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Wave Energy Converter Model Test Experiments

PURPOSE OF GUIDELINE

The purpose of this document is to offer guidance to research organizations on performing model tests of wave energy converters (WECs) according to the state of the art.

Model tests of WECs have some differences from tests of other offshore structures. The main challenges of WEC testing and the differences between tests of WECs and offshore structures may include:

- Rapid evolution of design of WECs: great diversity of concepts, some presenting novel challenges for model testing;
- Requirement for simulation and measurement of complex kinematics for articulated WECs;
- Requirement to simulate complex kinematics, material properties and fluid-structure interaction for flexible devices;
- Requirement to simulate devices with very large dimensions either parallel to or normal to direction of wave propagation;
- Requirement to include a simulated power take-off (PTO) mechanism in WEC tests. One of the important objectives in WEC tests is to evaluate device power capture; Realistic simulation of PTO may require relatively large scale models, leading in turn to a need for large-scale waves;
- Requirement for testing throughout the various experimental stages: the concept validation stage, the design validation stage, the system validation stage, and the prototype and demonstration stage. The model scale depends on the test stage;
- Possible requirement for tests of multiple device models corresponding to an array of WECs, requiring a very large tank for reliable results.

In general, model tests on WECs are employed to validate the device concept, to quantify the technical performance variables, to acquire information on power take-off (PTO) and data for optimized performance design, to confirm survivability characteristics, to investigate installation and tow-out methodology and to validate numerical models.

PARAMETERS

1.1 Experimental Stages

The development of a WEC from the original idea to a marketable product involve a series of test stages including the concept validation stage, the design validation stage, the system validation stage, and the prototype and demonstration stage.

These stages are commonly described in the renewable energy industry in terms of Technology Readiness Levels (TRLs) (e.g. Mankins (1995)). TRL 1-3 correspond to research stages up to and including proof of concept, TRL 4-5 correspond to component, sub-system and system validation in laboratories and/or simulated operational environments and TRL 6-9 correspond to prototype demonstration in operational environment through to system proving via successful deployment.

The main objectives of tests in concept validation stages (TRL 1-3) are to validate the device concept, to validate preliminary numerical "wave to wire" models of the device used to predict energy output, to investigate device variables and physical properties that affect the performance or energy capture, and to optimize the device for power production using small scale models. The scale range in this stage is typically between 1:25 and 1:100.

The main objectives of tests in the design validation stage (TRL 4-5) are to validate the device design, to validate advanced numerical wave to wire models of the device, to develop PTO control strategies for improved power production, and to verify the mooring and anchor system using medium scale models. If known, the wave spectrum at a specific site should be used. The scale range in this stage is normally between 1:10 and 1:25, however smaller scale models may be used to investigate survivability in extreme waves.

Tests in the system validation stage (TRL 6-7), and the prototype and demonstration stage (TRL 8-9) are typically carried out at large or full scale at sea.

1.2 Type of Wave Energy Converter

1.2.1 Device Types

WECs can be classified in a number of ways. One classification is by the nature of energy absorption: WECs can be categorised as point absorbers, typically small in both horizontal plane dimensions; attenuators, which are typically linear structures designed to be aligned with the principal direction of wave propagation, and terminators, which are typically linear structures designed to be aligned normal to the direction of wave propagation.

Devices may also be categorised by the physical process used to extract the energy. Falcão (2010) classifies devices into the following categories:

- Oscillating Water Columns
- Oscillating bodies
- Overtopping devices

Each of these categories can then be broken down by location (e.g. floating or submerged) and then by mode of operation. The classification is represented diagrammatically in Figure 1. This classification includes many devices currently under development.

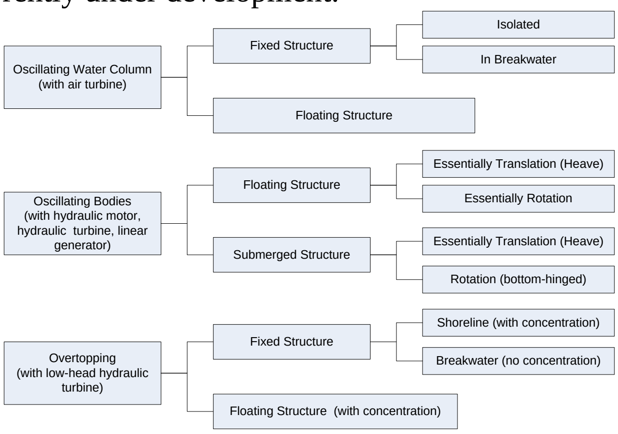

Figure 1: Classification of Wave Energy Devices (after Falcão (2010))

WECs can be installed in the shoreline zone, the near-shore to offshore zone, and the offshore zone. In each zone, WECs can be free-floating, fixed on the sea-bed, or mounted on other structures such as breakwaters, piers or piled structures.

Oscillating water columns extract energy from the motion of water in an internal chamber with a free surface, usually driving an air turbine. Oscillating bodies include rigid bodies such as heaving buoys, extracting energy from relative motion between the device and a fixed reference or heave plate, pitching devices reacting against various mechanisms including gyroscopic devices and gravity referenced systems, and articulated devices consisting of a series of floating elements connected by hinges extracting energy from relative motions of the sections. Overtopping devices extract the potential energy of water running up an artificial beach. Cruz (2010) gives details of seven devices which have been tested at full scale.

Device types not covered by this classification include flexible devices (either water or air-filled) constructed entirely or partly from flexible materials typically using pressure variations in waves to pump water or air, generating energy through a variety of mechanisms.

1.2.2 Power Take-Off Systems

Various Power Take-Off (PTO) systems may be installed in different WECs. For example, air turbines are typically used for OWC type device, linear or rotary generator systems with direct drive conversion or oil-hydraulic systems may be used for heaving, articulated, or flap type devices, and a water storage system for a wave overtopping device. These PTO systems must be simulated in the tests.

The PTO system for a moving body type WEC is normally modelled by an energy dissipating damper in the concept validation tests. In the design validation tests, a more sophisticated PTO simulator can be considered as a Coulomb damper or linear damper, and an active control system may be utilised. The PTO system for an OWC or other pneumatic device is often simulated using an orifice load in the concept validation stage tests(see section 3.2).

1.3 Test Facilities

Different facilities can be used at different stages of the design process. These may include:

- Wave Flumes / Towing Tanks with wave-makers suitable of generating long-crested waves;
- Ocean basins capable of generating both long- and short-crested waves;
- Ocean basins with Wave and Current Facilities.

It should be noted that the large scale models required for WEC testing can place substantial demands on wave-making in terms of both wave heights and run durations. Particular care must be taken to minimise build-up of reflected waves and to maintain the quality of wave field during long duration realisations of large waves.

1.4 Model Parameters and Scale

The choice of scale ratio will be based on the device size, the goal of the tests (e.g. power capture or survivability), the target wave conditions, and the test stage (e.g. concept validation, design validation etc.). It may be necessary to build models at different scales to assess power capture in operational conditions and survivability in extreme seas.

Achievable scale will be limited by the model basin dimensions, and its wave generation capability. Choice of scale should also consider the mooring system to be employed, and the simulation approach for the power take-off (for power capture tests). The impact of channel width on power capture when testing floating devices in a narrow tank is illustrated by Ersdal and Moe (2013).

Testing of arrays can present substantial challenges for many device types especially when realistic mooring systems are deployed, due to the large footprint required, and the potential importance of device interactions on mooring and foundation loads.

Performance of WECs will normally be scaled using Froude similitude. However some key parameters will not scale in this manner, leading to scale effects when extrapolating to full-scale. In order to minimize these errors, tests with large scales are recommended. Important factors in energy conversion that are not addressed by standard scaling procedures include, but are not limited to, the effects listed below:

The power output of devices utilising a pneumatic power take off is related to the compressibility of the air, which is dictated by atmospheric pressure and the absolute temperature of atmosphere. Therefore, the stiffness of the air "spring" will not be scaled correctly using Froude similarity if geometric similarity is maintained. In fixed devices this may be corrected by increasing the volume of air present either by increasing the dimensions of the pneumatic chamber or by adding an external accumulator. This approach may also be adopted in floating devices, but may present challenges in achieving appropriate mass properties in smaller models. The issues are discussed in detail by Weber (2007).

In small-scale model tests, viscous damping and in particular damping associated with vortex shedding from sharp edges cannot be scaled appropriately with Froude similarity and may be overestimated.

Mechanical friction, both static and dynamic, should be minimised as far as possible in model construction since it will not be scaled correctly according to Froude similitude.

1.5 Environmental Parameters

A discussion of key parameters related to environmental properties such as water depth, basin dimensions, calibration of wave characteristics (and current and wind where relevant), and combined environment characteristics can be found in the ITTC Recommended Procedure 7.5-02-07-03.1 *Floating Offshore Platform Experiments*.

In testing WECs, particular attention should be paid to impact of wave blockage, since WECs may affect the wave field in a more complex manner than conventional floating structures.

Testing in long-crested waves is commonly adopted at the concept validation stage, for comparative studies, and for component testing where appropriate. This process may include tests with the device oriented at different angles to the direction of wave propagation.

Concept validation testing may involve both regular wave tests to characterise device frequency response as well as testing in irregular sea states appropriate to the intended deployment site in order to estimate mean annualised power capture.

The power production of some WEC devices may depend on incident wave direction; hence, at later stages of the design process, when accurate estimates of power capture are required, tests in short-crested irregular waves considering the azimuth of the principal wave direction may be requested. For these tests, the directional wave spectral density function can be used to describe the short-crested waves. It is defined as the product of the wave frequency spectrum and the directional spreading function. The most popular model for the directional spreading is a cosine squared ($\cos^{2s}$) function originally proposed by Longuet-Higgins et al. (1963).

Goda (2010) suggests that the value of s varies with wave frequency, with the largest value s_{max} at the spectral peak frequency, and with the values decreasing for both lower and higher frequencies. For deep-water waves Goda recommends use of s_{max} = 10 for wind driven seas, s_{max} = 25 for swell with short decay distance and relatively large steepness, and $s_{max} = 75$ for swell with long decay distance and relatively low steepness. These values typically increase in shallower water.Alternatively, the wave spectrum of an actual site may also be used in the tests. Site data could suggest that sea states composed of multiple wave systems are common at that particular location. When device performance can be compromised by multi directionality, testing in sea states with multiple wave systems should be carried out.

1.6 Mooring Systems

Floating WEC concepts utilise a range of mooring systems including single point and spread moorings as well as catenary, taut and multi-element systems. Where tests are intended to determine power capture, accurate simulation of catenary moorings is not generally required, as studies have shown that catenary moorings have little impact on device response for oscillating bodies (Muliawan (2012), Vicente (2011)). In contrast, taut moorings can have a significant impact on device motions and thus power capture, and should be simulated accurately where detailed design information is available.

Where tests are intended to assess device survivability, accurate simulation of all mooring types is important, as mooring behaviour impacts upon extreme behaviour of the device including motions and loads.

Guidance on mooring installation and calibration can be found in ITTC Recommended Procedures for Floating Offshore Platform Experiments (7.5-02-07-03.1). Where the limitations on the physical size of a testing basin do not allow a full model of a mooring to be accommodated at a reasonable scale within the basin, guidance on the use of a hybrid mooring system may be found in ITTC Recommended Procedure 7.5-02-07-03.4 *Stationary Floating Systems Hybrid Mooring Simulation*.

At the concept validation stage of testing it is common that detailed information on mooring system properties is not available; in the absence of other information a simple soft elastic mooring can be used for devices which do not utilise moorings as part of PTO systems.

Where taut mooring systems are employed it is recommended that, where possible, free oscillation tests are carried out with and without mooring systems in order to determine natural frequencies and indicate the likely impact of the mooring systems on the wave frequency motions and energy capture performance.

1.7 Test Case Parameters

1.7.1 Energy Capture Performance Tests

In the tests of energy capture performance, the ability of the device to capture and convert the wave energy is regarded as the most important criterion. Tests on the energy capture performance should be carried out in regular and irregular waves. The test programmes should aim at investigating the effect of device design variables on energy capture and at optimizing the power production.

Model tests in irregular waves should normally be carried out for a duration corresponding to at least 30 minutes at full scale in order to gain statistically valid results. Details of procedures for simulation and measurement of irregular short-crested seas can be found in ITTC Recommended Procedures for Laboratory Modelling of Multidirectional Irregular Wave Spectra (7.5-02-07-01.1).

1.7.2 Numerical Model Validation Tests

In these tests the aim is to calibrate and validate mathematical and numerical "Wave to Wire" models of the device, used to predict energy generation. This is obtained by comparing time traces of numerical and experimental results for signals such as motions, pressures, and forces.

It is recommended that free oscillations and decay tests are carried out in order to calibrate coefficients required in the model, such as viscous damping. Device response should be measured in small waves to determine the accuracy of the numerical model in linear conditions. Next, by increasing the wave amplitude, the limitations on the domain of validity of the model can be investigated. Eventually, irregular wave cases may be generated to compare numerical and experimental response and power absorption in realistic scenarios.

1.7.3 Survivability Tests

Before undertaking sea trials, it is important to conduct survivability tests in model basins to evaluate the seaworthiness of a WEC including hull(s) and mooring system. The survivability tests should be conducted in long and short crested irregular waves. These tests must provide extreme motions, loads exerted on the hull, power take-off and mooring line loads under the design conditions corresponding to the metocean data of the installation site.

Survivability tests are typically carried out for a duration corresponding to three hours at full scale. A series of wave angles should be used to evaluate their effect on device motion and mooring forces. Tests involving failure modes with one or more mooring lines disconnected should be carried out to simulate line breaking scenarios.

Where the device has a survival mode (distinct from the operating mode), tests should be carried out in this condition. In addition where appropriate the PTO should be tested both in the fully undamped condition and in the fully locked condition in order to simulate typical failure scenarios which could result in excessive body motions and/or end stop problems.

1.7.4 Fatigue Limit State Test

Data from regular wave tests may be used to inform the estimation of fatigue limit states.

1.7.5 Tests for Arrays and Clusters

For an array with many WECs installed, the interaction of WECs may be inferred from tests involving a limited number of devices. Due to the cost and scale constraints, the behaviour of arrays involving a large number of WECs may be evaluated by numerical modelling.

1.8 Energy Capture Performance

The energy capture performance is generally expressed by the concept of a capture width which is the quotient of the absorbed device power and the wave energy flux (input wave power). For regular incident waves, the input power P_W transported per unit crest length is:

$$P_W = \frac{1}{2}\rho g a^2 c_g$$

where ρ is the density of water, g is the gravitational acceleration, a is the amplitude of the incident wave, and c_g is the group velocity expressed by

$$c_g = \frac{1}{2}\frac{\omega}{k}\left(1 + \frac{2kh}{\sinh 2kh}\right)$$

where ω, k, h are the angular frequency, the wave number of the incident wave and water depth, respectively (see for example Falnes (2002)). For long-crested irregular incident waves, the power P_W transported per unit crest length is

$$P_W = \rho g \int_0^{\infty} c_g(f) S(f) df$$

where f (Hz) is the wave frequency, $S(f)$ is the omnidirectional spectral density function of incident irregular waves. For deep water, P_W becomes

$$P_W = \frac{\rho g^2 H_s^2 T_E}{64\pi}$$

where the significant wave height H_s and energy period T_E are defined by

$$H_s = 4\sqrt{m_0}, \quad T_E = m_{-1} / m_0$$
$$m_n = \int_0^{\infty} f^n S(f) df$$

(see for example Folley *et. al.* (2012)). For short-crested irregular incident waves, the transported power is

$$P_W = \rho g \int_0^{\infty} \int_{\theta_0-\pi/2}^{\theta_0+\pi/2} c_g(f) S(f,\theta) d\theta df$$

where θ is the direction, θ_0 is the predominant wave direction, $S(f,\theta)$ is the directional wave spectral density function. If P is the mean power absorbed by the device, then the capture width C_W is defined by

$$C_W = \frac{P}{P_W}$$

Note that the expression of incident wave power above is based on linear theory. However, the nonlinear properties of waves increase with the increase of wave steepness, in terms of distortion of wave form and nonlinear interaction among spectral components, etc. For regular waves, nonlinear wave theory such as the second-order Stokes wave theory and the higher–order wave theories may be considered. For irregular waves, the second-order nonlinear random model considering the secondary interaction term of the spectrum may be also considered.

DESCRIPTION OF TEST PROCEDURE

1.9 Model and Installation

Guidance on preparing the model including model geometry, ballasting and loading can be found in the ITTC Recommended Procedure 7.5-02-07-03.1 *Floating Offshore Platform Experiments*.

Special care should be taken for articulated and flexible models; for articulated models it is important to achieve correct mass properties for each moving segment as well as for the model as a whole; for flexible models it is important to scale the material properties correctly to achieve the correct elastic behaviour at model scale. Particular attention should be paid to the design of moving parts with minimal static and dynamic friction in order to limit uncertainty related to scale effects in extrapolation.

The model is prepared with a damping unit that simulates the characteristics of an actual PTO system. As the experimental stage advances from the concept validation stage to the design validation stage, the model scale increases and a more sophisticated PTO simulator is used.

For a PTO simulator in the concept validation stage, it is sufficient for the mechanism to be adjustable at stepped values which apply external damping to the relative motion between the WECs moving parts. In concept validation testing the PTO is typically simulated using a simple passive damper, which should be calibrated to characterise performance. Passive damping systems may involve the use of small-scale hydraulics (oil or water), pneumatic dashpot systems, or callipers. An alternative to dissipating energy through a damper is to store energy through a simple mechanism such as a weight which can be lifted via a ratchet system; however this may create additional challenges in some cases, such as the impact on stability and moments of inertia on floating devices.

In all cases close attention should be paid to the reduction of unwanted static and dynamic mechanical friction, especially for smaller scale models, from components such as hydraulic seals. Systems based on DC or AC motors may also be used with simple controllers and drives in a manner which simulates the behaviour of passive dampers.

Challenges of simulating PTOs with passive dampers include achieving desired ranges of travel of dampers, especially when using linear dampers on angular systems, and non-linear friction behaviour, especially where coefficients of static and dynamic friction are substantially different. With some simple mechanical damping systems it can prove difficult to set damping in a repeatable fashion, presenting challenges to parametric studies. This can be especially true when temperature and humidity change during testing, and where surfaces may be wet or dry

For a PTO simulator in the design validation stage, a more sophisticated PTO is desirable allowing continuous variation of damping. In these stages of testing an actively controlled system may be employed to simulate the behaviour of the full-scale PTO in a realistic fashion, and to investigate the impact of different damping strategies on power capture and extreme loads This may require the use of a programmable digital controller (e.g. Ersdal & Moe (2013)) or a PLC-based system (e.g. Banks *et. al.* (2013)). Such systems may be capable of eliminating friction with an appropriate control strategy. However care must be taken to ensure that active control strategies do not result in energy input to the system. Other challenges of use of active systems include weight of system, waterproofing, and impact of cabling on floating models.

Whether passive or active damping systems are used, it is beneficial to carry out appropriate tests of the damping system prior to installation in the model, in order to characterise the linearity of the relationship between damping force and velocity, to provide a quantitative estimate of the magnitude of damping at different settings, and to confirm the repeatability of damping settings.

1.10 Instrumentation and Modelling of PTO Systems

The accuracy, resolution and repeatability of sensors should be examined carefully, especially for the case in which an active control system is used to simulate the PTO.

1.10.1 Direct Drive

For a linear generation system with direct drive in moving body type WECs, the instantaneous power of the device is obtained from the product of the velocity (dx/dt) of the linear generator and the corresponding force across the PTO simulator. The force can be measured using a load cell whilst the relative displacement of the generator can be measured by using a potentiometer, encoder, LVDT, or can be determined from a video-based motion capture system with markers placed on both ends of the simulated generator. The velocity of the relative motion can be obtained by differentiation of the measured displacement.

A similar approach may be employed in cases where a rotational motion is generated, for example in a flap-type device. If the axis of rotation is submerged, it may be convenient to measure the rotation angle using an video-based motion capture system with markers placed on components either side of the axis of rotation, in order to reduce the need for submerged instrumentation.

1.10.2 Hydraulic Systems

For hydraulic systems of moving body type WECs, the instantaneous power of the device is obtained from the product of the flow rate and the corresponding pressure of hydraulic fluid.

Since the hydraulic pressure and the flow rate are calculated from the force acting on the cylinder and the displacement of the piston, a load cell and a potentiometer/LVDT can be used in the tests in a manner similar to that described in 1.10.1. A similar approach can be employed where the hydraulic system is simulated using another damping such as a pneumatic dashpot. In either case the force may also be obtained from pressure measurement.

1.10.3 Pneumatic Systems

In tests of pneumatic devices, such as OWC type WECs, the air turbine can be simulated using an orifice to restrict the air flow and to increase the pressure in the air chamber. By calibrating the orifice, it is possible to obtain a relation between pressure drop over the orifice and the flow rate. Sheng *et.al.* (2012) suggest that the orifice area for optimal power conversion efficiency is typically 0.5-2.0% of the water column area.

It should be noted that calibration between differential pressure and flow rate may be affected by frequency in oscillatory flow, and hence calibration in steady flow may induce some error. The pressure drop across the orifice is typically measured by using a differential pressure gauge. In some cases it is convenient to measure water level using a wave probe inside an OWC device, which can be used to make an independent estimate of flow rate. As discussed in section 1.4, care must be taken to account for scale effects on pneumatic stiffness of the system.

It has been argued that the damping generated by an orifice is less linear than the Wells turbine often intended as the full-scale power take-off for OWC devices, and more similar to the damping from and impulse turbine. One alternative is to use a porous membrane in place of the orifice, which can give more linear behaviour (Lewis *et.al*, 2003). However Forestier et al (2007) show that the porous membrane and the orifice PTOs yield very similar power extraction on a 1:15 scale device. Calibration of both types of simulated PTO is discussed in detail by Sheng *et. al*. (2013).

1.10.4 Overtopping Systems

The power absorbed from overtopping systems can usually be estimated by measuring the change in the reservoir level, which is an indication of both the inlet and outlet volumes.

1.11 Calibration of Environment

Details of the calibration of environment parameters can be found in the ITTC Recommended Procedure 7.5-02-07-03.1 *Floating Offshore Platform Experiments*. Particular attention must be paid to the reflected waves by beach and wave makers in model basin. It is possible to evaluate the effect of the reflected waves by using standard techniques of resolving incident and reflected waves.

1.12 Collection of Data

The main measured quantities are typically:

- All degrees of freedom (DOF) of motions of the model; note that 6-DOF is adequate for rigid bodies, but more degrees of freedom will be required to be measured for articulated or flexible devices ;
- Wave elevations local to model to determine phase of response as well as far up-wave and down-wave as appropriate;
- wind and current velocities (where appropriate);
- PTO forces & displacements / velocities (linear or rotational generator type);
- Pressure drops and flow rates across the PTO energy dissipating simulator (Pneumatic type);
- Overtopping rates (Overtopping type);
- Mooring forces where appropriate.

Studies may also investigate the detailed flow field around or inside devices, using techniques such as Particle Imaging Velocimetry (PIV), in order to assess how device performance may be improved; however this may require techniques of phase-averaging to be applied to correct for small variations in response phase during tests (see for example Fleming *et. al*. (2012)).

1.13 Data Analysis

Both time-domain and frequency-domain analysis are applied to analyse the raw data obtained in regular and irregular wave tests. If the WEC is a resonant type device, harmonic analysis can be used to obtain the characteristic of the device effectively. Details of the harmonic analysis of regular wave tests can be found in the ITTC recommended Procedures 7.5-02-07-03.2 *Analysis Procedure for Model Tests in Regular Wave*.

Test data in irregular waves should be subjected to spectral and statistical analysis, as described in the ITTC recommended Procedures 7.5-02-07-02.1 *Seakeeping Experiments*.

1.14 Extrapolation to Full Scale

All test results of the model tests are presented as prototype values. Model values are scaled to full scale by applying Froude's similitude law.

As discussed in Section 2.9, there are many important factors in energy conversion tests that are not addressed by standard scaling procedures. Special considerations are needed to address their effects.

1.15 Presentation of Results

A report on tests of a wave energy device should contain at least the following information:

- List of test objectives;
- Summary of tests;
- Description of test facilities and instruments;
- Basic assumptions, coordinate systems and sign conventions;
- Model description;
- Description of experimental set-up;
- Target and actual environmental conditions,
- calibration procedures and results;
- instrumentation calibration procedures, results, and statement sheets;
- Description of test programs, procedures and parameters;
- Description of data acquisition and data analysis procedures;
- Accuracy and uncertainty analysis;

- Tabulated and graphical results for energy capture capability; and
- Conclusions on model behaviour.

The test report should normally also include photographs and video films.

1.16 Uncertainty Analysis

Uncertainty analysis should be performed following the approach presented in 'Uncertainty Analysis in EFD, Uncertainty Assessment Methodology' (QM 4.9-03-01-01), 'Uncertainty Analysis in EFD, Guidelines for Uncertainty Assessment' (QM 4.9-03-01-02), and 'Uncertainty Analysis, Example for Resistance Test' (QM 7.5-02-02-02).

In general particular attention should be paid to uncertainties associated with the reciprocating nature of many wave energy devices/PTOs which can result in behaviour which is not directly comparable to steady state motion of similar components.

REFERENCES

Banks, D., van't Hoff, J., & Doherty, K., 2013, "The Development of an Experimental Force Feedback Dynamometer to investigate the real Time Control of an Oscillating Wave Surge Converter", Paper OMAE2013-10766 Proceedings, 32nd Int. Conf. on Ocean, Offshore and Arctic Engineering (OMAE2013) June 9-14, Nantes, France

Cruz, J., 2010, "Ocean Wave Energy", Springer-Verlag, Berlin.

Ersdal, S. & Moe, A. M., 2013 "Model Test of the Aker Wave Energy Converter Concept", Paper OMAE-10537, Proceedings, 32nd Int. Conf. on Ocean, Offshore and Arctic Engineering (OMAE 2013) June 9-14,Nantes, France

Falcão A. F. de O., 2010 "Wave energy utilization: A review of the technologies", Renewable and Sustainable Energy Reviews, Vol. 14 pp 899–918

Falnes, J., 2002, "Ocean Waves and Oscillating Systems", Cambridge University Press, Cambridge UK.

Fleming, A., Penesis, I., Macfarlane, G., Bose, N. & Hunter, S., 2012, "Phase averaging of the velocity fields in an oscillating water column using splines", Proceedings, Inst. Mech. Eng., Part M: J. Eng. for the Maritime Environment, Vol. 226, (4) pp. 335-345. ISSN 2041-3084

Folley, M., Cornett, A., Holmes, B. Lenee-Bluhm P. & Liria, P., 2012 "Standardising resource assessment for wave energy converters", Proceedings, 4th International Conference on Ocean Energy (ICOE 2012), Dublin, Ireland, 17 October

Forestier, J. M., Holmes, B., Barret, S. and Lewis, A., 2007, "Value and validation of small scale physical model tests of floating wave energy converters," Proceedings, 7th European Wave and Tidal Energy Conference (EWTEC 2007), Porto, Portugal, 11-14th Sep.

Goda, Y., 2010, "Random Seas and Design of Maritime Structures", World Scientific, Singapore (3^{rd} Ed.)

Lewis, A., Gilbaud, T. & Holmes, B., 2003, "Modelling the Backward Bent Duct Device-B2D2, a comparison between physical and numerical models", Proceedings, 5th European Wave and Tidal Energy Conference (EWTEC 2003), Cork, Ireland, 17-20th Sep.

Longuet-Higgins, M.S., Cartwright, D.E. & Smith, N.D., 1963, "Observations of the directional spectrum of sea waves using motions of a floating buoy". In: "Ocean Wave Spectra", Prentice Hall, New York, pp.111–136

Mankins, John C., 1995, "Technology Readiness Levels: A White Paper", NASA, Office of Space Access and Technology

Muliawan, M. J., Gao, Z., Moan, T., & Babarit, A., 2012, "Analysis of a two-body floating wave energy converter with particular focus on the effect of power-take off and mooring systems on energy capture", J. Offshore Mechanics & Arctic Engineering Vol. 135

Sheng, W., Lewis T. & Alcorn R., 2012, "On wave energy extraction of oscillating water column device", Proceedings, 4th International Conference on Ocean Energy (ICOE 2012), Dublin, Ireland, 17 October

Sheng, W., Thiebaut, F., Babuchon, M., Brooks, J., Lewis, A. & Alcorn, R., 2013, "Investigation to Air Compressibility of Oscillating Water Column Wave Energy Converters", Paper OMAE2013-10151, Proceedings, 32nd Int. Conf. on Ocean, Offshore and Arctic Engineering (OMAE 2013), June 9-14, Nantes, France

Vicente, P., Falcão, A.F. de O. & Justino, P.A.P., 2011, "Slack-chain mooring configuration analysis of a floating wave energy converter", Proceedings, 26th International Workshop on Water Waves and Floating Bodies, Athens, Greece, 17-20 April

Weber, J., 2007, "Representation of non-linear aero-thermodynamic effects during small scale physical modelling of OWC WECs", Proceedings, 7th European Wave and Tidal Energy Conference (EWTEC 2007), Porto, Portugal, 11-14th Sep.