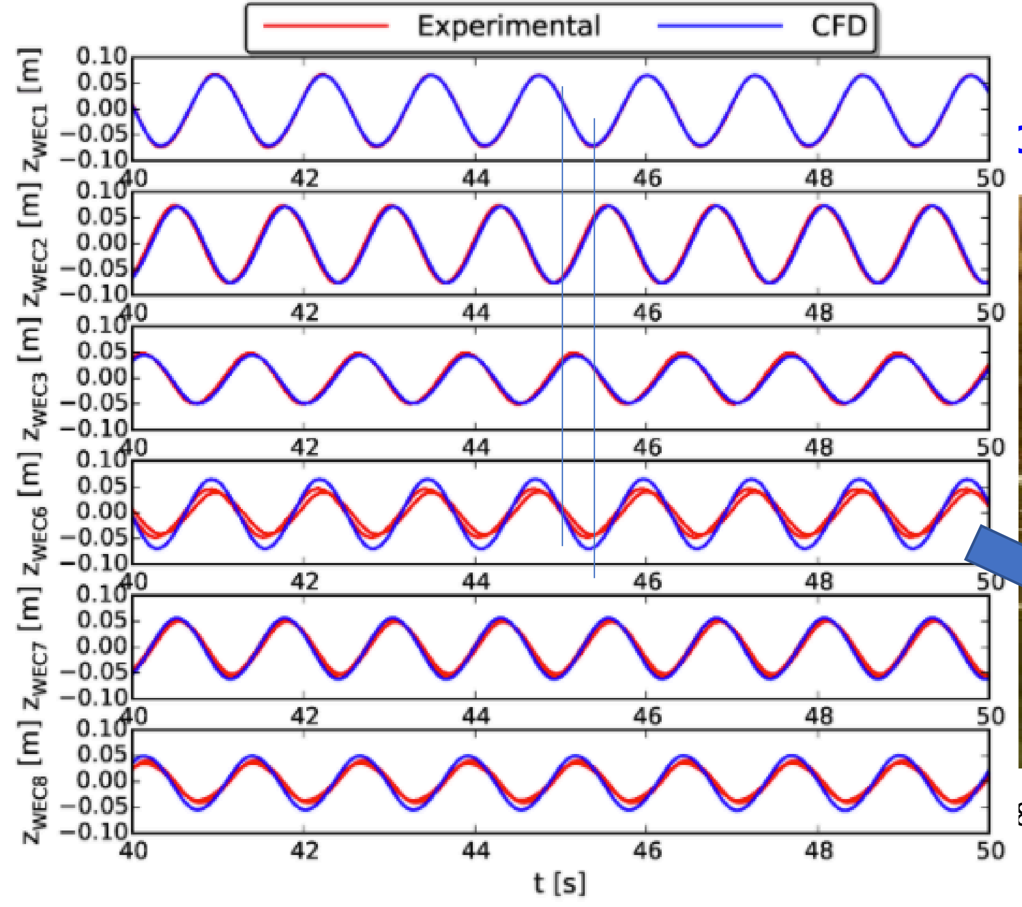


(b) Electricity generation per day in June, 2016

analysis)



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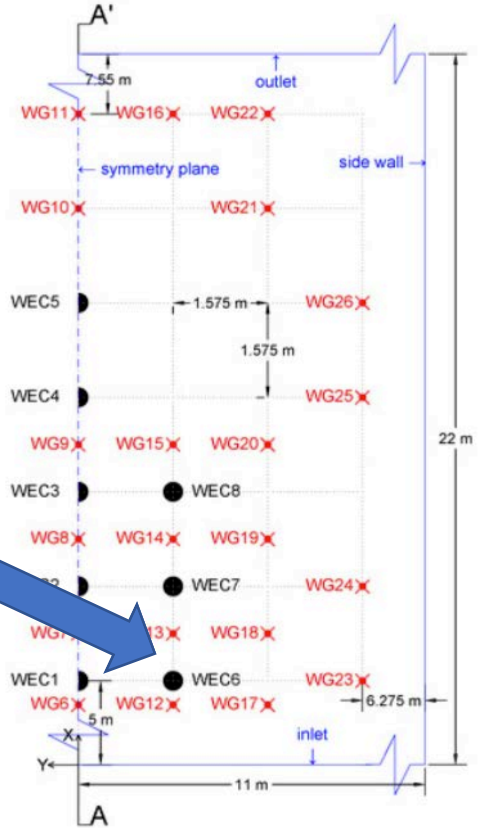

Advantages

Drawbacks

Modelling of WEC arrays (numerical analysis)

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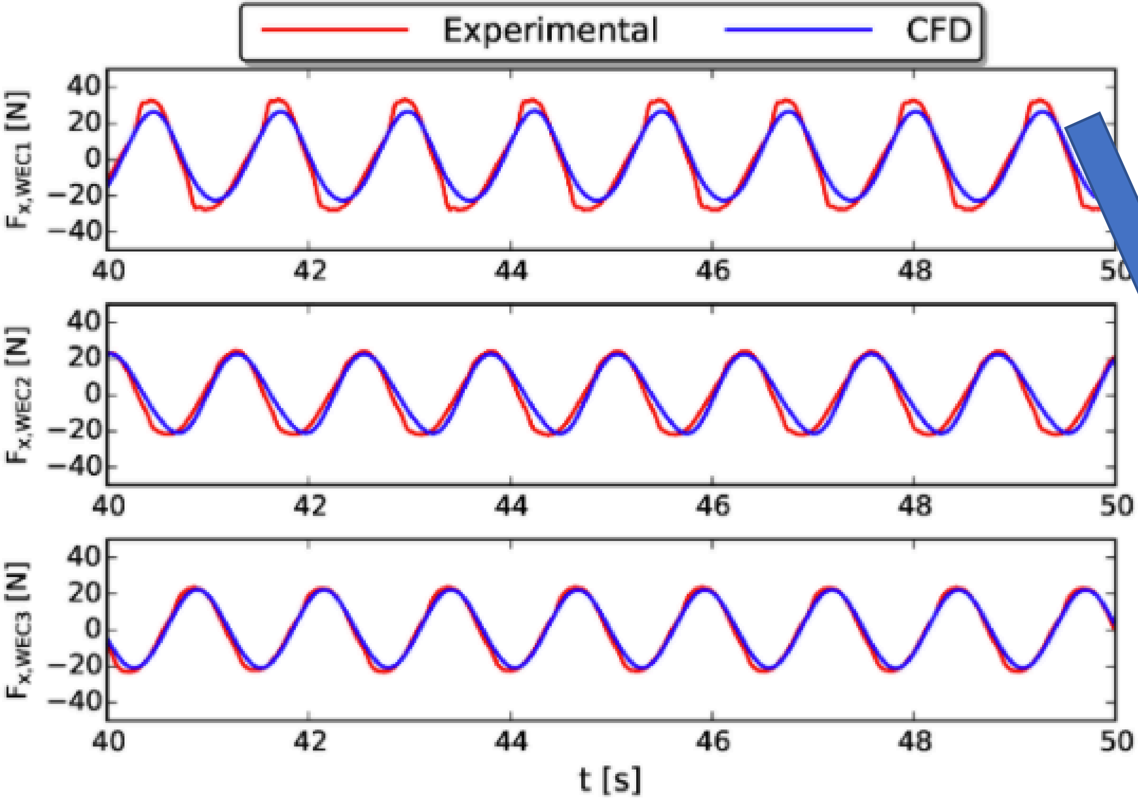

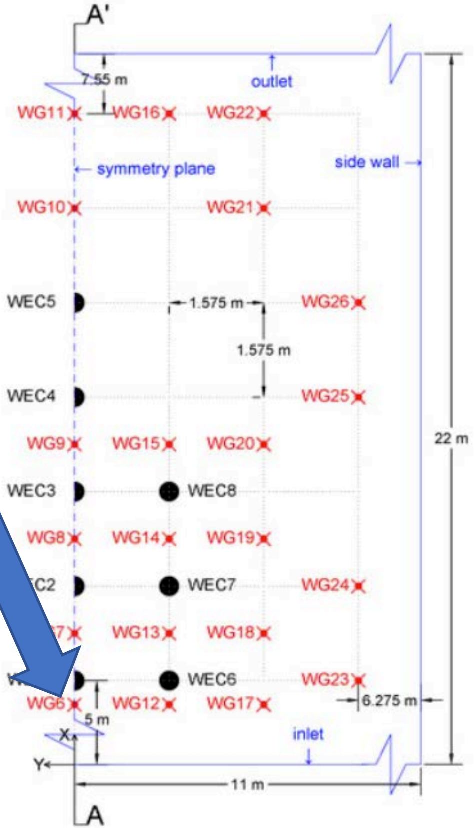

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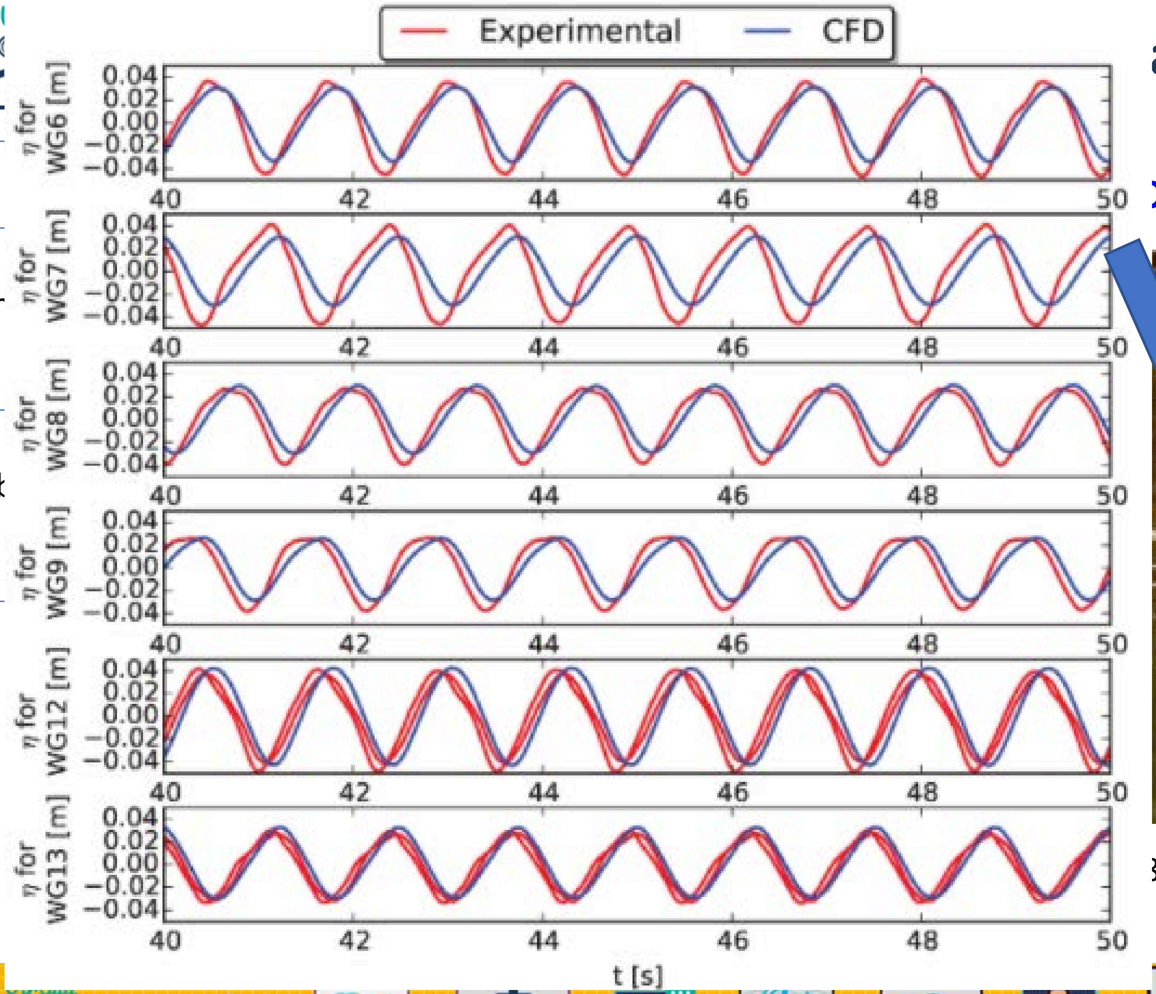

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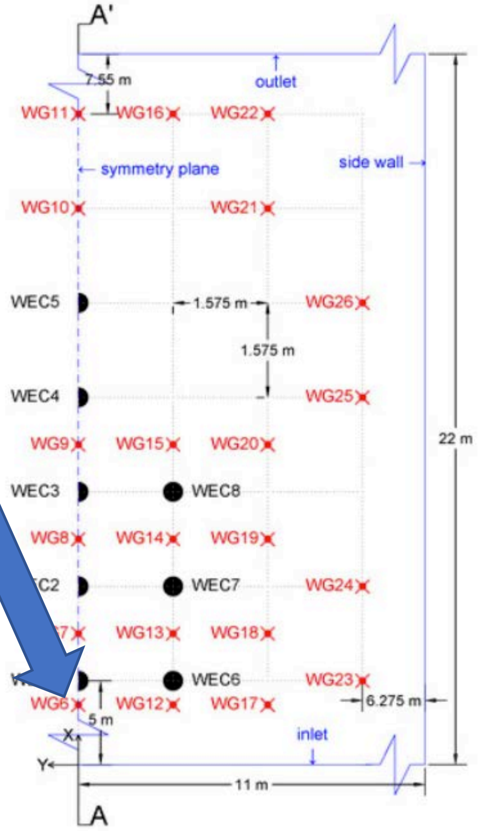


Modelling of WEC arrays - Park optimization

Most of the new numerical works clearly state the reliability of the numerical methods either compared with other numerical schemes or with experimental data.
The uncertainty of the data has driven the development of the park optimization techniques from

Parameter sweep

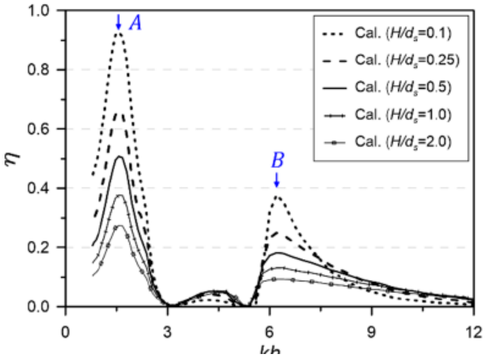
Regularly change a single parameter and see its effect on the power fluctuation or the power output

Metaheuristic algorithms

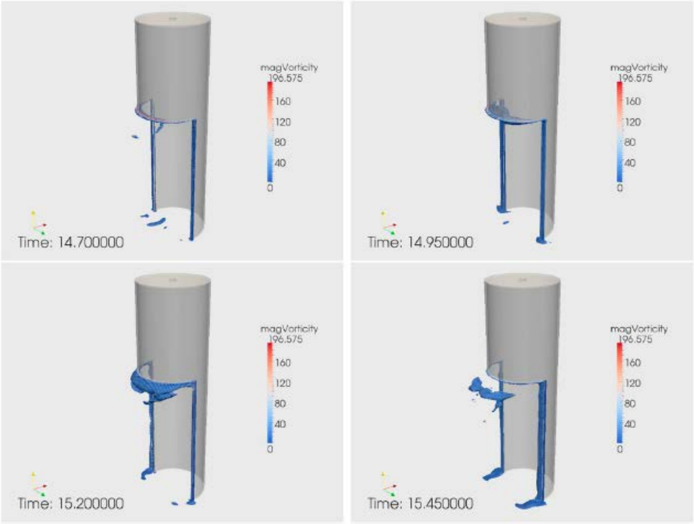
look for the solution space of sufficiently good solution.
Best suited to conditions where *imperfect* information is available.

Developments in WEC PTO Modelling

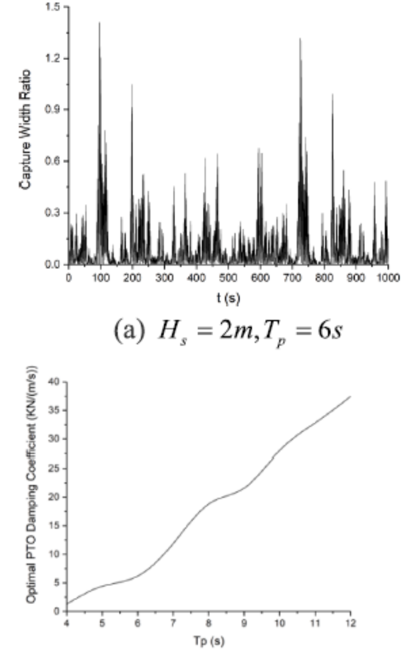
❖ Key Issues in Recent R&Ds



Nonlinear Effects
(Kim et al., 2021)



CFD Simulation
(Xu et al., 2019)



(a) $H_s = 2m, T_p = 6s$

(a) Optimal PTO Damping Coefficient

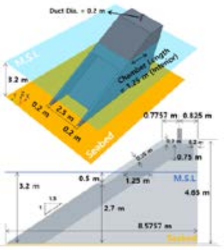
Unsteady Characteristics
(Kong et al., 2019)

Developments in WEC PTO Modelling

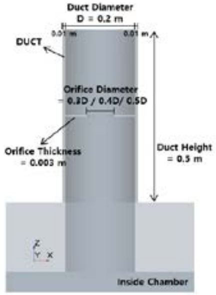
❖ Benchmark Tests by IEA-OES Group

- Comparison of various numerical modellings of OWC PTO

(Bingham et al., 2021)

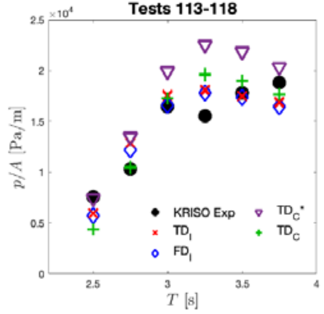


(a) The OWC chamber.

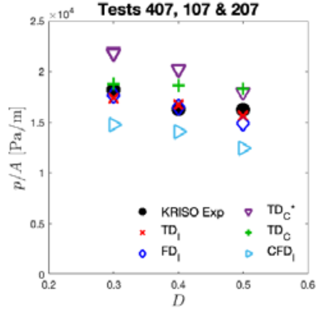


(b) The duct.

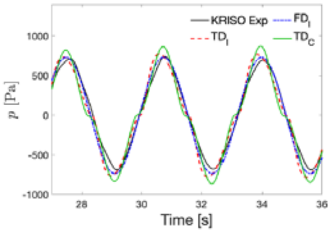
(c) The chamber installed in the basin.



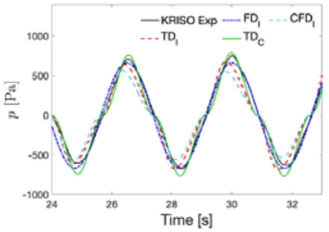
(c) High wave height; orifice size of 0.4D.



(d) Different orifice sizes at med wave height.



(e) Test 106 pressure difference time history.

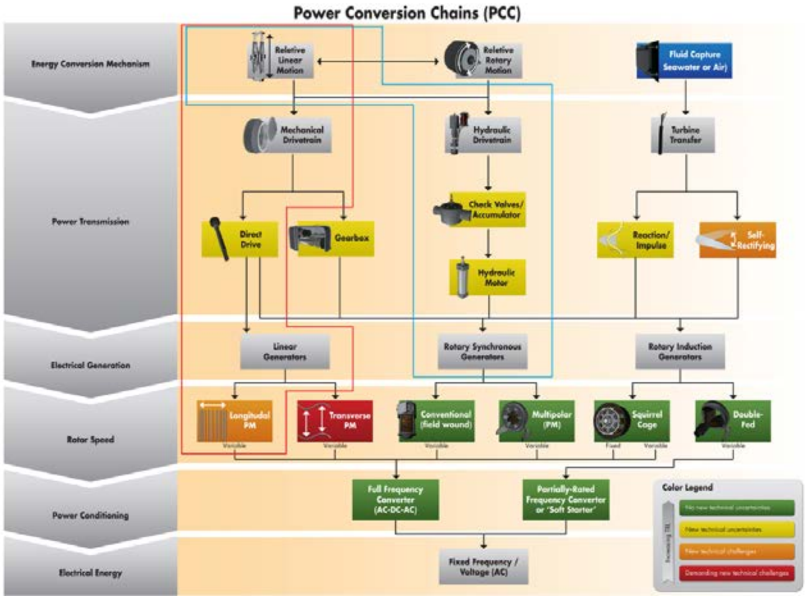


(f) Test 207 pressure difference time history.

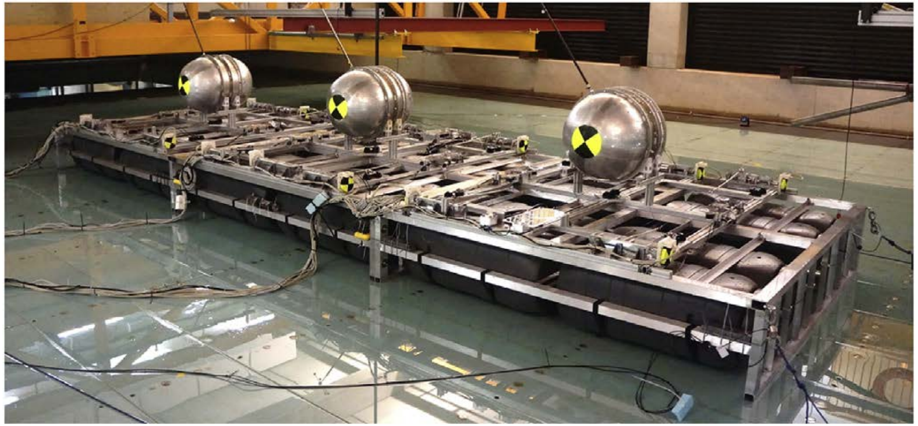
Developments in WEC PTO Modelling

❖ Progress in Integrated Simulation & Experiment Modelling

- Coupled analysis of the interaction between PTO components



PTO-Sim
(So et al., 2015)



WaveSub
(Faraggiana et al., 2020)

Survivability for WECs

- There are still a lot of unknowns related to survivability for WECs
- Very little information is shared from deployed full scale devices related to their survival response
- Due to the complexity of WECs (compared to other offshore structures), there is still a strong need to update guidelines ands standards for survivability testing of WECs

Specification for benchmark tests for CT

- General specification for benchmark tests developed to
  - Understand bias between experimental facilities
  - Provide geometry, boundary conditions and performance data for CFD validation and verification
  - Provide data to assess performance scaling and predictions

- Some key components for successful tests should include:
  - Replication and measurement of typical inflow conditions
  - Broad scope of measurement types including flow field, visualization, steady and unsteady loads and noise measurements
  - Neutral format databases for CT device and facility installation and measurements
  - Uncertainty analysis
  -
- Benchmark test should leverage existing tested or full-scale horizontal-axis turbine geometries

Modelling of arrays Current turbines-Main Effort

Effort in Basic Modeling Approach
Improving Efficiency

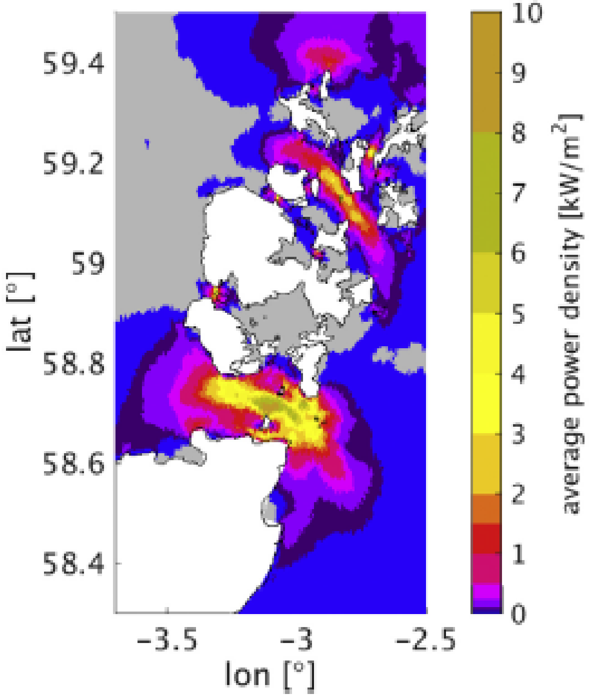
Free Surface Effect
New physics

Control Algorithm
New functions

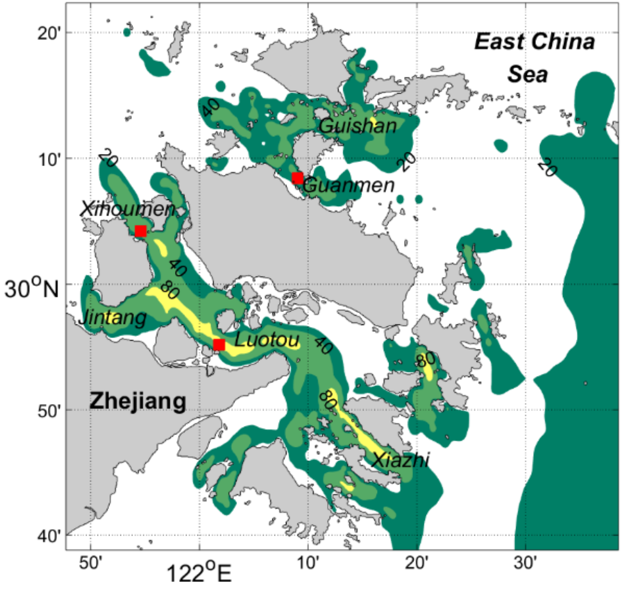
Interaction with Ambient Flow
Energy and Environment

- Large number of researchers still work on basic methods development
- New topics are expanded into new physics and inter-disciplinary studies

Modelling of arrays Current turbines-Energy and Environment



Pentland Firth,UK
(De Dominicis et al. 2017).



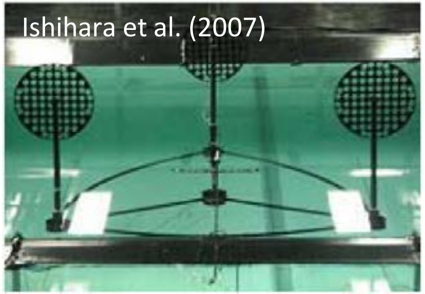
Zhoushan Site-China
(Deng et al 2019).

Testing methodology for OWT

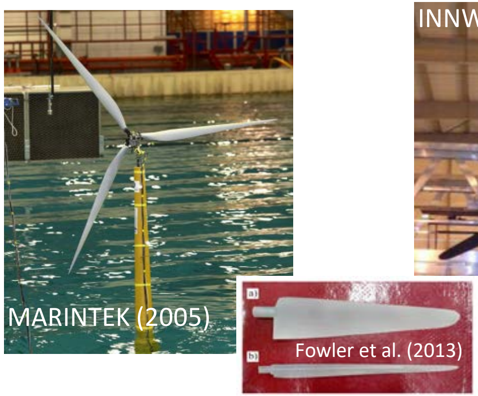
Main challenges with wave tank testing of offshore wind turbines:

- Generation of high-quality wind in tank facilities.
- Incompatibility between Froude and Reynolds scaling laws.

Solid or perforated disc

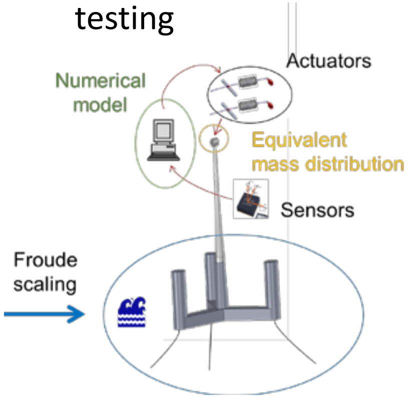


Geometric scaling



Performance scaling

Hybrid model testing

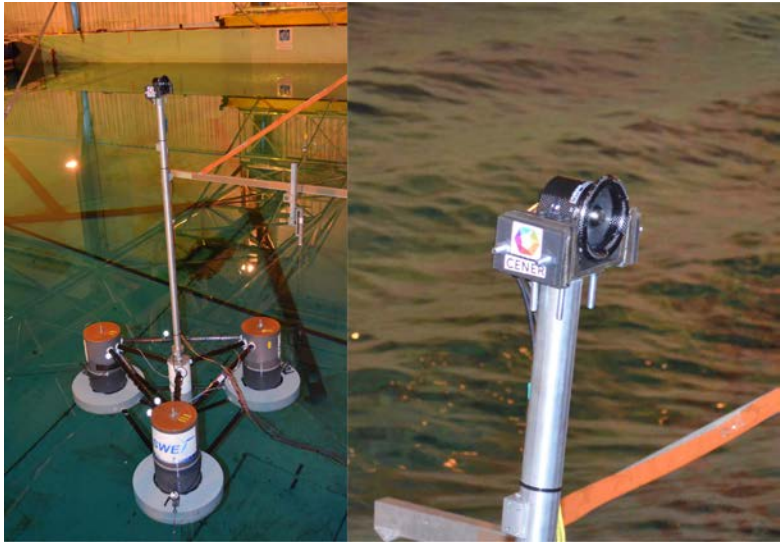


Increasing complexity

Testing methodology for OWT

Hybrid testing - Software-In-the-Loop (SiL) hybrid method

Single ducted fan



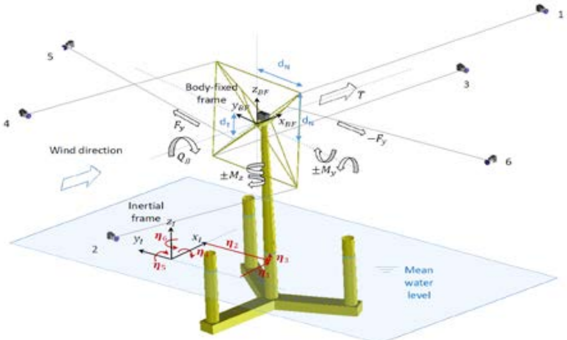
Courtesy of CENER

Multiprop actuators

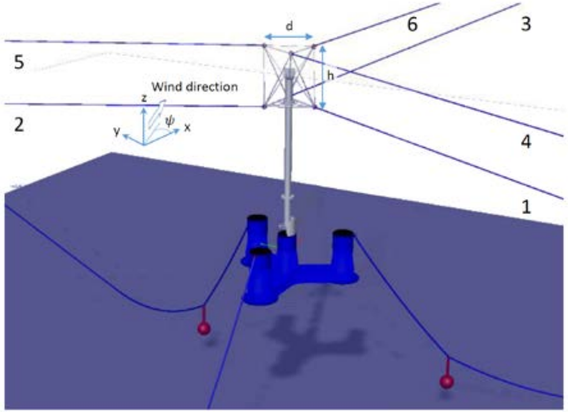
Courtesy of CENER

Testing methodology for OWT

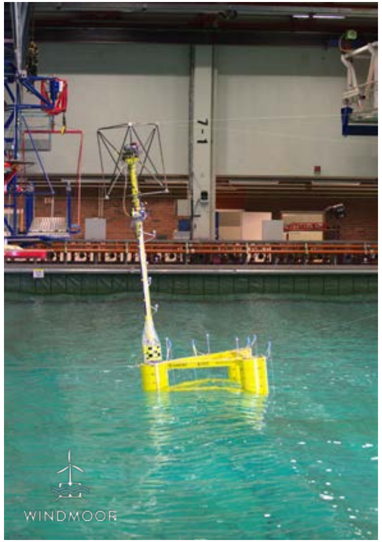
Real-Time Hybrid Model (ReaTHM) testing – cable driven parallel robots



NOWITECH
SINTEF Ocean (2015)
(from Chabaud et al., 2018)



EU H2020 LIFES50+, SINTEF Ocean (2017)
(Chabaud et al., 2018)



(Thys et al., 2021,
Courtesy of SINTEF Ocean)

Testing methodology for OWT

Hybrid model testing in windtunnel

Existing regulations

The development of the standards and rules and their application to (floating) offshore wind turbines have allowed the wind turbine industry to gain confidence in the (floating) offshore wind turbine designs. Also, the standards, guidelines and certifications address how they are about to change from addressing prototype installations with a few unit to large scale (floating) offshore wind farms consisting of many identical units, as a central 'repository' of knowledge and experience. (Garrad, 2012).

- IEC TS 61400-3-2, Design requirements for floating offshore wind turbines, April 2019;
- IEC IS 61400-3-1, Design requirements for offshore wind turbines, April 2019;
- ISO 29400, Ships and marine technology — Offshore wind energy — Port and marine operations, May 2020;
- ABS Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations, July 2020;
- ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations, July 2020;
- BUREAU VERITAS NI 572, Classification and Certification of Floating Offshore Wind Turbines, January 2019;
- Class NK, Guidelines for Offshore Floating Wind Turbine Structures, July 2012;
- Class NK, Guidelines for Certification of Wind Turbines and Wind Farms, May 2014;
- DNV, DNVGL-RU-OU-0512, Floating offshore wind turbine installations, October 2020;
- DNV, DNVGL-ST-0126, Support Structures for Wind Turbines, July 2018;
- DNV, DNVGL-ST-0119, Floating Wind Turbine Structures, July 2018;
- DNV, DNVGL-SE-0422, Certification of Floating Wind Turbines, July 2018;
- DNV, DNVGL-RP-0286, Coupled analysis of floating wind turbines, May 2019;

Utilizing the experience and lessons learned from certifying based on standards can make the (floating) offshore wind turbine industry to know where the largest cost savings can be found and how standards and certification can be used to eliminate risk from the project while maintaining the same level of confidence.

Recommendations for Future Work: General

1. Continue interactions with IEC.
2. Review interactions between model scale and moderate/full scale test sites.
3. Review of testing of deployment (transportation, installation) and O&M for marine renewable devices.
4. Review testing of multipurpose platforms (e.g. combined WEC/OWT/ Solar/Aquaculture platforms).

Recommendations for Future Work: WECs

1. Continue to monitor development of new concepts of WECs.
2. Continue to monitor developments in PTO modelling both for physical and numerical prediction of power capture.
3. Assess the feasibility of developing specific guidelines for numerical and experimental survival testing of WECs.
4. Assess support to using the benchmark round robin data for numerical comparison and/or for evaluating facility biases and scale related uncertainties.
5. Update the uncertainty analysis of WEC testing to include the uncertainties of the power capture and potentially of a different type of device technology.
6. Update and extend array section of the guidelines for numerical modelling of WECs.
7. Review and report on the different PTO control strategies for power optimisation and survivability modes.
8. Review and report on comparisons between full scale data and numerical work/experimental model testing.

Recommendations for Future Work: CT

1. Continue to monitor development in physical and numerical techniques for prediction of performance of current turbines.
2. Assess the support for round robin test of a 3-blade horizontal axis turbine (such as the DoE turbine). If there are enough willing participants develop a technical delivery plan.
3. Review and report the techniques use for CFD modelling current turbines. This should include the use of combined EFD/CFD techniques for scaling and blockage corrections and methodologies for replicating environmental conditions.

Recommendations for Future Work: OWT

1. Continue monitoring and report on the development in full-scale installation of floating offshore wind turbines.
2. Report on possible full-scale measurement data available and address how these data can be utilized for validation of simulation tools and evaluation of scaling effects from model scale tests.
3. Continue monitoring and report on the development in model testing methodology for offshore wind turbines.
4. Review and report on recent development of physical wind field modelling in open space with application for wave tank testing of floating offshore wind turbines, including modelling of turbulence and measuring and documentation of the wind field.
5. Review and report on the development of numerical offshore wind farm modelling.

Acknowledgement

The Committee would also like to acknowledge the contributions from Maxime Thys (SINTEF Ocean) and Katarzyna Patryniak (University of Strathclyde) for the support provided in writing up the report