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Wave Structure Interaction Computation and Experiment Roadmap Part 1: A Report on the 1st CCP-WSI Focus Group Workshop

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Wave Structure Interaction Computation and Experiment Roadmap

Part 1: A Report on the 1st CCP-WSI Focus Group Workshop

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Executive Summary

As part of the Collaborative Computational Project in Wave Structure Interaction (CCP-WSI), the first CCP-WSI Focus Group Workshop took place on 14th July 2016 at City University London, bringing together over 50 national and international academics and industry experts to discuss WSI challenges covering three key areas: offshore wind; wave and tidal energy, and; offshore, maritime and coastal engineering. Each of the three sessions consisted of a presentation from industry followed by a break-out session in which participants discussed the current status and main challenges faced by the WSI community. As a result, a priority list of activities was developed to inform future focus group events and WSI road-mapping exercises. Among the highest priority activities identified were the need to:

- improve the speed/efficiency of WSI simulations;
- couple/integrate WSI codes under a common interface;
- create Full System Modelling tools;
- improve our understanding and prediction of extremes;
- develop comprehensive validation and verification protocols for model tests;
- develop models capable of predicting compressibility/aeration effects;
- improve scour modelling methods;
- develop models capable of modelling installation, deployment and maintenance operations involving multiple body interactions.

The first CCP-WSI Focus Group Workshop was highly successful building strong support for CCP-WSI activities, including the proposed bid for a High End Computing (HEC) consortium in WSI, and generating a number of new project proposals.

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An Introduction to the CCP-WSI

Marine renewable energy, offshore wind and offshore, maritime and coastal engineering are all of high national priority for the UK. There is a pressing need to fully understand the environmental forces that lead to critical implications for the safety of personnel and the survivability of offshore structures. Computational codes must be available early in the design process in order to quantify reliably the expected loads and supplement complementary laboratory measurements and field tests.

The Collaborative Computational Project in Wave Structure Interaction (CCP-WSI) brings together the community of researchers, including those from Plymouth University, Manchester Metropolitan University, City University London, Exeter University, Bath University and the Science and Technology Facilities Council. The group of the researchers will carry out activities under the shared objective of developing and maintaining a robust and efficient, open-source WSI modelling tool. The Numerical Wave Tank (NWT) code is held within a central code repository, professionally software engineered, shared and tested against new fundamental experiments for benchmarking and validation. The Project provides advanced training in computer science and software engineering including quality assurance, characterisation of data, verification and validation of computational models. Driven by focus group workshops and road-mapping exercises, the CCP-WSI provides a framework for innovation, code rationalisation and development of strategic software in an area of national importance.

The 1st CCP-WSI Focus Group Workshop

The first CCP-WSI Focus Group Workshop took place at City University, London, on Thursday 14th July 2016. The Workshop brought together over 50 members of the WSI Community, including international academics, key stakeholders and industry experts, providing a forum for WSI discussions covering a broad range of offshore and coastal applications. WSI challenges were identified and a priority list of activities was developed to inform future targeted focus group meetings. The goal of these meetings is to capture community requirements, ensure a strategic approach to software support in WSI and form consortia for research project proposal development. As part of this activity, the CCP-WSI carries out road-mapping exercises for WSI computation and experiment, informing CCP-WSI strategy and future UK research funding calls. This will ensure that new developments, applications and understanding in WSI are addressed while helping to maintain the nation's world-leading status in offshore and coastal engineering.

The Workshop was made up of three sessions: offshore wind; wave and tidal energy structures; offshore, maritime and coastal engineering. Each session consisted of a presentation from an industry expert followed by a 'break-out' session in which participants discussed, in groups, the current status and main WSI challenges faced by each industry (see Appendix 2 for a list of questions posed in the break-out session). A priority list of required WSI activities was then devised from a synthesis of the common challenges identified in each session.

Session 1: Challenges in Offshore Wind

The first session in the CCP-WSI Focus Group Workshop considered WSI challenges in Offshore Wind. Dr Steven Downie of the Advanced Technology + Research group at Arup presented the industry's perspective, first outlining a number of challenges in offshore wind regarding the reality of environmental conditions at sea including that:

- the bathymetry over a project area is highly variable and can include areas of mobile sediments that can influence the local wave/tidal conditions;
- irregular wave kinematics in intermediate/shallow depths and refraction/shoaling over sandbanks is not well understood.

Following this the trends in turbine/substation foundation technologies were outlined, starting with the commonly-used, shallow-water monopile. In this case, the industry perception is that, for quasi-static response, wave loading on slender structures is well understood and existing analysis tools are adequate (they don't deal with higher harmonics but it doesn't matter in this case). However, for the dynamic response of monopiles, including the effects of ringing and springing, the 'representation of WSI is poor and it matters'. This is a significant issue that depends on the sensitivity of the structure and the industry guidance (DNV-OS-J101) recommends consideration of the ringing effects, however, none of the standard, more-computationally-efficient models have been shown to predict accurately either the magnitude or the phase of these the higher-order harmonics in the applied loads. CFD provides a reliable method for calculating the applied loads, but, the computational expense of such models demands a deterministic design event that is presently unavailable. For the more deep-water jacket-type foundations, the jackets are usually stiff enough to avoid dynamic effects and analytical methods are available for calculating the wave loading. Despite this, it was noted that scour assessment for multi-legged structures is difficult and currently there is limited industry guidance other than “it should be assessed”. For large-volume, gravity-based structures linear diffraction models are typically used to assess the wave loading with CFD methods employed to overcome the limitations of these models in intermediate/shallow waters. In terms of wave loading, breaking waves are probably the main challenge left to solve. Again, scour assessment for gravity-bases is difficult and scour protection is usually required in sand. Substation platforms are subject to the same issues as turbine foundation design with the additional requirement of an air-gap assessment, i.e. there needs to be a 1m air gap for 100 year crest elevation. If this criterion is not met, the platform needs to be assessed for wave-in-deck loads. Some simple methods exist (Kaplan’s method) but it is not clear if these are acceptable for design purposes and so wave tank experiments are often required to verify air gap and/or assess wave-in-deck loads. Finally, in the offshore wind industry, rock blankets and berms are frequently used as scour protection and along transmission cable routes. Both are technically “structures” and need to be designed against extreme wave loading. This leads to large diameter rocks but these can be undermined by secondary scour and so a possible move towards designing “dynamic” structures has been proposed requiring better methods to reduce the uncertainty over maintenance costs.

In the break-out session it was noted that the most challenging simulations presently being performed (in the context of offshore wind) were either to understand the effect of ringing or the load on structures due to breaking waves. Ringing is considered via a combination of in-house codes and Morison-type calculations but typically wave tanks and physical modelling are used to investigate the phenomenon. For breaking wave simulations Smooth Particle Hydrodynamics (SPH) methods are popular as are Computational Fluid Dynamics (CFD) methods including Lattice Boltzmann methods (LBM).

In terms of routine research and development a wide range of codes/analysis tools are used. But, developers are constrained by having to work with multiple models, scales and levels of complexity. There is a desire for a greater level of physics to be included in routine design codes, including:

- improved definitions of waves in intermediate and shallow water depths;
- design waves for extreme events and plunging breaker impacts;
- fully nonlinear potential flow models with higher-order structural dynamics;
- prediction of turbine vibrations and ringing effects;
- scour prediction.

Developers want to be able to include the interaction between waves, wind, currents and structures, including floating wind turbine and mooring coupled systems, in any water depth; they wish to include scour prediction and assess impulsive loads from breaking wave impacts; the ultimate goal being to model the whole farm (turbines, substations, cable transmission routes etc.) in real time allowing for autonomous operations including changes in climate/resource and colocation of systems. Despite this ambitious goal, there is still major concerns that sophisticated models, such as CFD, are too computationally expensive to run the desired number of sea states etc. limiting them to deterministic cases which have questionable validity when compared to real sea conditions. Either CFD needs to be faster or we need more confidence in the deterministic cases. Furthermore, there remain a number of unknowns:

- viscous/shallow water effects and turbulence;
- the precise loads on structures due to breaking waves;
- soil properties and how to model scour numerically;
- scale effects on a single machine/an array/the shoreline;
- component interactions/non-rigid-body dynamics;

and unanswered questions:

- What is the required confidence level – acceptable difference between numerical and physical results?
- What level of fidelity is required in each case, i.e. what level of physical complexity is needed for the case under investigation?
- What is the difference between survival mode and operational and what is the worst case wave in terms of survivability?

As a result, a number of new software developments and physical investigations have been identified as crucial, in terms of WSI considerations, to development of the offshore wind industry. There is a strong push in the industry for:

- a 'monolithic system' of WSI codes, i.e. efficient integration/coupling of functionally distinguishable software including the required level of fidelity at each level of code complexity. This type of system has been described in a number of ways (hybrid or surrogate modelling, zonal or domain-decomposition, or code-coupling) but essentially relies on the concept of reduced order modelling (ROM) to ensure an efficient method that automatically includes the required level of physical complexity only when necessary;
- an improved understanding and prediction of extremes. There is a need for more detailed met ocean data, summarised into design criteria and a transfer from extreme wave to extreme response. There is considerable support to move away from deterministic 'design wave' survivability testing and a requirement for recreation/simulation of multimodal seas in experiments and the resulting extreme conditions and structural response;
- functionality to model compressibility/aeration effects in breaking waves and the associated loads from plunging breakers on offshore installations;
- fluid-Structure-Interaction (FSI) models coupling hydrodynamic codes with structural codes to assess high-order ringing effects, turbine vibrations etc.;
- improved scour modelling methods including three-phases (soil, structure and water) in CFD (potentially coupled VOF/Lagrangian methods) as well as new benchmarking experiments for scour issues and sediment dynamics;
- combined wave, wind and current modelling;
- scale experiments of floating wind and full identification of scaling issues.

Session 2: Challenges in Wave and Tidal

The second session of the Workshop considered the WSI challenges in the Wave and Tidal Energy Industry. Dr Ben Child, Senior Engineer / Technical Lead for Wave & Tidal Energy Advisory at DNV GL, presented the industry perspective on the WSI challenges in Wave and Tidal Energy. Among some of the general modelling aspects, a number of particular elements were highlighted:

- Coupling of individual aspects of a system (e.g. mooring or the PTO) is often important for accurate load and performance predictions.
- Optimisation algorithms are desirable in the design process, but in practice the efficiency of the model, the simulation stability and the smoothness of the objective function must be considered.
- Machine learning algorithms may be useful in the design process.

In terms of more specific challenges a number of key areas were discussed:

- **PTO and control.** Time-domain solvers currently used have sufficient accuracy in performance conditions to allow control algorithms to be designed. However, accurate hydrodynamic loads are still needed for design of PTO and control algorithms to reduce loads in extreme waves. Furthermore, there is a requirement that the dynamics/hydrodynamics of complex systems be made to run in close to real-time for 'hardware in the loop' testing.
- **Mooring and foundations.** Quasi-static and dynamic mooring design tools are available but few tools couple the full mooring analysis with a detailed description of the rest of the wave/tidal energy converter. Coupled, dynamic models of mooring lines, including drag and other hydrodynamic effects, need to be incorporated into a range of solvers whilst ensuring both the efficiency and stability of the simulations.
- **Balance of plant.** Many of the other parts of a wave/tidal energy installation are unaffected by waves, however, some elements, such as umbilicals, exposed pipes and substations, may require hydrodynamic load and coupled dynamic modelling particularly in extreme waves.
- **Installation and operations & maintenance.** The cost of installation and maintenance can be high. Some modelling is done but further modelling of the installation/operation procedures (e.g. anchor and mooring deployment, offshore lift dynamics, towing dynamics) would be beneficial.
- **Performance assessment.** An accurate prediction of the annual energy yield of a particular device is crucial. Presently CFD and fully nonlinear potential flow solvers are too time-consuming to cover the required parameter space. Commonly used methods rely on solutions based on linear wave theory. Corrections to linear hydrodynamics, including nonlinear forcing, interactions between waves and highly mobile structures and the effects of fluid structure interaction and hydroelasticity, need to be implemented consistently.
- **Array modelling and environmental impact.** Commercial reality dictates that devices will be deployed in arrays to make the best use of the available resource at the site. However, it is critical that this does not significantly diminish the overall performance of the converters or adversely affect the surrounding environment. Modelling tools exist but these typically employ significant simplifications in terms of bathymetry, hydrodynamics and the interactions between bodies as the

computational time for more accurate tools increases rapidly with number of devices. The challenge it therefore to include an accurate prediction of the device behaviour and realistic environmental conditions whilst maintaining simulation efficiency.

- **Reliability and survivability.** A considerable challenge in the wave and tidal energy industry is to ensure that devices not only survive the hostile marine environment, i.e. design for extreme conditions, but that the millions of oscillations in load applied to the structure do not cause fatal fatigue damage. Standards refer to empirical formulae but these may not be appropriate, nor might the 'design wave' approach be appropriate for dynamic structures. CFD and SPH are used for extremes and Finite Element Modelling is used for structural analysis but these are not commonly coupled and tank tests are still used in situations where CFD is not practical/reliable. There remains some concern over how to model extremes and other energetic/non-performance cases accurately. Furthermore, there is a need to select cases and indicative loads for analysis in more computationally demanding codes.

In the break-out part of the wave and tidal session, it was noted that the most challenging simulations we can run now are significantly less sophisticated than required. Annual performance estimate models (for the operational regime) are reasonably well established/accurate but waves and devices are typically considered separately. Fully nonlinear CFD models of single body machines have emerged but present models tend to separate/uncouple parts of the system, e.g. the moorings or Power Take-Off (PTO).

As in the offshore wind industry, there are a huge range of numerical models used for wave and tidal device analysis, from frequency and spectral models to time domain simulations, considering different scales and incorporating various levels of nonlinearity. There are a number of well-established, stable and user-friendly commercial codes allowing for weakly nonlinear analysis but at present numerical modelling still requires manual identification and implementation of the required physics. Furthermore, crucial resonance effects are difficult to assess with simplified codes. However, as in the case of offshore wind, fully nonlinear methods like CFD still suffer from excessive execution times. Therefore, due to the number of simulations required physical modelling is, presently, the only way to understand the statistics of loading mechanisms and remains paramount in the development and design optimisation of wave and tidal devices.

The wave and tidal sector arguably boasts the most challenges in terms of WSI. Not only because of its relatively immature status compared to other offshore industries, but because devices (particularly wave energy devices) are designed to be positioned in areas and behave in ways that would historically have been avoided in offshore engineering. Over the next 25 years, developers have proposed a large number of new applications that need to be investigated/simulated:

- Over the next 5 years the main concern appears to be survivability. Developers wish to be a position to be able to apply statistical methods to extreme events in order to identify the design load. An improved understanding of extreme wave loading is require including breaking waves and waves approximately equal to the size of the devices. In terms of tidal stream, a better understanding of blade loading is required including: the effect of waves, wave-current interaction, extreme currents and turbulence (both ambient and around the blades).

- In 10 years the goal is to have achieved bankability and improved device performance. A better representation of the nonlinearities is needed and fully-coupled models need to be developed to include the WSI of the devices, plant, infrastructure etc. (wave-to-wire).
- By 2050 it is anticipated that commercial scale arrays, consisting of large numbers of small devices, will be underway. Numerical models will need to be developed, and validated against new experimental data, to simulate multi-body interactions, assess environmental impact, and allow for farm optimisation.
- In addition, there is a requirement for codes to be capable of modelling installation, deployment and maintenance operations in high sea states and in the high energy nearshore environment.
- Furthermore, as in the offshore wind industry, developers want real-time simulation for device control and operational optimisation.

To compound the WSI challenges faced by the wave and tidal industry, there also exist a number of unknowns requiring new knowledge/understanding including:

- a lot of variability in the devices (particularly in wave energy) and little-to-no field data/industrial examples available raising questions over what data is needed and how this can feed into the loop between the field and research tools for refinement of prediction;
- uncertainties over wave condition characterisation and parameterising extreme events/environmental contours;
- assessment of the stochastic nature of loading and what scenario causes the largest load;
- the influence of currents on waves;
- the effect of turbulence on wake recovery and the influence of the sea bed;
- the effect of scale in experiments and what constitutes appropriate validation;
- the cost of these developments and how the present funding gap can be filled.

Consequently, a number of WSI developments were highlighted as critical in realising the potential of wave and tidal energy. These include:

- a proper representation of the Power Take Off (PTO) unit in simulations, assessment of PTO statistics and development of real-time, simulation-based control algorithms;
- improved mooring models, connected multi-body dynamics and fluid-structure-interaction (coupled hydrodynamics and solid mechanics) for deformable/flexible structure modelling;
- multiple body interaction models and array optimisation tools;
- improved meshing techniques for large motions of devices;
- wave-current interaction including sheared currents and directionality;
- prediction of breaking wave loads including aeration;
- identification of the most critical cases for survivability assessment;
- validated turbulence models and improved turbulent boundary layer meshing;
- sediment modelling and scour prediction;
- whole-system, multi-scale modelling - coupling of models (waves – wind – currents - PTO – device motion – moorings…) including a common interface for the range of

tools and an autonomous process where necessary model complication is chosen during simulation, i.e. a monolithic system.
- identification of data requirements and measurement of required data in physical experiments, i.e. velocity field measurements in large tank, pressure on structures etc.;
- numerical modelling guidelines, benchmark cases etc.

Session 3: Challenges in Offshore, Maritime and Coastal Engineering

In the final session of the Workshop, Dr Karl Mitchell, Principle Naval Architect at Lloyd's Register, presented the WSI Challenges in Offshore Engineering stating that "one of the main drivers for undertaking certain analysis is to satisfy National Authority Requirements". Within the UK (for offshore installations): "Duty holders must demonstrate that structures have a low probability of catastrophic failure when subject to extreme environmental actions". The policy considers issues such as:
- green water and wave slamming events
- overall and local strength (in extreme waves)
- air gap
- peak responses

and performance standards for Safety Critical Elements (SCEs) need to address these issues. For an FPSO (Floating, Production, Storage and Offloading), for example, the Safety Critical Elements include the hull, the mooring systems, and the turret structure. For Performance Standards relating to harsh weather, designers need to satisfy the following criteria and tools need to be available to allow them to do this:
- The hull structure must be capable of avoiding progressive collapse and breach of the hydro carbon containment system when subject to the following environmental events at a 10,000 year return period level:
    - global hull loads, with particular consideration to midship bending and to shear load through the hull at the turret centre;
    - loads due to green water in relation to head of water on deck and in support stools due to possible wave slam on topside modules;
    - localised wave slam events on hull envelope plating including and in particular on bow and bottom structures;
    - sloshing impact loads within cargo tanks.
- The turret structure and interface to the hull (bearings and support structure) must be capable of avoiding progressive collapse and loss of weather-vaning capability when subject to the following environmental events at a 10,000 year return period level:
    - Wave impact loads on turret underside and chain table due to bottom of vessel clearing the water surface;
    - Load from single mooring line;
    - Combined load from mooring lines acting in unison;
    - Inertia load due to entrained water mass within turret and around chain table, particularly when bottom of vessel clears the water surface.
- The mooring system needs to be capable of maintaining the 10,000 year return period unit's excursions within the riser design limits. Individual mooring lines must

be capable of withstanding extreme 10,000 year return period loads with no line breakage and no loss of anchor holding capacity.

Linear diffraction analysis is applicable for structures that are large compared to the waves and where motions are 'small'. Extreme responses and global loads can be modelled reasonably for FPSO units using linear diffraction analysis techniques. However, diffraction analysis can give poor results for semi-submersible-like units – particularly those with a shallow draught or for 'small' units. Some of the challenges for these types of structure are:

- To determine the internal loads: twisting/splitting; mooring loads; air gap; wave impact loads on deck. Peak response may not occur in 'large' waves (splitting).
- Wind loads; heading for turret moored units; loads of wind turbines.

CFD is used to evaluate local non-linear effects such as impact loads on turret underside and sloshing within cargo tanks. Some of the issues, however, are:

- How are critical instances determined – what moment (instant) in hundreds of sea states?
- How can CFD be mapped on a FEA model for structural analysis?
- Can the length of CFD simulation be 'suitable for daily design work' (10,000 years of sea state with structural response with CFD in seconds… …including wind)?
- How are results verified? How can we be sure of results without model tests?

From the final break-out session, it was noted that the most challenging simulations currently being performed in the offshore, maritime and coastal engineering sector typically fall into two categories: those which use 'cheap' tools, such as 2nd order diffraction codes and potential theory, for long term statistical analysis, and; those that use 'expensive' tools, such as CFD, for short term deterministic applications like wave-in-deck assessment in regular waves. Again a range of codes is used in design/research with the appropriate model being selected manually based on the acceptable computational cost/complexity. As is evident from the first two sessions, fully nonlinear simulation in the time domain is not considered practical. Furthermore, with no 'design wave' for coastal structures, and stability issues in CFD codes, physical modelling is still in regular use for assessment of extreme loading on structures. As a consequence, and despite significant cross-over with the other two sessions/industries, a number of new WSI applications have been proposed to tackle the challenges in offshore, maritime and coastal engineering. These include:

- violent plunging breakers;
- wave-in-deck loading in irregular waves (including design wave groups);
- run-up, over-topping and suction on coastal structures including structural stability assessment;
- ringing with flow separation;
- rock armour placement, scour and sediment transport;
- simulation of marine operations, such as installation and decommissioning, involving multiple body interactions (quay/ship, ship/ship, ship/platforms).

Some of the present unknowns requiring new knowledge include an understanding of:

- probabilistic/statistical assignment to extreme events/conditions and identification of extreme loading mechanisms;
- how well we characterise nearshore conditions – based on offshore wave climate;

- how we can reduce safety factors and optimise designs;
- how well models (both numerical and physical) represent real life applications.

Despite the majority having already been discussed in the previous two sessions, a number of developments were also listed as being particularly important to the offshore, maritime and coastal engineering sector. These include:

- development of higher order methods and nonlinear wave interaction;
- development of functionality to allow for aeration effects to be included in models;
- development and validation of turbulence models;
- coupling of models and improvements in numerical efficiency;
- integration of met ocean data into numerical models and physical experiments;
- development of design standards for wave breaking cases;
- comprehensive validation for model tests and numerical codes.

Summary

In summary, the first CCP-WSI Focus Group Workshop was highly successful and well received by a wide range of WSI community members. Three thought-provoking presentations were given by leading members of the core WSI industries and participants provided a substantial number of contributions through guided break-out sessions. There was strong support for the CCP-WSI project activities, including the proposed bid for a High End Computing (HEC) consortium in WSI, and a number of new research project proposals resulting from the meeting. The broad nature of this first focus event gave the desired range of discussion points and identified a large number of community requirements/challenges. As a result, a priority list of the required WSI activities has been compiled.

Priority list of WSI activities

1. Improve the speed/efficiency of WSI simulations
It appears that the challenge with the highest priority for the WSI community is to improve the speed/efficiency of WSI simulations. It is crucial that larger numbers of more complex scenarios can be modelled, covering a wider parameter space and allowing for accurate prediction of loads on structures. The ultimate goal is to achieve 'real-time' solutions to complex WSI simulations for applications such as device control and operational optimisation. Possible ways to tackle this challenge include: a. making corrections to simplified models, including a better understanding of irregular wave kinematics in shallow/intermediate water and higher-order structural dynamics; b. improving solution methodologies, e.g. through the use of adjoint; c. utilising High Power Computing (HPC) facilities and emerging computer architectures, e.g. GPU, Many Integrated Core (MIC) architectures, shared memory and heterogeneous node layouts, cloud computing, etc. As a consequence there is strong support from the community to form a High End Computing (HEC) consortium in WSI to take advantage of the available HPC resources.

2. Coupling/integration of WSI codes
Another high priority activity for the WSI community (and another way to improve the speed/efficiency of simulations) is the coupling/integration of WSI codes under a common interface to form a 'monolithic system'. This system uses reduced order modelling to ensure an efficient method that automatically includes the required level of physical complexity only when necessary and allows developers to include multiple scales and levels of functionality/physical complexity within a single numerical tool. For

this to be achieved we require a greater understanding of:

a. the level of fidelity needed/the threshold for each element of the system;
b. the position of boundaries between elements/models, and;
c. the transfer of data between elements/models.

3. Developing Full System Modelling tools

In addition to a monolithic system, there is considerable demand for Full System Modelling tools that simultaneously include:

a. combined wind, wave and current loading, requiring greater knowledge of the influence of wind and currents on waves for example;
b. coupling of individual system components, e.g. dynamic hull structures, PTO systems, moorings etc., which requires improved descriptions and proper representation of the PTO, combined dynamic mooring analysis tools and connected multi-body dynamics models;
c. the dynamic response of structures by coupling hydrodynamic and structural loading codes, i.e. Fluid-structure-interaction (FSI), allowing for ringing and springing to be represented as well as the hydroelasticity of deformable structures such as novel wave energy devices;
d. the balance of plant, i.e. the cables, cable routes and substations etc., including rock armour placement and rock blankets for scour protection;
e. multi-body interactions and arrays.

4. Improving our understanding and prediction of extremes

In terms of a specific area of concern, an improved understanding and prediction of extremes is of the highest importance and extends across the entire spectrum of WSI related-industries. There is a need for more detailed met ocean data, summarised into design criteria and a transfer from extreme event to extreme response. There are still questions over extreme loading mechanisms and how critical instances can be determined, particularly for dynamic systems and for coastal structures. Until greater confidence can be generated in deterministic simulations, there is considerable support to move away from 'design wave' testing in favour of probabilistic/statistical assignment to extreme conditions and structural response through simulating long-term, multimodal sea states.

5. Validation and verification

Another key area highlighted was validation and verification. Questions were raised over how well models, both numerical and physical, represent real life applications and whether or not we fully understand the limitations of physical facilities as well as numerical models. There is a clear need for comprehensive validation of model tests but there exists uncertainty over the required confidence levels. Furthermore, there are still considerable concerns over scaling effects and a strong push towards identification of scaling issues and validation at multiple scales (in particular full scale verification using field data). A greater use/integration of met ocean data was requested and thorough validation of turbulence modelling was highlighted.

6. Predicting compressibility/aeration effects in breaking waves
In terms of functionality, models capably of predicting compressibility/aeration effects in breaking waves and the associated loads caused by plunging breakers are of high priority as is the air-gap assessment and prediction of wave-in-deck loading on offshore structures; the run-up, over-topping and suction on coastal structures, and; green other water effects.

7. Improved scour modelling methods
Additionally, improved scour modelling methods are required as well as new benchmarking experiments for scour issues and sediment dynamics. Scour is a big issue across the board and the science of predicting the impact of storms on mobile sediments and rock armour needs to be developed.

8. Modelling installation, deployment, maintenance and decommissioning operations
In terms of applications, there is a strong desire for codes able to model installation, deployment, maintenance and decommissioning operations, particularly in high sea states and in the high energy nearshore environment, specifically involving multiple body interactions.

9. Improve the usability/reliability of CFD models
Another activity mentioned was to make CFD models more user-friendly and reliable in terms of stability. Open-source codes were expressly preferred based on cost savings and their ability to be modified but there is a desire for: a. data reductions/feature extraction while simulation is running; b. adaptive termination criteria based on statistical requirements; c. real-time visualisation of the results.

10. Develop guidelines and standards
Lastly, the WSI community expressed strong support to develop guidelines and standards for particular cases, e.g. breaking wave cases, extreme loading, scour and sediment dynamics, as well as benchmarking test cases to support the guidelines.

Appendices

Appendix 1: List of registered attendees

Name	Company/Institution
George Aggidis	Lancaster University
Peter Arnold	Minerva Dynamics
James Bridgwater Court	University of Bath
Eugeny Buldakov	University College London
M. Sergio Campobasso	Lancaster University
Derek Causon	Manchester Metropolitan University
Simon Cheeseman	Offshore Renewable Energy Catapult
Ben Child	DNV GL
Ronan Costello	Wave Venture Ltd.
Angelos Dimakopoulos	HR Wallingford
Steven Downie	Arup
Kevin Drake	Noble Denton marine services, DNV GL
Matt Edmunds	Swansea University
Bettar el Moctar	University of Duisburg-Essen
Katherine Freeman	Engineering and Physical Sciences Research Council
Glenn Goodall	Engineering and Physical Sciences Research Council
Deborah Greaves	Plymouth University
Gurpreet Grewal	University of Strathclyde
Valentin Heller	University of Nottingham
Suzana Ilic	Lancaster University
Lars Johanning	University of Exeter
Peter Lai	Saipem S.p.A.
Paul Lamont Kane	Queen's University Belfast
Ming Li	The University of Liverpool
Qingwei Ma	City University London
Zhihua Ma	Manchester Metropolitan University

Ed Mackay	Wavepower Technologies Limited
Pedro Martinez	Manchester Metropolitan University
Allan Mason Jones	Cardiff University
Karl Mitchell	Lloyds Register
Louise O'Boyle	Queen's University Belfast
Blanca Pena	Houlder Ltd.
Gemma Poulter	Science and Technology Facilities Council
Ling Qian	Manchester Metropolitan University
Edward Ransley	Plymouth University
James Russell	Houlder Ltd.
Pal Schmitt	Queen's University Belfast
Narakorn Srinil	Newcastle University
Dimitris Stagonas	University College London
Robin Stephens	BMT ARGOSS
Jinghua Wang	City University London
Paul Weston	A&P Group
David Witcher	Wavepower Technologies Limited
Shiqiang Yan	City University London
Erica Yang	Science and Technology Facilities Council
Yan Zhou	City University London
Feng Fu	City University London
Martyn Hann	Plymouth University
Qiang CHEN	University of Bath
Rajab Said	ESI Group
Pierre-Henri Musiedlak	Plymouth University
Gavin Tabor	University of Exeter

Appendix 2: Questions posed in the break-out sessions

What is the current status of WSI in the particular industry?

- What are the most challenging simulations we can do now?
- What codes/analyses are used for routine design/innovation/research?
- What experiments/models tests are used for routine design/innovation/research?
- What are the constraints?

What are the WSI challenges in the particular industry?

- What applications do we need to simulate in 5 years; 10 years; by 2050?
- What are the unknowns?
- What developments are needed? New knowledge/understanding, laboratory and field data, new models, applications, hardware?
- How would you prioritise the WSI Challenges?

Is there a need for High End Computing Consortium in WSI?

What are the WSI common challenges across offshore Wind, Wave and Tidal, Offshore, Maritime and Coastal?