Collaborative Computational Project for Wave Structure Interaction

Wave & Tidal Energy - Challenges

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14 July 2016

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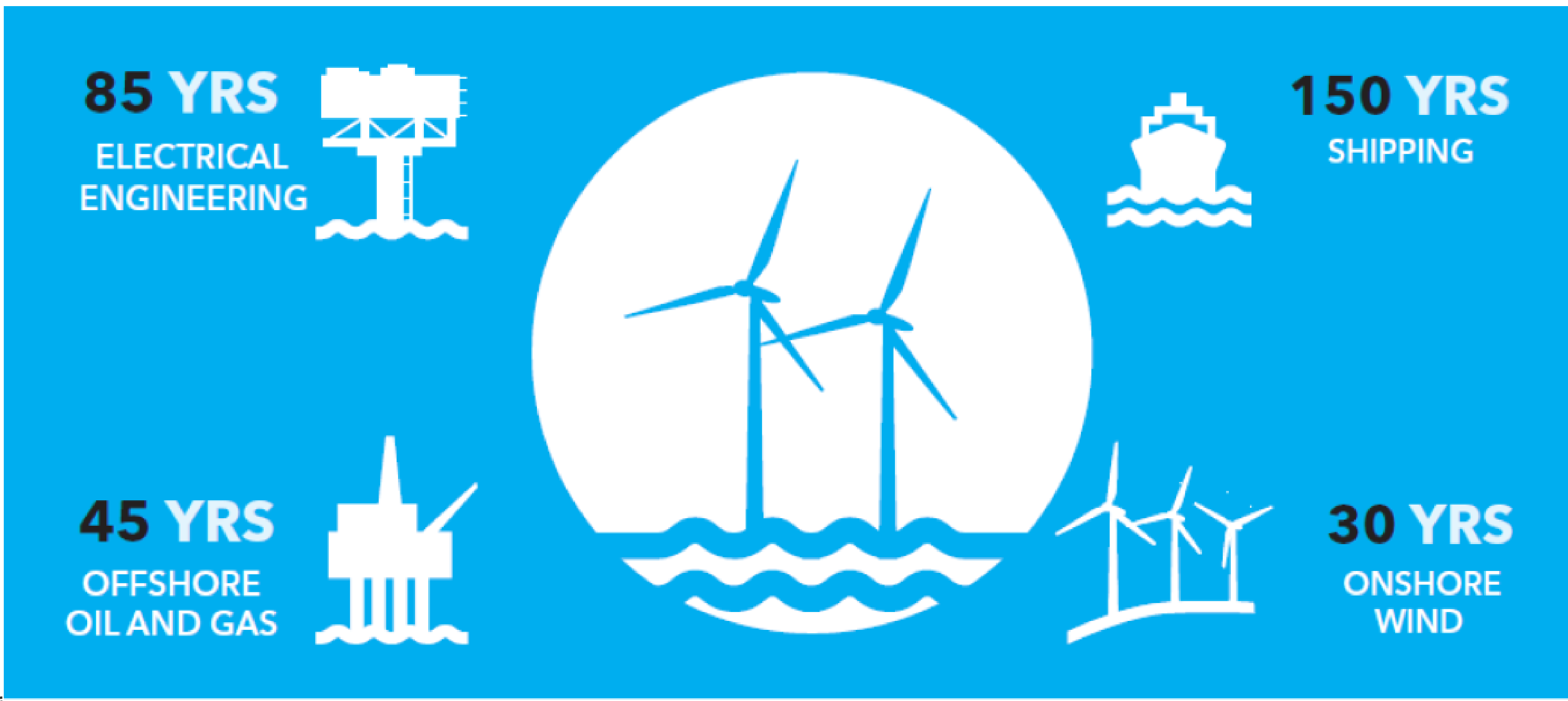
DNV GL Experience for the Offshore Renewables Industries

DNV + GL + KEMA + Nobel Denton + Garrad Hassan =

DNV GL – Energy

The world's largest certification and advisory firm in renewable energy

(with uniquely extensive offshore renewables competence)



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Services

Device developers/ manufacturers

- Device design
- Control system development
- Innovative technology evaluation
- Measurement services
- Device type approval and certification support
- Marine warranty services
- Strategic and policy advice
- Training courses

Project developers

- Project development support
- Site feasibility studies
- Environmental and permitting services
- Resource and energy analysis
- Site suitability studies
- Device consulting
- Due diligence
- Interconnection
- Construction phase modelling and operations and maintenance modelling
- Construction / installation services
- Strategic and policy advice
- Training courses

Investors/lenders

- Due diligence services
- Marine warranty services
- Strategic and policy advice
- Training courses

Owners/operators

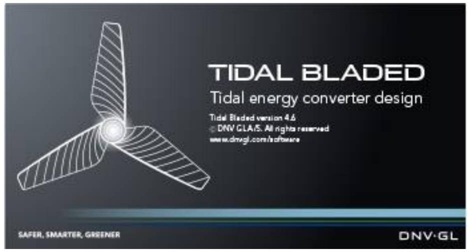
- Owner's engineering support and FEED studies
- Due diligence
- Asset management and optimisation services
- Energy assessment
- Measurement services
- Marine warranty services
- Supply of SCADA systems
- Strategic and policy advice
- Training courses

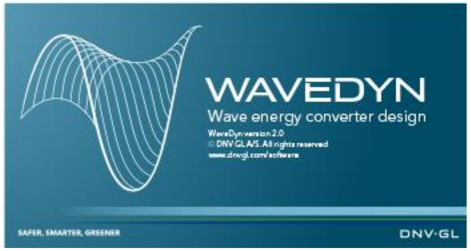
Government/NGOs

- Market intelligence
- Policy and regulatory studies
- Specialist strategic studies

DNV GL in-house renewable energy tools

Device modelling





Array modelling

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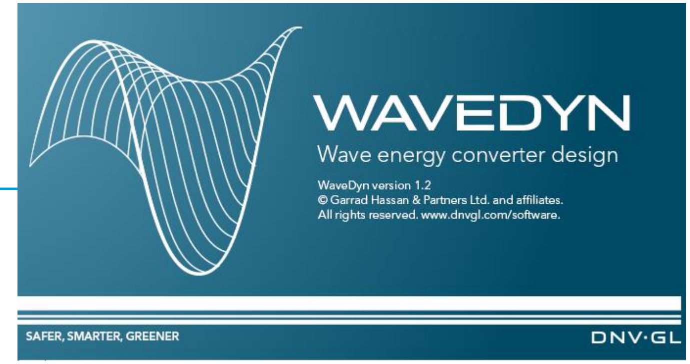
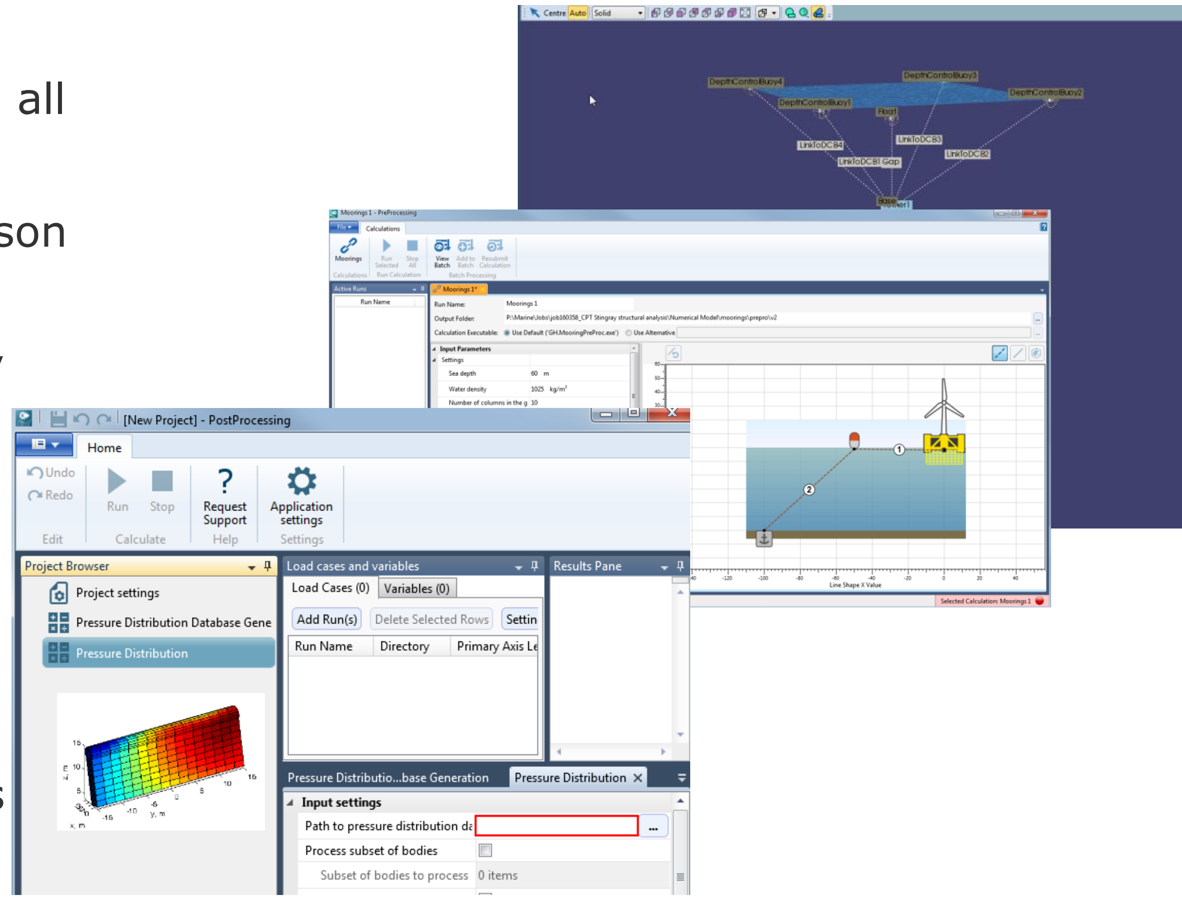
WaveDyn 1.2 – New features



Released February 2016

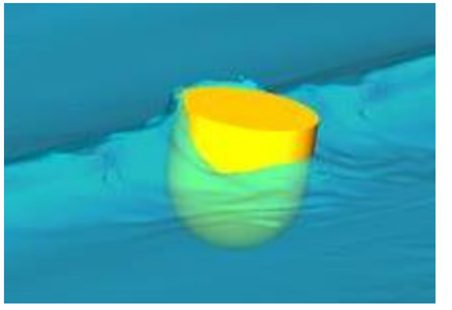
- Pre-processing
  - Moorings line look-up table generation
- Arbitrary external loading on all bodies possible using a DLL
- Viscous drag elements (Morison loading)
- Instantaneous Froude Krylov and hydrostatic forces
- Post-processing
  - Pressure distribution
- 3D model viewer
- Reporting:
  - Loads in body-fixed coords
  - Bryant angles

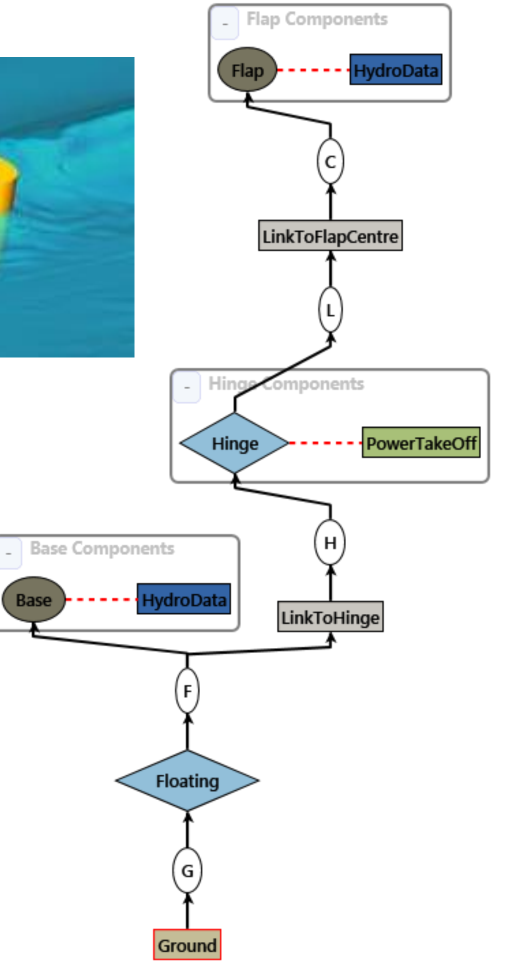


Current Wave Structure Interaction Research

- DNV GL-sponsored studentship at Plymouth University looking at coupling
  - Hydrodynamics

  from the Computational Fluid Dynamics (CFD) solver OpenFOAM with the WaveDyn WEC simulation tool, incorporating:
  - Multibody structural modelling
  - Moorings representation
  - Power take-off (PTO) modelling
- Aim to be able to analyse the most extreme wave conditions whilst also incorporating a realistic description of the rest of the machine





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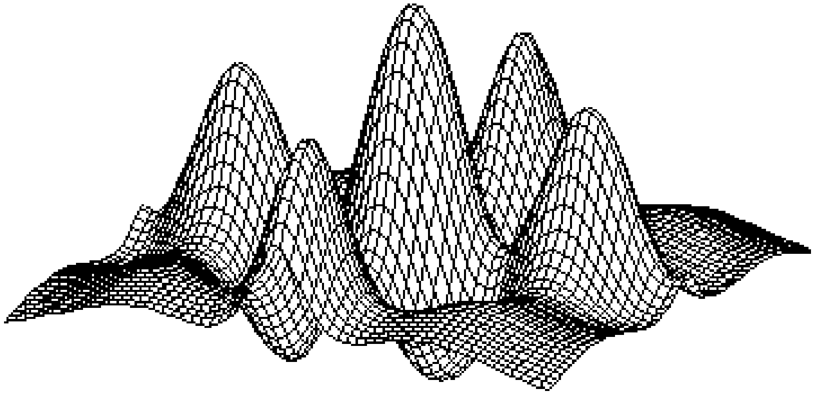
General modelling aspects

- **Coupling:**
  - Many aspects (e.g. moorings or the PTO) can be modelled relatively straightforwardly independently but it is often important for accurate loads and performance predictions that these are modelled in a coupled system
- **Optimisation:**
  - In principle, once simulations are possible for any input parameter, an optimisation algorithm can iterate on the parameter(s) in question to produce an optimum which can be used in the design process. However, practical aspects that must be considered include:
    - Efficiency
    - Simulation stability
    - The smoothness of the objective function (e.g. due to random effects)
- **Machine Learning:**
  - Another set of tools that may be useful in the design process are machine learning algorithms which could, for example, help to efficiently predict loads.



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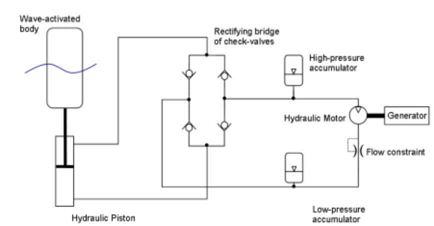
PTO and control

- **The task:**
  – Power take-off (PTO): Incorporate a cost-effective, efficient, reliable power conversion mechanism into the device
  – Control: Achieve maximum time-average power absorption and minimise loads
- **State of the art:**
  – Time-domain solvers currently used and have sufficient accuracy in performance conditions to allow control algorithms to be designed.
- **WSI topics:**
  – Accurate hydrodynamic loads are needed for design of PTO and control algorithms
- **The challenges:**
  – How can the accuracy of loads be improved upon?
  – How can the dynamics/hydrodynamics of complex systems be made to run in close to real-time for Hardware In the Loop testing?
  – How can control be used to reduce loads in extreme waves?



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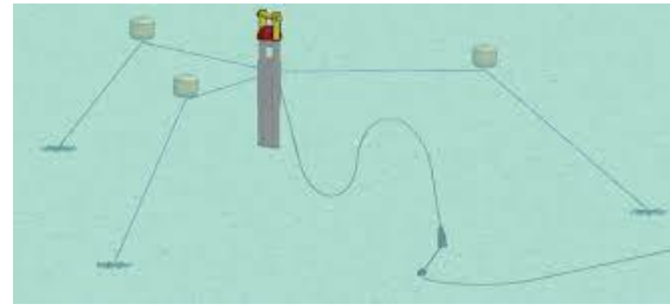
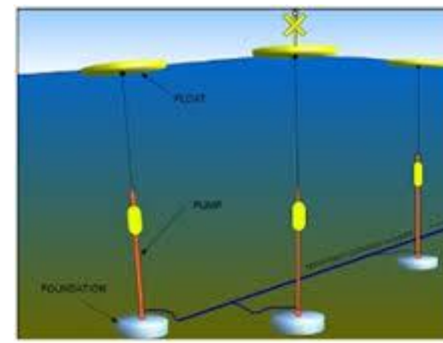
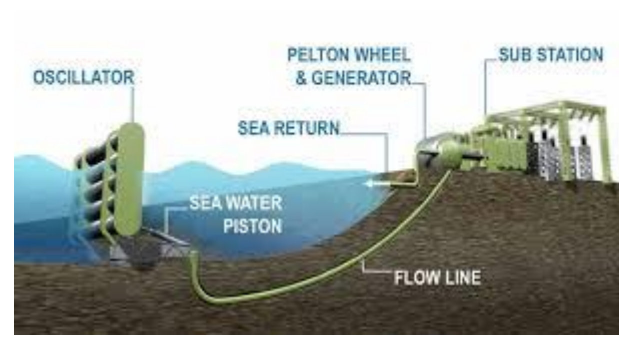
Moorings and foundations

- **The task:**
  - Ensure that the device stays on-station but is not adversely restricted in its motions, whilst efficiently utilising the sea bed area and minimising cost
- **State of the art:**
  - Common mooring design tools available:
    - Quasi-static approach
    - Dynamic mooring line approach

    Few tools couple full mooring analysis with detailed description of the rest of the wave/tidal energy converter
- **WSI topics:**
  - Dynamic simulation of mooring lines with drag and other hydrodynamic effects
  - Coupled detailed simulation of mooring lines and wave/tidal energy converter
- **The challenges:**
  - How do we ensure that complex time-domain simulations with moorings remain stable?
  - How can we couple complex mooring models into a range of solvers and ensure efficiency?







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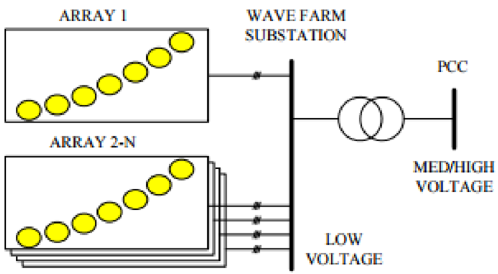
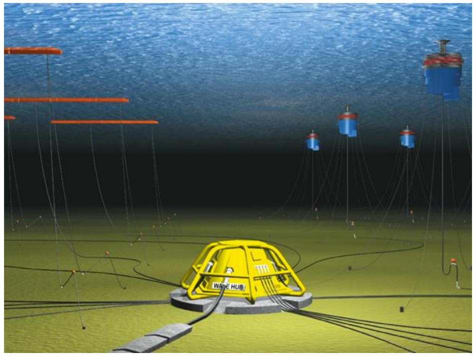
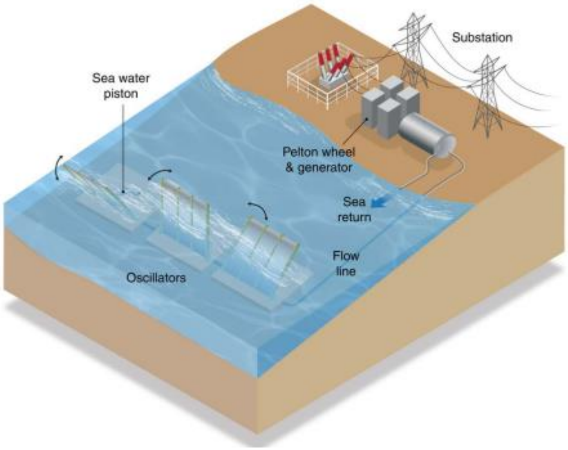
Balance of Plant

- **The task:**
  - Transfer power to on-shore connection point as efficiently, reliably and cheaply as possible:
    - Electrical (high or low voltage) connection
    - Pressurised water transfer
- **State of the art:**
  - Much of the BoP is unaffected by waves but some elements do need closer analysis. Some of this can be done with existing design tools.
- **WSI topics:**
  - Umbilicals: Hydrodynamic loads and coupled dynamics with wave/tidal energy converter
  - Exposed pipes/cables: Possible vibrations due to wave excitation
  - Offshore substations: Fixed to seabed – wave loads only. Floating – full dynamic analysis needed.
- **The challenges:**
  - How do we best model the loads on BoP elements in the wave environment, especially in extremes?







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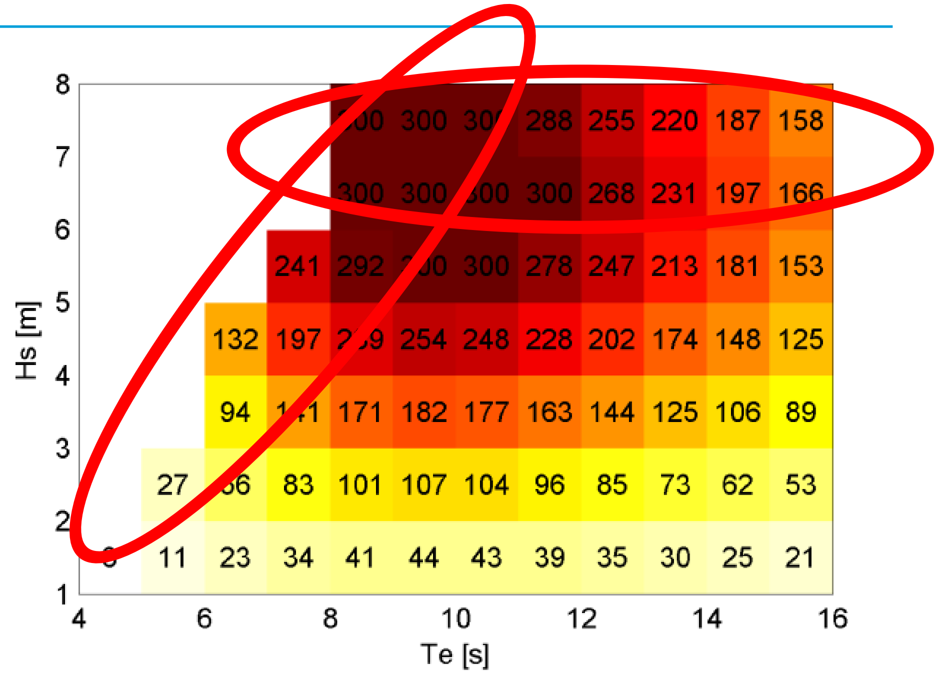
Installation and Operations & Maintenance

- **The task:**
  - Install and maintain devices at the lowest cost (i.e. with the cheapest capable vessel, that can operate in the greatest range of conditions)
- **State of the art:**
  - Vessels from other industries generally used
  - Some modelling done in software packages e.g. Orcaflex
- **WSI topics:**
  - Design of vessels
  - Sheltered areas for O&M
  - Modelling installation/operation procedures (e.g. anchor and mooring deployment, offshore lift dynamics, towing dynamics)
- **The challenges:**
  - Can design tools for these tasks be integrated with tools for design of devices to streamline the whole process?

Performance assessment

- **The task:**
  - Accurately predict annual energy yield for a particular device
- **State of the art:**
  - Frequency and Time domain (e.g. WaveDyn) solutions based on linear wave theory from boundary element methods typically used
  - CFD and fully nonlinear potential flow currently too time-consuming
- **WSI topics:**
  - Corrections to linear hydrodynamics:
    - Parameterising viscous effects
    - Nonlinear excitation force
    - Nonlinear buoyancy forces
    - Nonlinear radiation forces
  - Nonlinear / steep, non-breaking wave-structure interaction
  - Interaction of waves with bodies undergoing large motions
  - Interaction of waves with deformable bodies, air column (e.g. in OWC)



- **The challenges:**
  - How can corrections to linear hydrodynamics be implemented consistently?
  - Are there models that can determine power accurately in steep/large sea states but can be run for a large number of sea states?

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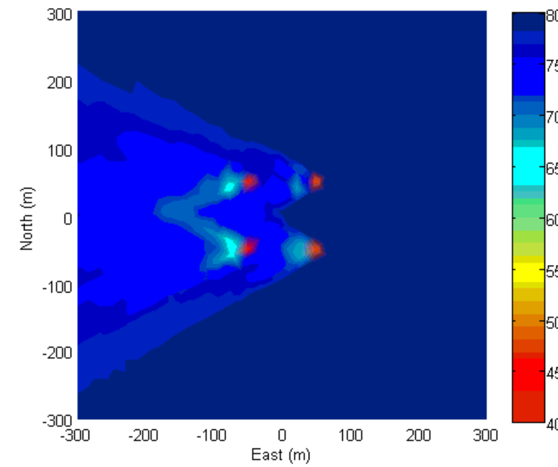
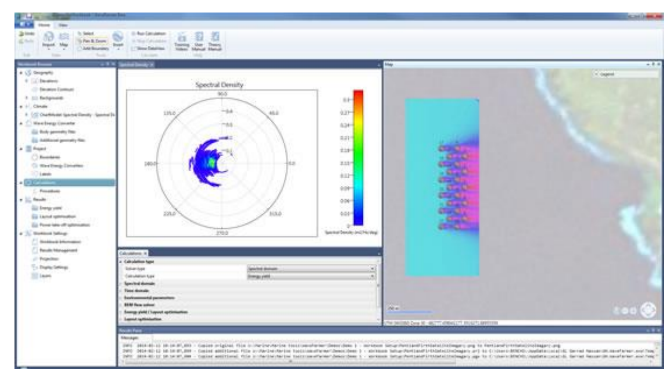
Array modelling & environmental impact

- **The task:** Deploy devices in an array that makes best use of the available resource at the site but does not significantly diminish overall performance of the converters or adversely affect the surrounding environment.
- **State of the art:**
  - Modelling tools exist (e.g. WaveFarmer) that incorporate a range of approaches:
    - Modified spectral wave models
    - Frequency domain
    - Time domain
- **WSI topics:**
  - Accurately predicting device behaviour when placed in a realistic environment involving many other devices as well as:
    - Varying bathymetry across site
    - Currents
    - Wave-wave interactions, breaking etc.
  - Environmental impact of energy extraction and disturbance to wave field
  - Performance and loading modification due to hydrodynamic interactions between devices
- **The challenges:**
  - How do we make the simulations efficient when the computational time for the more accurate tools increases rapidly with number of devices?





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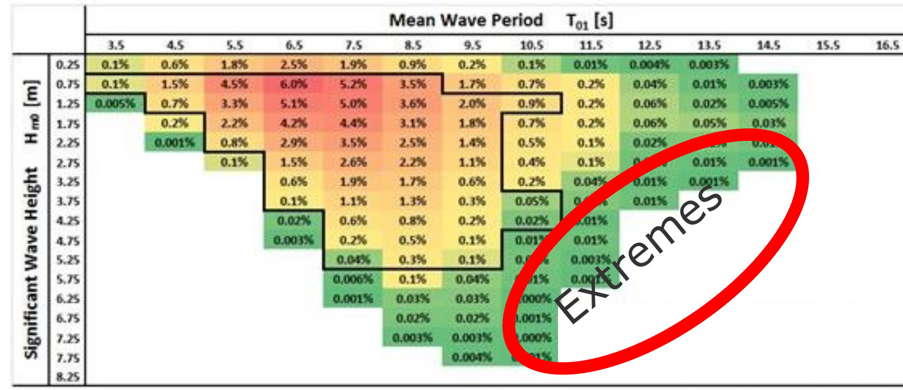
Reliability and survivability (1/2)

- **The task:**
  - Survive "hostile" marine environment i.e. design for extremes conditions (1 in 100 year , 1 in 50 year events)
  - Make sure the millions of oscillations in load applied to the structure does not cause fatal fatigue damage (reliability)
- **State of the art:**
  - Empirical formulas for loads occasionally taken from standards but may not be appropriate
  - "Design wave" approach may not be appropriate
  - Time-domain solvers with linear hydrodynamics (e.g. WaveDyn) can be used for many fatigue cases
  - Second order hydrodynamic solution available from common boundary element methods e.g. WAMIT.
  - CFD (Navier Stokes solvers) and Smoothed Particle Hydrodynamics (SPH) used for extremes
  - Finite Element Modelling used for structural analysis
  - Tank tests commonly used where CFD is not practical/reliable



Significant Wave Height H_{m0} [m] \ Mean Wave Period T_{01} [s]	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
0.25	0.1%	0.6%	1.8%	2.5%	1.9%	0.9%	0.2%	0.1%	0.01%	0.004%	0.003%			
0.75	0.1%	1.5%	4.5%	6.0%	5.2%	3.5%	1.7%	0.7%	0.2%	0.04%	0.01%	0.003%		
1.25	0.005%	0.7%	3.3%	5.1%	5.0%	3.6%	2.0%	0.9%	0.2%	0.06%	0.02%	0.005%		
1.75		0.2%	2.2%	4.2%	4.4%	3.1%	1.8%	0.7%	0.2%	0.06%	0.05%	0.03%		
2.25		0.001%	0.8%	2.9%	3.5%	2.5%	1.4%	0.5%	0.1%	0.02%	[illegible]	[illegible]		
2.75			0.1%	1.5%	2.6%	2.2%	1.1%	0.4%	0.1%	[illegible]	0.01%	0.001%		
3.25				0.6%	1.9%	1.7%	0.6%	0.2%	0.04%	0.01%	0.001%			
3.75				0.1%	1.1%	1.3%	0.3%	0.05%	[illegible]	0.01%				
4.25				0.02%	0.6%	0.8%	0.2%	0.02%	[illegible]					
4.75				0.003%	0.2%	0.5%	0.1%	[illegible]	0.01%					
5.25					0.04%	0.3%	0.1%	[illegible]	0.003%					
5.75					0.006%	0.1%	0.04%	[illegible]	[illegible]					
6.25					0.001%	0.03%	0.03%	[illegible]						
6.75						0.02%	0.02%	[illegible]						
7.25						0.003%	0.003%	[illegible]						
7.75							0.004%	[illegible]						
8.25														

- **WSI topics:**
  - Determining point and distributed loading on structures and components in:
    - Nonlinear wave cases (as for performance calculations)
    - Breaking wave loads (including aeration effects)
    - Wave slamming
    - Wave and current environments
    - Marine growth, icing, ship impact, green water scenarios

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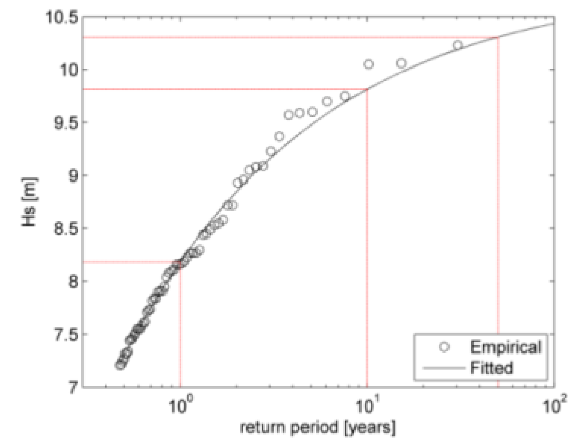
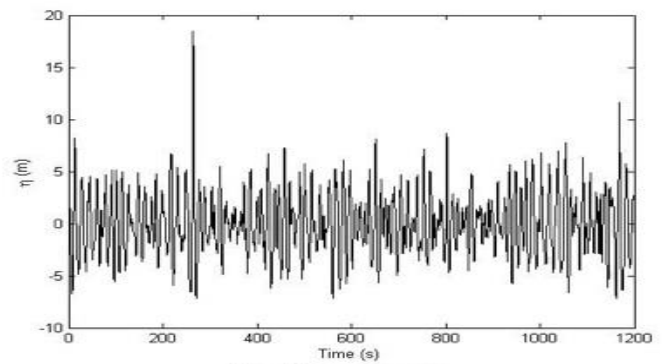
Reliability and survivability (2/2)

- **The challenges:**
  - How do we model extremes accurately?
  - How do we model all other energetic/non-performance cases well?
  - How do we select cases and indicative loads for analysis in computationally demanding codes?
  - How can we make CFD models easier to run and more reliable?
  - How can we improve the efficiency of CFD?
  - Can we be sure that structural response from linear models is accurate? Is more validation needed?
  - Can simpler methodologies (formulas, design waves) be attained from more exhaustive calculations?





The Draupner wave

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Thank you!

Ben Child
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