

Testing of Wave Energy Converters in Wave Tanks

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Ocean and Coastal Engineering Laboratory

- Department of Civil Engineering moved into new building at AAU main campus in Sept. 2016
- New Wave Laboratories an important part of the new building
- Greatful for grant from the Obel Family Foundation for new wave maker equipment etc.



Wave Basin

- **Wave generator: 13 x 1.5 m (width and height).**
- **30 individually controlled wave paddles (snake type configuration) powered by electric motors.**
- **Accurate generation of 3D waves due to narrow vertically hinged paddles (0.43 m segment width).**
- **Maximum wave height up to 45 cm (at 3 s period).**
- **Typical maximum significant wave height in the range of 0.25-0.30 m**
- **Pumps with a total maximum flow of 3500 m³/h for generation of strong current in the basin (up to 0.15 m/s at 0.5 m water depth). Structures can be tested in combined waves and current (following or opposing).**



Deep pit (+7 m) in middle of basin

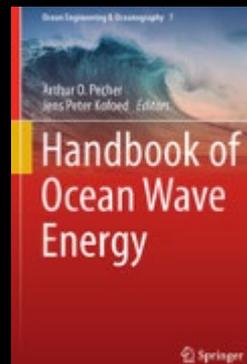
Wave Energy at Department of the Built Environment

Experimental testing in lab and at sea
Numerical modelling and optimization

Involved in all primary Danish – and numerous international – concept development within the sector

Project driven, based on cooperation with:
Private companies – developers, suppliers, consultants
Danish and international universities and institutions

But also:
Testsites
PhD courses
Standardization
Partnerships



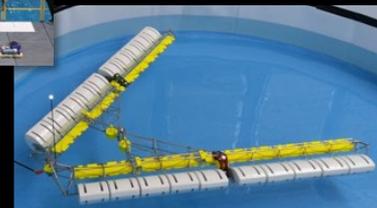
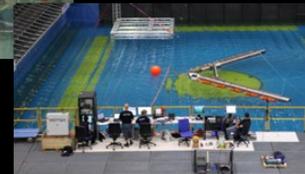
Wave Dragon



Wavestar



WEPTOS

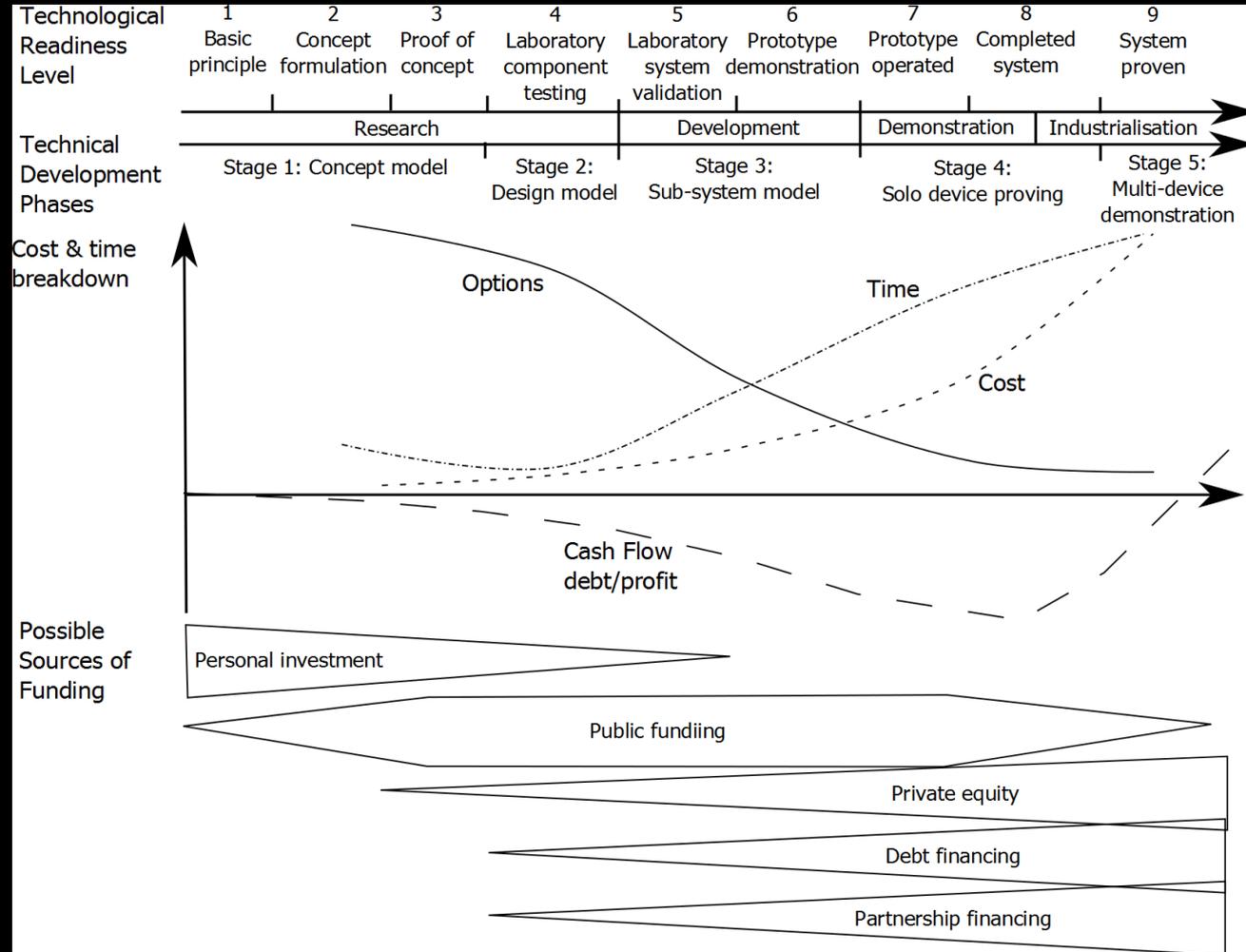
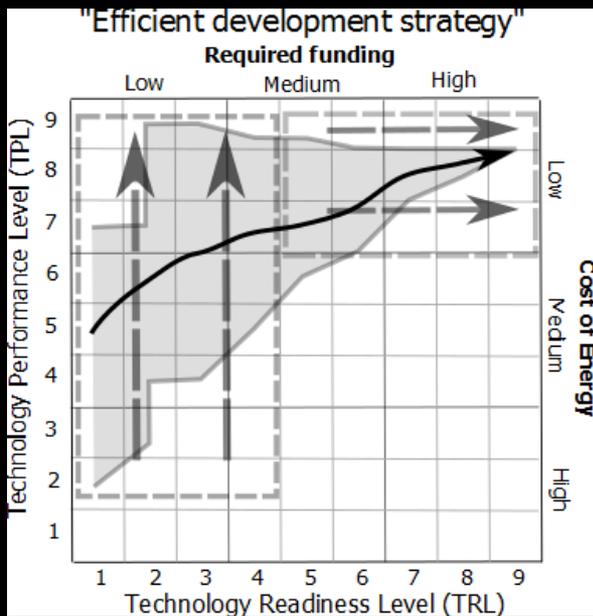


Why model testing?

Most important question is

LCOE

Project costs vs Energy produced
Loads vs Performance



Why model tests?

- Performance
- Loads & motions
- Installation & operations

- Seek qualitative insight
- Obtain measurements to check theoretical results
- Obtain measurements to validate/calibrate numerical results
- Obtain measurements of phenomena too complicated for theoretical/numerical evaluation

How to get performance data?

- The straight way is full scale experience... normally not a reasonable option!
- We need model testing and/or numerical modelling

What is a physical model?

- A physical system reproduced (at reduced size) so dominant forces are represented in the model in correct proportion to the prototype

Principles of similitude – scaling laws

- To ensure similitude between prototype and model, the following requirements must be met:
 - Geometric similarity – ratio between dimensions constant [L]
 - Kinematic similarity – ratio between motions constant [L T]
 - Dynamic similarity – ratio between forces constant [L T M]
- Impossible for ALL forces. Evaluation of violations necessary – these are the scale effects.

Model laws and scaling

Froudes Model law:

- Inertia forces are dominating. These are proportional to the volume/mass of the device.
- Friction forces are negligible.
- Geometrical similar with full scale device.

Choice of scaling ratio:

- Measuring accuracy \Rightarrow model size \uparrow
- Ratio between friction and inertia forces \Rightarrow model size \uparrow
- Surface tension \Rightarrow model size \uparrow
- Modelling of PTO system \Rightarrow model size \uparrow
- Handability \Rightarrow model size \downarrow
- Time restrictions \Rightarrow model size \downarrow
- Available laboratory size \Rightarrow model size \downarrow
- Economics \Rightarrow model size \downarrow

Parameter	Model	Full Scale	Example 1:100
Length	1	S	100
Area	1	S ²	10000
Volume	1	S ³	1000000
Time	1	S ^{0.5}	10
Velocity	1	S ^{0.5}	10
Force	1	S ³	1000000
Power	1	S ^{3.5}	10000000

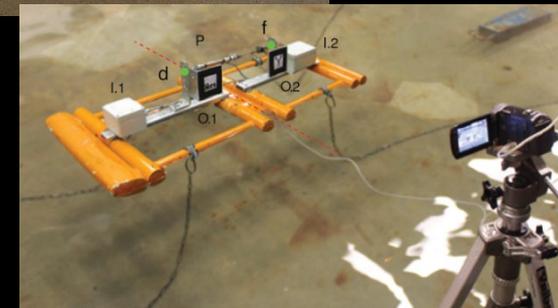
\Rightarrow Scaling ratios of 1:25 – 40 often used in our lab. (1 W ~ 80 – 400 kW !!!)

Measuring techniques – an overview

Measurements of:

- waves (surface elevations)
- pressures
- Forces (strain / stress)
- Motions (displacements / velocity / accelerations)
- Flow
- Torque
- Current velocity
- Dimensions
- ***

Particularly for WECs – PTO!



Modeling the power take-off system

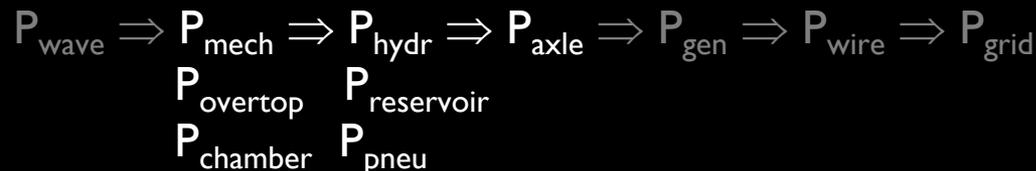
Challenges

- Scaling the PTO normally does not follow the Froud scaling laws. Therefore, a direct model of the full scale PTO can not be used
- The load from the PTO feeds back to the hydraulic behavior of the device, and is normally of paramount importance for the performance of the device. Therefore, the load from the PTO on the system have to be controlable

Solutions

- In smaller scale, "just" model the loading from the PTO
- Measure the power production early in the power chain

Beware of where in the chain of power you are measuring!



Some examples – weights lifted by rotating axle

Power measured through weight, axle diameter, displacement and time

Pros

- Very simple and direct measurement. Easy to change loading – weights and/or axle diameter

Cons

- Limited test durations – need large heights for long tests. Therefore best for regular wave tests
- Not possible to change loading "on the fly"
- Gives a constant torque on axle – not realistic loading characteristic of a generator



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Some examples – friction force and velocity

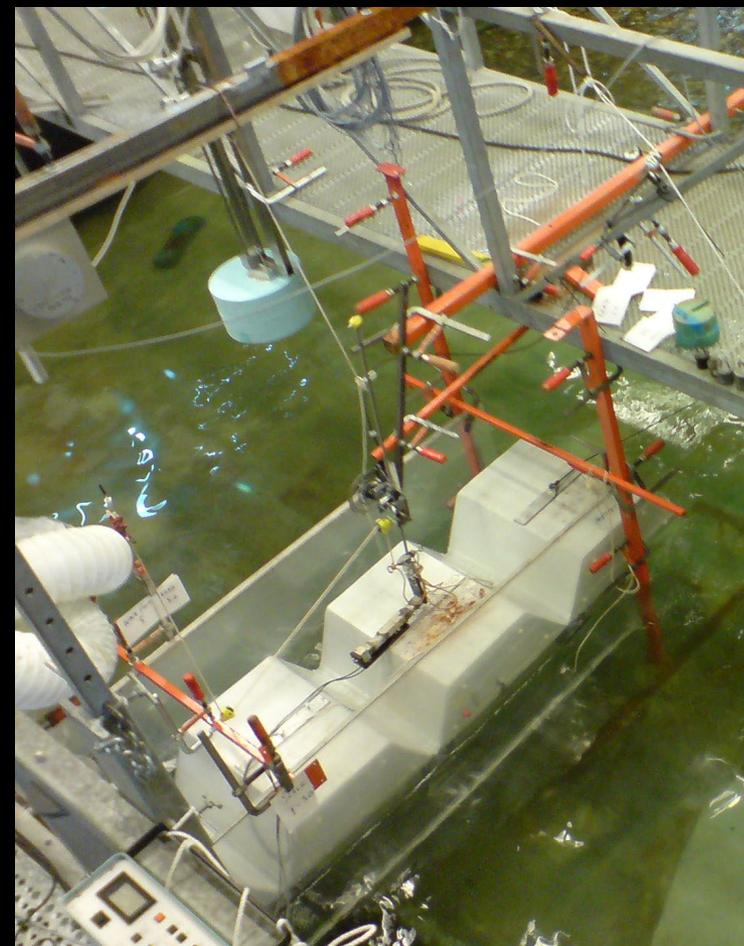
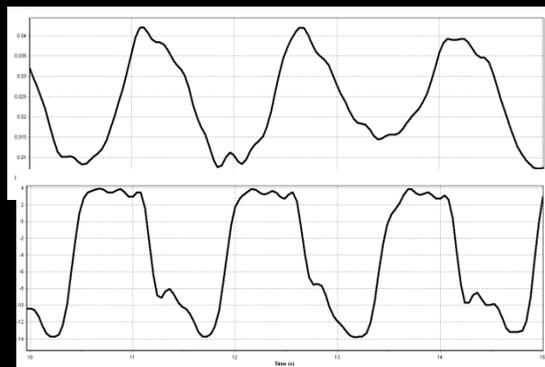
Power measured through force and displacement time series

Pros

- No limitations on test duration
- Loading can in principle be changed "on the fly"

Cons

- Risk of changing load characteristics due to heating of brakes
- Sometimes hard to get little enough friction for small waves



Some examples – air flow

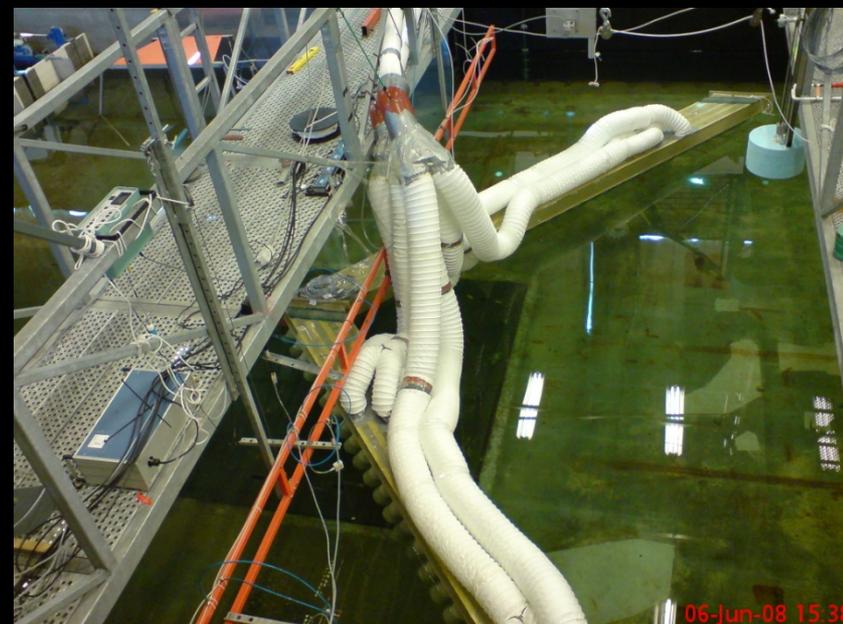
Power measured through flow and pressure time series

Pros

- Most appropriate for OWCs to get power measurements as early in the power chain as possible

Cons

- Difficulties in measuring fluctuating air flows



Some examples – overtopping flow

Power production measured through crest height and overtopping flow time series

Pros

- Simple and direct measurement
- Easy to change loading – crest height
- Power obtained very early in the power chain

Cons

- Resolution of flow in time
- Not possible to change loading "on the fly"
- Power obtained very early in the power chain



Some examples – Controllable force and velocity

Power production measured through force and velocity time series

Pros

- Full control – can be run in force or displacement control mode

Cons

- Cost
- Complexity



Some examples – Controllable torque and rotational speed

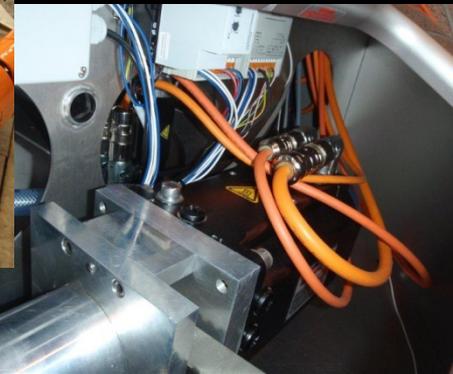
Power production measured through torque and rotational velocity time series

Pros

- Full control – relation between torque and rotational velocity can be specified

Cons

- Cost
- Complexity



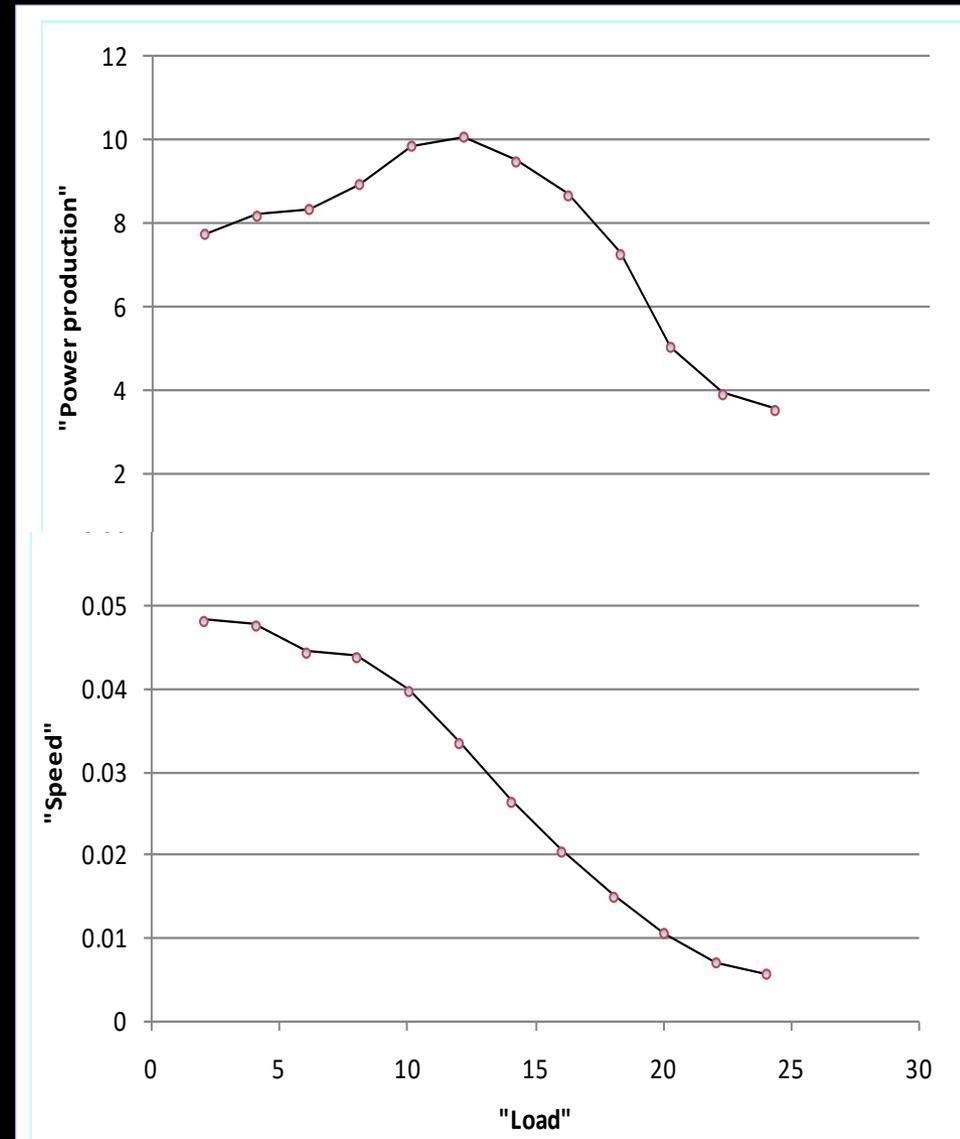
Load optimization

Often load optimized using regular waves
(maintaining energy contents)

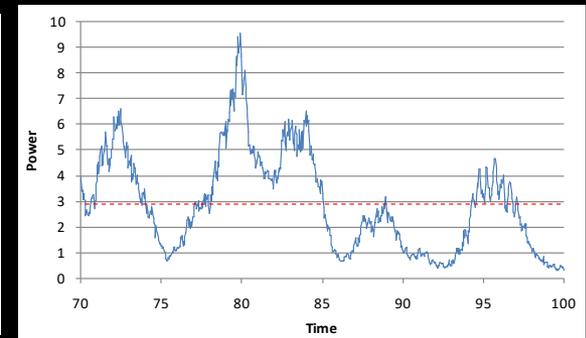
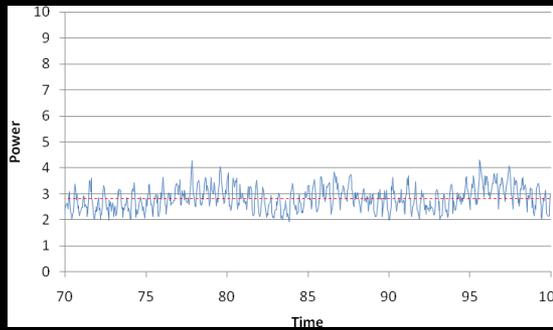
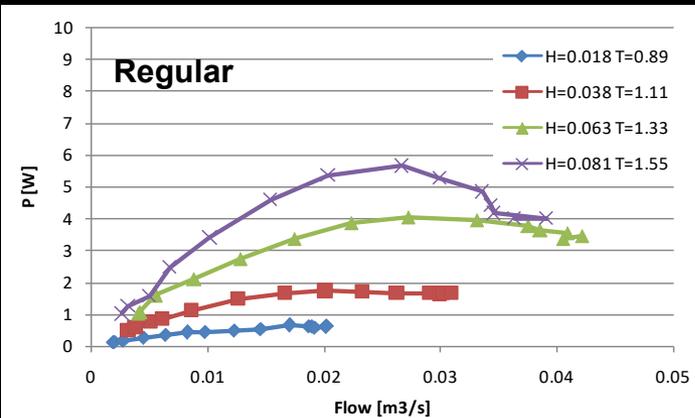
- $H = H_{m0}/\text{sqrt}(2)$
- $T = T_p$

Optimization for each wave condition

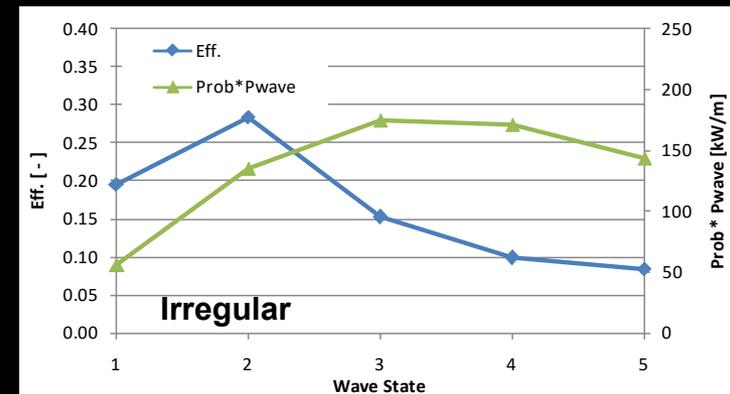
Power production measured in irregular waves using found optimal load setting
(plus check runs on either sides)



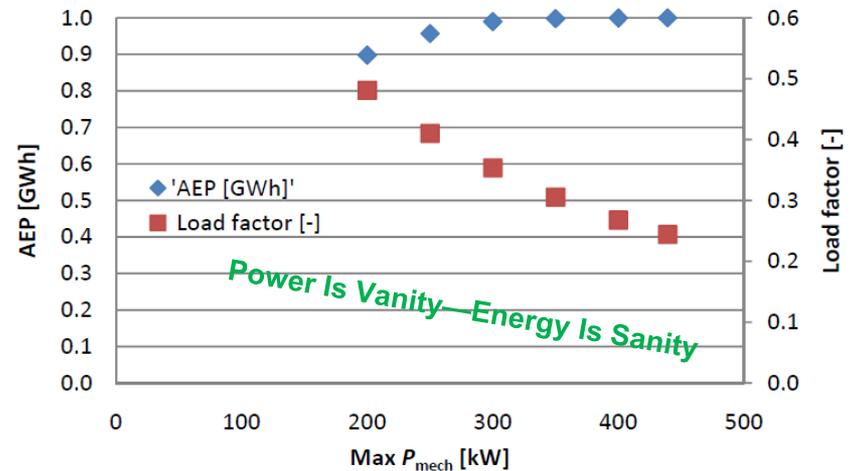
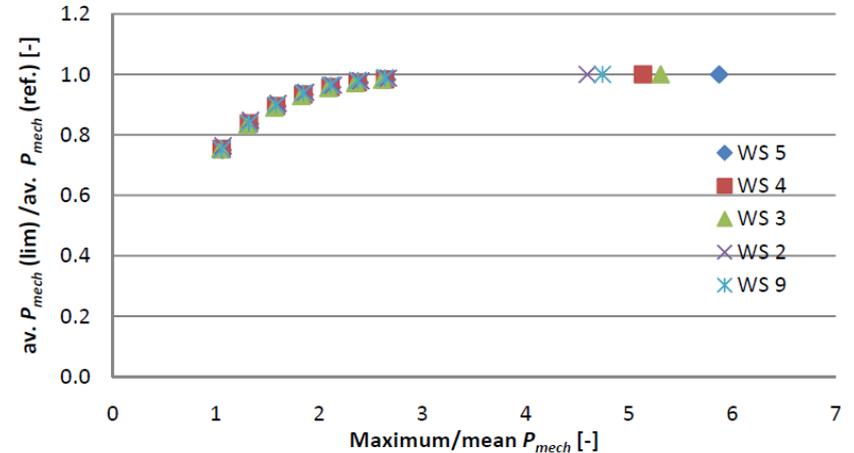
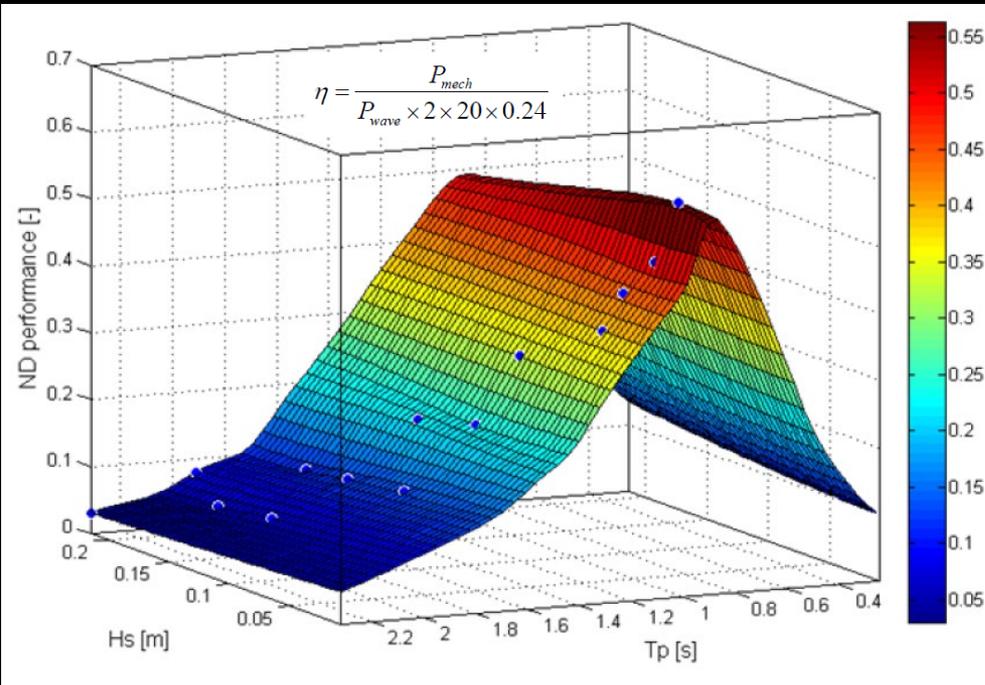
Estimation of yearly power production



Wave State	Pwave [kW]	Prob [%]	Prob*Pwave [kW]	Eff. [-]	Energy prod. [kW]	Pgen [kW]
1	120	0.468	56	0.195	11	23
2	598	0.226	135	0.284	38	170
3	1616	0.108	175	0.152	27	246
4	3351	0.051	171	0.098	17	330
5	5985	0.024	144	0.084	12	505
Yearly average [kW]			680		105	
Overall eff. [-]					0.154	
Yearly prod. [MWh/y]					919	
Max. Pgen [MW]						0.505
Load factor [-]						0.21



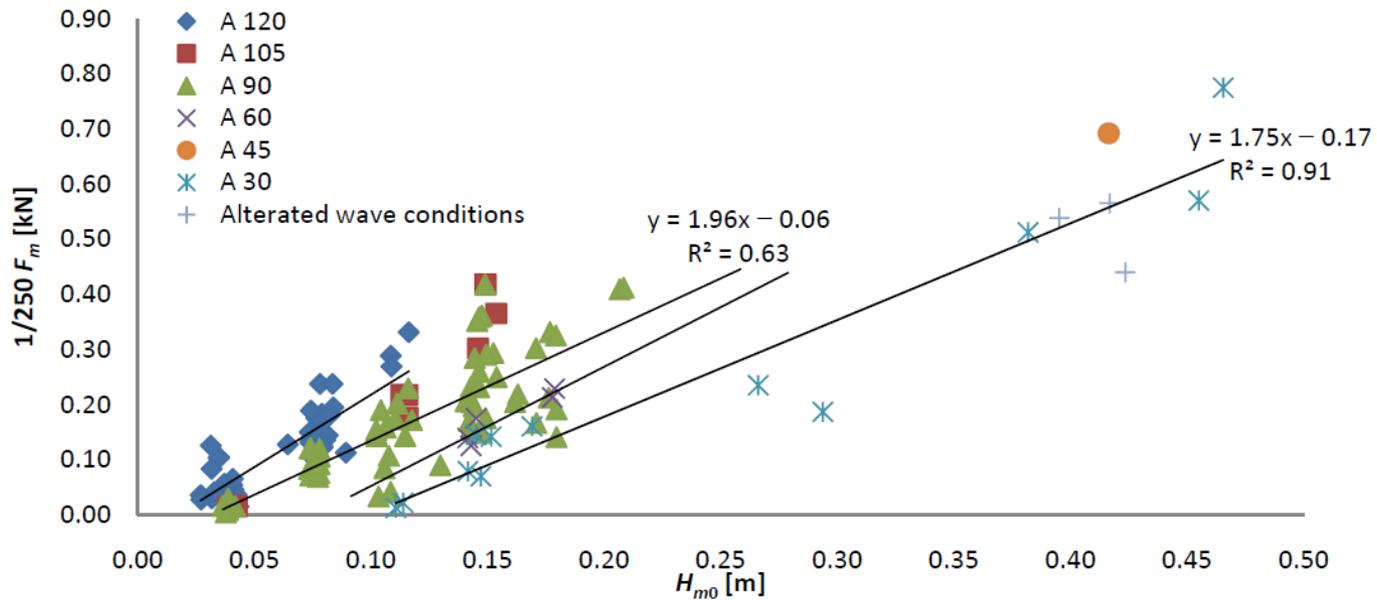
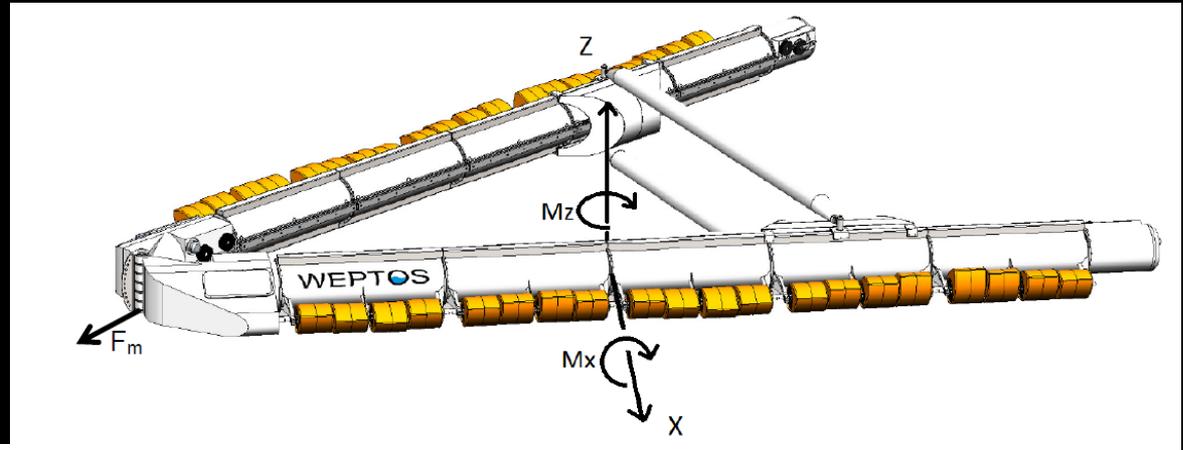
Power production measurements

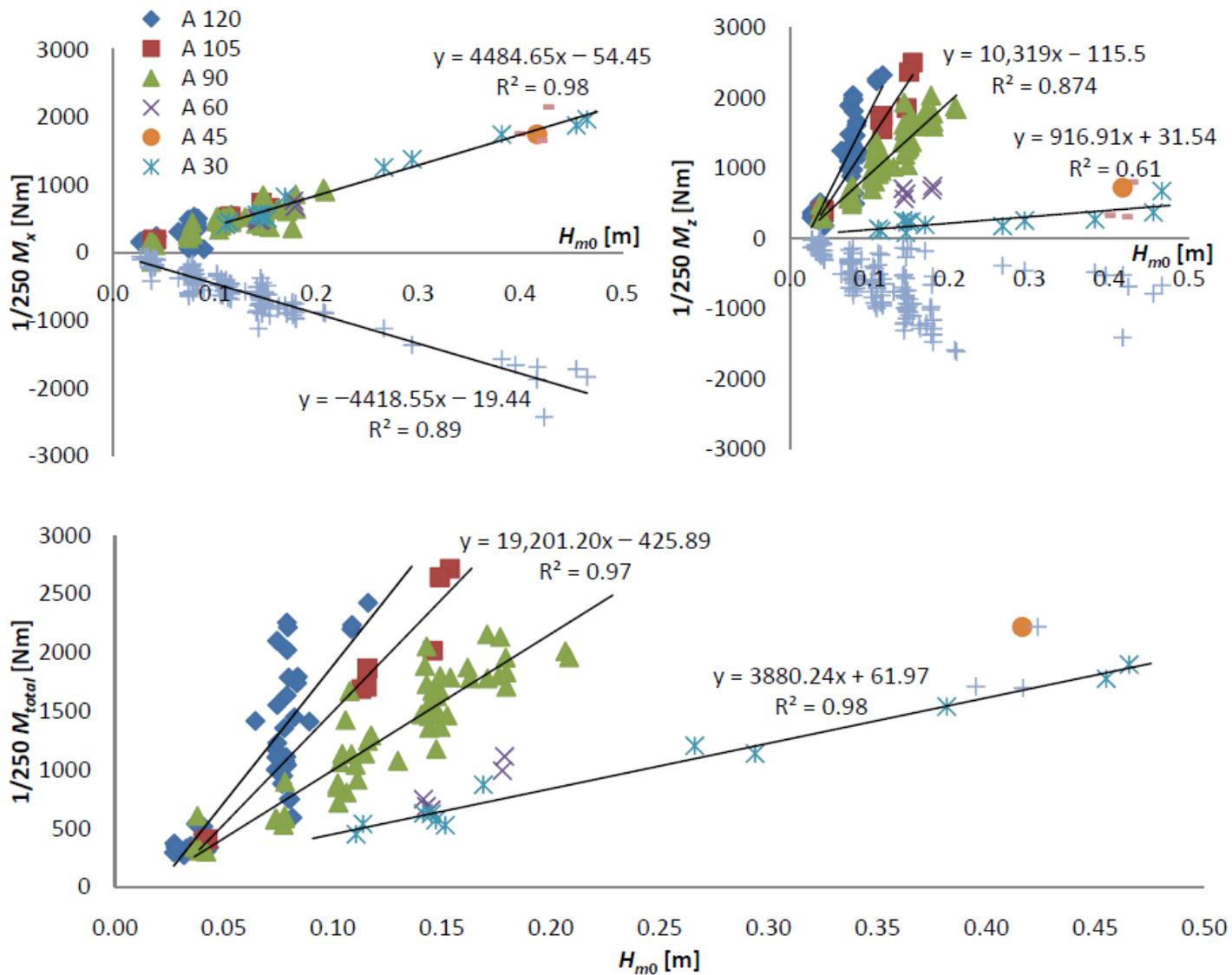


Weptos



Loadings





COE Calculation spreadsheet

COE Calculation Tool

version 1.6



JULIA F. CHOZAS
CONSULTING ENGINEER

Reference machine

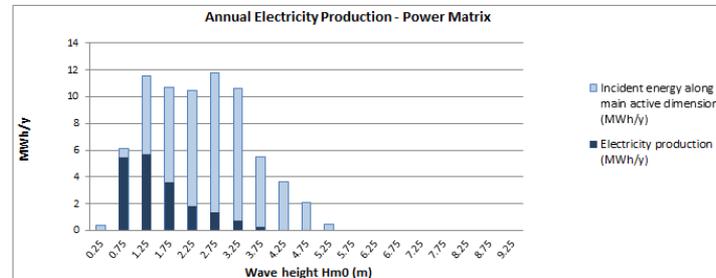
Name of project:

Power known as:

Power matrix refers to:

Location: Wave: 7.1 kW/m

Capacity factor	41%
Annual electricity production	19 MWh/y
Average annual electricity production	2 kW
Average wave-to-wire efficiency	25%

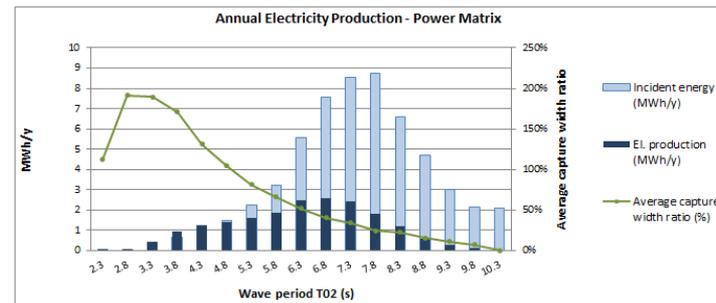


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Legend

- Editable cell
- Default values
- Used values

Currency	EUR	Development stage: Phase 4 / TRL 8		[40 to 40%] uncertainty
FIT-UK (€/MWh)	367.5	600.0		
Total CapEx	0.25 M€	Annual OpEx	20.10 k€/y	
Payback period	Greater than project lifetime			
Discount rate	0%	4%	8.0%	
LCOE (15 years, in €/MWh)	1933	2154	2402	
NPV (15 years, in k€)	-381.3	-347.7	-325.5	



WEC's features and performance

	Default	Enter	Used
Scale	1.00		1.00
Main active dimension		1.2	1.20 m
Secondary dimension (length/width)		3.6	3.60 m

Costs (CapEx and OpEx)

	Default	Enter	Used	
Engineering and management	0.0		0	DKKx1000
Planning and consenting	0.0		0	DKKx1000
Development	54.9		55	DKKx1000
Main material	Concrete	0.8	1	DKKx1000

Standard values

3% CapEx

1500 DKK/ton

COE sheet

[http://vbn.aau.dk/en/publications/user-gui%2de--coe-calculation-tool-for-wave-energy-converters\(78b135d9-ea66-43f8-959f-c799dc4df1a9\).html](http://vbn.aau.dk/en/publications/user-gui%2de--coe-calculation-tool-for-wave-energy-converters(78b135d9-ea66-43f8-959f-c799dc4df1a9).html)

<https://www.ocean-energy-systems.org/library/technical-reports/cost-of-energy/document/international-levelised-cost-of-energy-for-ocean-energy-technologies-2015/>

Guidelines and data sources ...

ANNEX II
Task 1.1 Generic and Site-related Wave Energy Data
September 2010

A report prepared by the RAMBOLL and LNEG to the OES-IA under the Annex II – Guidelines for Development and Testing of Ocean Energy Systems
September 2010
OES-IA Document n° TD2-1.1

DANISH ENERGY AGENCY LNEG RAMBOLL IEA | OES Ocean Energy Systems

www.iea-oceans.org

International Agency for Energy Agency

WAVE DATA CATALOGUE FOR RESOURCE ASSESSMENT IN IEA-OES MEMBER COUNTRIES

March 2009

A report prepared by INETI to the IEA-OES under ANNEX I - Review, Exchange and Dissemination of Information on Ocean Energy Systems
IEA-OES Document No: T0103

INETI IEA | OES Ocean Energy Systems

COMMISSION OF THE EUROPEAN COMMUNITIES COOPERATION

Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact
Grant agreement number: 213380

EquiMar

Deliverable D2.2
Wave and Tidal Resource Characterisation

<https://www.wiki.ed.ac.uk/display/EquiMarwiki/EquiMar>

IEC International Electrotechnical Commission

TC 114 International Standards and Conformity Assessment for all electrical, electronic and related technologies

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Standards development > How we work > Technical Committees & Subcommittees > **TC 114 Dashboard**

TC 114 Marine energy - Wave, tidal and other water current converters

Scope **Structure** Projects / Publications Documents Meetings

TC 114 Scope

To prepare international standards for marine energy conversion systems. The primary focus will be on conversion of wave, tidal and other water current energy into electrical energy, although other conversion methods, systems and products are included. Tidal barrage and dam installations, as covered by TC 4, are excluded. The standards produced by TC 114 will address: "system definition" "performance measurement of wave, tidal and water current energy converters" "resource assessment requirements, design and survivability" "safety requirements" "power quality" "manufacturing and factory testing" "evaluation and mitigation of environmental impacts"

Further information

Secretariat: United Kingdom
Strategic Business Plan

Tools (members only)

- Collaboration Tools: Access restricted to TC 114 members only
- Document open for vote/comment

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Questions - comments?

Thank you!

