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Application of the Aero-Hydro-Elastic Model, HAWC2-WAMIT, to Offshore Data from Floating Power Plants Hybrid Wind- and Wave-Energy Test Platform, P37

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Abstract

As the depths of sites consented for offshore wind increases, the need to develop floating foundations for wind turbines increases, as fixed foundations are only economically viable up to approximately 50 m water depth [2]. Key to developing the floating wind turbine industry is the development of accurate numerical models, which can combine the aerodynamic, hydrodynamic, structural flexibility and mooring components. Very little offshore data exists, however, in order to validate these numerical models.

Floating Power Plant are the developers of a floating, hybrid wind- and wave-energy device. The device uses the pitching wave energy devices, not only to increase and smooth the power output from the platform, but also to take the energy from the waves in a controlled manner, resulting in a stable platform for the wind turbine and a safe harbour for O&M. They are currently developing the final design for their first full-scale prototype, the P80, which has a width of 80 m. As part of the development, Floating Power Plant have completed 4 offshore test-phases (totalling over 2 years offshore operation) on a 37 m wide scaled test device, the P37.

This paper focuses on the comparison of one of the leading numerical models for floating wind turbines, developed by DTU Wind Energy, to the offshore data from P37. The numerical model couples DTU's own aeroelastic code, HAWC2, with a special external system that reads the output files generated directly by the commercial wave analysis software, WAMIT.

1 Introduction

Areas are being consented for offshore wind farms in increasingly deeper water due to the large available area out of sight from the coast, the better energy resources further offshore, and the need for wind farms in areas where the depth increases rapidly moving away from the coast. Moving further into deeper waters requires the use of floating foundations, as traditional fixed wind turbine foundations are only economically feasible up to approximately 50 m water depth. There is increasing interest in the offshore renewables industry, not only in providing floating foundations for wind turbines, but in combining technologies. One example of this is the European Union Seventh Framework Programme H2Ocean project (www.h2ocean-project.eu), which develops a proof-of-concept design for a new fully integrated multi-purpose platform to make the most of the sea resources, fostering activities such as renewable power harvesting + aquaculture + environmental monitoring, and to assess the impact of such platform at environmental and economical levels. Floating Power Plant (a partner within the H2Ocean project) develop a floating wind and wave energy device, and have already for operated a 37 m wide, grid-connected test platform for over 2 years, and are currently working towards their first commercial device, P80, which will be 80 m wide.

Key to developing the floating wind turbine industry is the development of accurate numerical models, which can combine the aerodynamic, hydrodynamic, structural flexibility and mooring components. DTU Wind Energy Department have been developing a numerical model that couples their own aeroelastic code, HAWC2 with a special external system that reads the output files generated directly by WAMIT and generates a system with the same response. The HAWC2 model has been extended to account for the wake effects within arrays of wind turbines using the Dynamic Wake Meander Model. The combined model will be referred to as HAWC2-WAMIT from herein.

There is currently very little available empirical data from floating wind turbines with which to validate the numerical models. This paper focuses on the validation and comparison of both numerical models when applied to the offshore data acquired by Floating Power Plants test platform, P37. The platform is a semi-submersible structure which has a water-plane area similar to a cross geometry. The cross-geometry is 37 m wide with a hull through the centre which is attached to a mooring-buoy fore of the cross-point. The platform is able to rotate (vane) 360 degrees around the turret mooring system. There are 10 pitching wave energy converters along the width of the platform, whose motion generates power, stabilises the platform and causes the platform to rotate around the mooring buoy to face the incident waves. On top of the platform, there are three Gaia 11 kW wind turbines, one on either side and one on the aft of the hull. The wind turbines are two bladed in a downwind configuration with teeter hinge, fixed pitch stall control and a passive yaw system that aligns the single rotor towards the incoming wind.

The P37 platform has undergone four complete offshore test-phases, during which the motions and accelerations of the platform, each of the floaters and the wind-turbines were measured in a variety of meteorological conditions. Strain gauges were also located within the nacelles of the wind turbines and load cells within each of the three catenary mooring lines. In the last two test phases alone, over 2000 hours of offshore data were recorded. This paper details an approach to validating the HAWC2-WAMIT numerical model using this offshore data.

Comparisons are made in this paper of the numerical model to a theoretical floating turbine for which published results are available, and to offshore data from the 4th operational stage of the P37. Initial results are given in this paper considering the motions of the platform and loads on a mooring chain, together with an outline of the next steps to take in the process of validating the numerical code by comparison to the offshore data.

2 The Floating Power Plant Offshore Device, P37

The offshore data to which DTU model, HAWC2-WAMIT, will be compared was measured on the 37 m wide hybrid wind- and wave-energy device, P37, developed by Floating Power

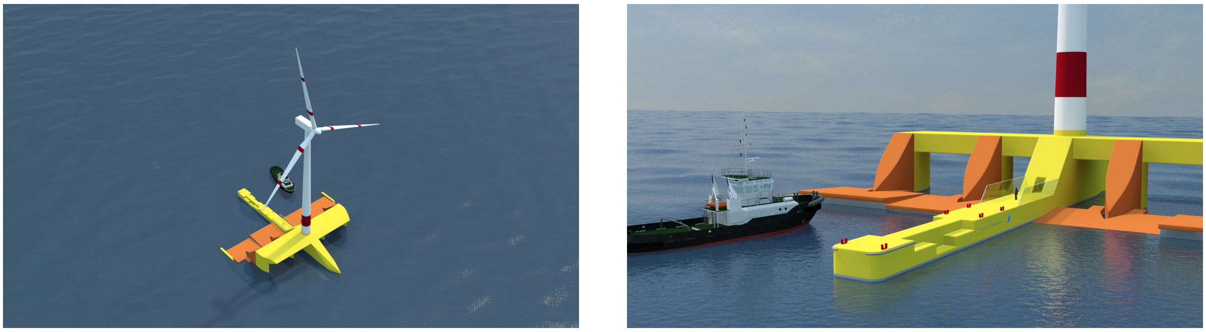

(a) (b)

Figure 1: Artists impression of Floating Power Plant's P80 device

Plant A/S. This section offers a brief history to the development of the device followed by a description of it.

2.1 Development Background

Floating Power Plant are the developers of a novel, floating, wave- and wind-energy hybrid device. The design for the first commercial device, the P80, is currently being finalised. In short, the P80 will consist a semi-submersible platform which will be approximately shaped like a cross, with a central hull, an 80 m wide perpendicular cross-bridge, and damping plates located far beneath the free surface. At the fore end of the hull, a mooring turret will be located, about which the platform will be able to rotate freely in order to face the incoming waves. Across the cross-bridge, four pitching wave energy converters will operate, each attached to its own PTO house, which will be an oil hydraulic system housed within a dry 'engine room'. On top of the hull, a single wind turbine will be located. The unique, patented technology provides a stable platform for any offshore wind turbine, hence is not specific to any one wind turbine manufacturer.

Since the initial conception of the invention, Floating Power Plant have performed hydrodynamic tests on their device at 1:16 and 1:14.5 scale in wave flumes, 1:33, 1:9.5 and 1:50 scale in wave basins, and 1:50 scale in a combined wind and wave facility with the purpose of design development and optimisation. Special attention has been paid during the research and development to the patented wave energy technology, in which the unique geometry of the floaters interact with the platform to maximise their performance, the stability of the platform and the PTO control system.

A key part of the development has been the design, build and operation of Floating Power Plant's 37 m wide test platform. This has been undergoing offshore testing for four complete test phases (totalling more than 2 years). The test platform provides electricity to the grid from both wind and wave energy, however its purpose is purely for research and development.

The first test phase focused on the platform and WECs and the installation of appropriate measurement sensors. The second test phase included the installation of the wind turbines. The third test phase focused on the installation of the PTO system, and, following wave flume tests on the WECs, the replacement of two of the WECs with different sizes more suited to the P37 wave conditions. The fourth test phase focused on testing different control strategies for the PTO system.

The PTO for the WECs has undergone rigorous testing and optimisation through both dry and offshore testing. The key drivers for this optimisation are both increasing the power output across a wide range of wave conditions and smoothing the power output to meet grid demands. Through refining the PTO control strategy, the mean wave to wire efficiency (including all data from the entire test period, and all control strategies tested), was increased to over 30 % in test phase 4 [4]. Further details on the test undertaken up to February 2014 can be found in the public report, [8]. Since this report, combined wind and wave tests were performed at 1:50 scale in October 2014, and further dry testing of the PTO unit undertaken.

2.2 The P37 Offshore Test Device

The P37 is not a directly scaled version of the P80, but is instead specifically designed for a Danish offshore site in order to test and obtain operational data and knowledge on the key design components of the P80. Instead of four large wave energy converters, 10 smaller wave energy converters (WECs) are operated across the cross-bridge. The eight inner WECs are larger than the outer two WECs, in order to test the relationship between the WEC size and its motions in different waves. All floaters have the ability to be ballasted to tune their natural period to the incident waves, however in the fourth test phase constant ballast was used in order to compare different PTO control strategies.

A complex control algorithm, developed in partnership with Fritz Schur Energy A/S, is applied to oil hydraulic PTO unit of the most starboard WEC. Throughout the test periods, the PTO algorithm has been developed and fine-tuned. In-between test periods, the PTO unit from this WEC was removed from the platform and dry-tested in a laboratory to further develop PTO control algorithms.

As with the P80, the motion of the WECs results in the passive vaning of the platform about its mooring turret so that the WECs face the incoming waves, with high efficiencies found when the WECs face within 30 degrees of the predominant incident wave direction. Also like the P80 platform, the P37 is actively ballasted in order to maintain even keel in all conditions.

Unlike the P80, which has a single wind turbine of 2.3 to 5 MW, the P37 has three smaller turbines (Gaia 11 kW), one on either side and one on the aft of the hull. The wind turbines are two bladed in a downwind configuration with teeter hinge, fixed pitch stall control and a passive yaw system that aligns the single rotor towards the incoming wind. The turbines were selected in order to obtain the necessary data using off-the-shelf turbines with a hub height appropriate to the platform size. The water depth of a site suitable for the P80 is 45 to 200 m, so to adhere directly to Froude scaling, the P37 would need to be in a depth of 23 to 93 m, however the P37 site is only 7 m in depth. The catenary mooring system designed for the P37 site therefore has different characteristics to the P80 system.

There have been innumerable lessons learnt during the operation of the P37 which will be invaluable in the design and operation of the P80 device. Although there are key differences between the P37 and P80 designs and sites, the vast amount of data gathered over the two year operational period, is used for testing and validating numerical models on all components of the device. Once validated, these same models can be used to enhance the design for the P80 device.

This paper focuses on a model which combines the wind turbines, floating platform and mooring system, but neglects the motion of the WECs and the WEC PTO units.

(a) Aerial photograph taken from a helicopter on a calm day

(b) Photograph taken from P37 webcam during a storm

Figure 2: Photographs of Floating Power Plant's 37 m wide offshore test platform, P37

3 The HAWC2-WAMIT Numerical Model

HAWC2 (Horizontal Axis Wind turbine simulation Code 2nd generation) is an aeroelastic code intended for calculating the response of both floating and fixed foundation Horizontal Axis Wind Turbines in the time domain.

The aerodynamic model within HAWC2-WAMIT is based on the Blade Element Momentum Theory, with modifications to account for wake expansion and swirl and extensions to account for dynamic inflow, skew inflow, shear effect on induction, the effect from large blade deflections, tip losses and two dynamic stall models (Stig ye and Modified Beddoes-leishmann models).

The flexible dynamic mooring line is model by a general cable element formulation which is similar to e.g. ([1]). The model is able to handle mooring line systems that includes cable and beam elements, as well as buoys and clump weights. Springs are included to account for bottom contact but are only activated when there is a contact between sea floor and the line. The formulation used allows for very large deformations of the mooring lines. Hydrostatic buoyancy and hydrodynamic drag forces are considered throughout the analyses. This formulation only holds for cables with uniform properties, so each section of different cable type (chain, synthetic rope etc.) is modelled as a separate body and connected by ball joint constraint in HAWC2s multi-body formulation. Point masses are implemented with both linear and quadric viscous damping terms to model clump masses and drag buoys.

The mooring system model uses a special interface to HAWC2, which enables externally formulated equations of motion to be solved together with the core equations of motion in the HAWC2 code ([5]). The external system interacts with the HAWC2 model through a set of constraint equations which describe how the external system degrees of freedom (DOFs) and the HAWC2 DOFs are related. Both the EOM for the external system and the constraint equations are specified in an external DLL which is then called by the HAWC2 solver during the simulation.

The structural model includes flexible rotating bodies which include masses, and inertial, centrifugal and gyroscopic forces.

The model applied in this paper includes a standalone coupling to the wave analysis software, WAMIT. The external DLL interface in HAWC2 is used to read the WAMIT output files directly and input to a HAWC2-WAMIT module, ESYSWamit, in a similar way to the coupling with the mooring module.

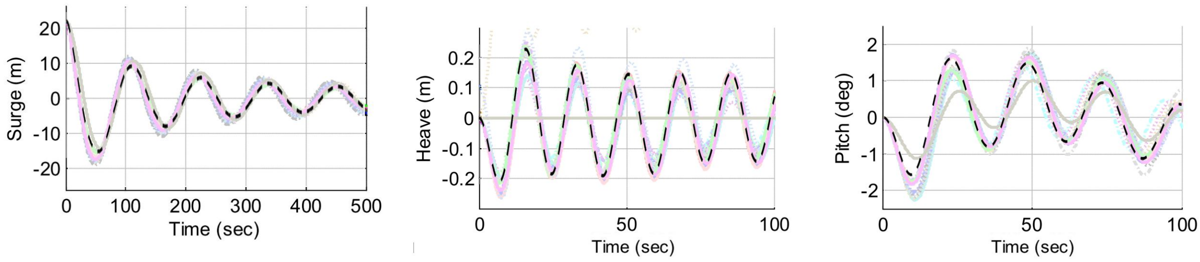
A more detailed description of the model is given by [3].

4 OC4 Comparison

The International Energy Agency (IEA) devised the OC4 project ([7]) under Wind Task 30 in 2010 to investigate wind-turbine coupled simulations with both jacket structures (Phase I) and semi-submersible platforms (Phase II). The aim of the project was to perform code to code comparisons of state-of-the-art simulation codes for offshore wind turbine modelling. In phase II, 21 load cases were applied with varying levels of complexity and a variety of metocean conditions. The cases are clearly defined, hence a small selection of them are applied here for an initial comparison of the FloVAWT and HAWC2-WAMIT codes.

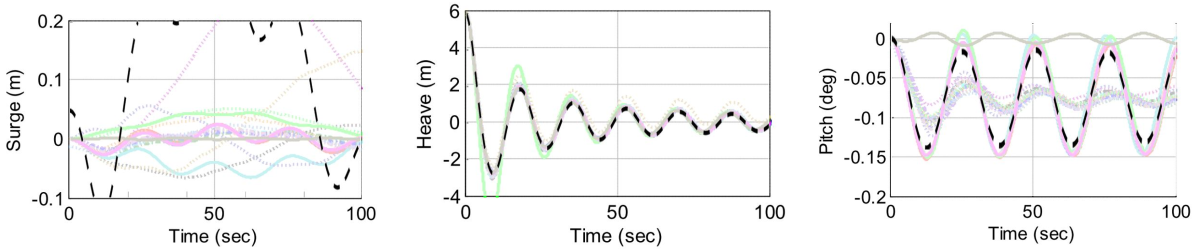
The device to which these load cases are applied is a semi-submersible floating offshore wind system developed for the DeepCwind project. The platform is 20 m draft, with a tripod configuration with a distance of 50 m between each of the three circular legs. The turbine is the NREL 5MW reference turbine which has a tower height of 77,6 m, attached to the platform 10 m above the free-surface when at rest.

Out of the 21 load cases defined in the OC4 Phase II code comparison, only 3 are applied as this comparison is not the key focus of this paper, Load Cases 1.3, 2.1 and 3.1. The results are discussed in the following sections.



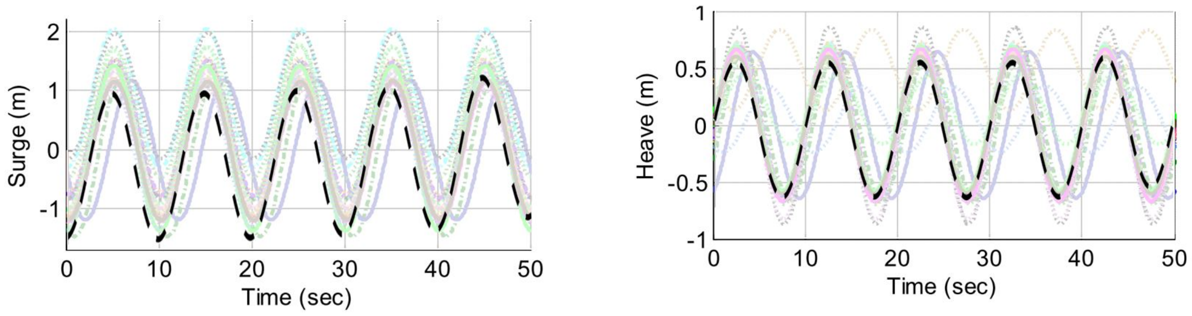
(a) Surge (b) Heave (c) Pitch

Figure 3: OC4 load case 1.3a: HAWC2-WAMIT (black dashed line) overlaid onto Figure 4 from [7]

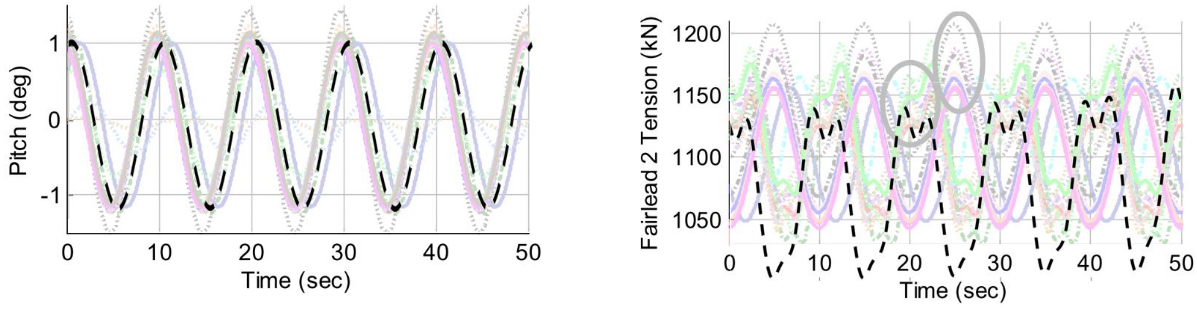


(a) Surge (b) Heave (c) Pitch

Figure 4: OC4 load case 1.3b: HAWC2-WAMIT (black dashed line) overlaid onto Figure 5 from [7]



(a) Surge (b) Heave



(c) Pitch (d) Fairlead Tension 2

Figure 5: OC4 load case 2.1: HAWC2-WAMIT (black dashed line) overlaid onto Figure 6 from [7]

5 Implementation of P37 in HAWC2-WAMIT

HAWC2 (Horizontal Axis Wind turbine simulation Code 2nd generation) is an aeroelastic code intended for calculating the response of both floating and fixed foundation Horizontal Axis Wind Turbines in the time domain.

The aerodynamic model within HAWC2-WAMIT is based on the Blade Element Momentum Theory, with modifications to account for wake expansion and swirl and extensions to account for dynamic inflow, skew inflow, shear effect on induction, the effect from large blade deflections, tip losses and two dynamic stall models (Stig Øye and Modified Beddoes-leishmann models).

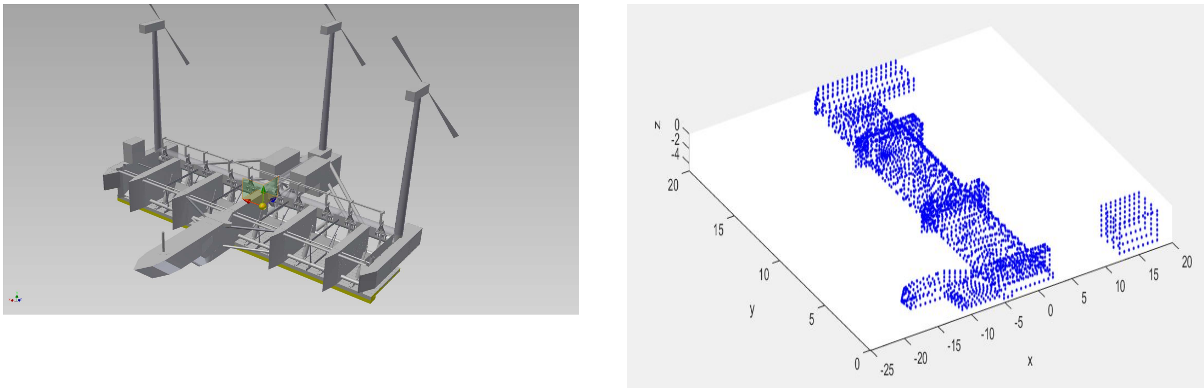
Within the mooring module, an iterative solution of the quasi-static equilibrium between the free anchor chain and the angle at the connection point of the chain and the platform is used to compute the bottom contact point. The horizontal and vertical components of the line force at the connection point are then determined from the weight of the floating chain and the angle of the chain at the connection point. A fully dynamic analysis is then performed on the mooring line from the connection point to the bottom contact point. This is performed by dividing the line into sections, a uniform stiffness, mass and hydrodynamic characteristic, with each section then subdivided into 2-node elements on which the analysis is performed.

The structural model includes flexible rotating bodies which include masses, and inertial, centrifugal and gyroscopic forces.

The model applied in this paper includes a standalone coupling to the wave analysis software, WAMIT. The external DLL interface in HAWC2 is used to read the WAMIT output files directly and input to a HAWC2-WAMIT module, ESYSWamit. A more detailed description of the model is given by [3].

5.1 Implementation Within the HAWC2-WAMIT Modules

The complex submerged structure of the P37 was simplified for implementation in WAMIT, by removing smaller pipes and substructures. The simplified submerged structure was converted to a system of panels, each with 3 or 4 vertices, for implementation in WAMIT using the 3D CAD software, Rhino, together with the mathematical software, MATLAB (see Figure 6).



(a) 3D CAD drawing

(b) Panel model used within WAMIT

Figure 6: 3D CAD drawing of P37 and the corresponding simplified panel model of the submerged geometry implemented in WAMIT device

The P37 platform is actively ballasted to maintain close to even trim in different conditions. The exact ballasting recordings were not always recorded accurately and have not yet been correlated with the processed measurement data. Based on the design conditions the centre of gravity has been calculated by naval architects, however in reality this will vary according to the exact ballasting conditions.

As the initial measurement period selected is a period during which the wind turbines are non-operational, the initial test case does not include any wind applied to the model. In future iterations, the wind will be applied even with the wind turbines non-operational, as the drag from the wind may influence the platform behaviour.

The three spread catenary mooring system is implemented into the mooring module, connected to the mooring turret within the anchor buoy at the front of the hull. As the platform rotates about the mooring point, the motions are given with the origin at the intersection of the undisturbed free surface and the mooring turret.

5.2 Selecting Suitable Offshore Data Period

The P37 is not an exact scale of the commercial platform, P80, but is instead designed for obtaining suitable offshore measurements. Sensors are placed on all aspects of the device, including load links in each of the mooring lines, two inclinometers on the platform to determine platform pitch and roll, gps to track platform direction, a sonic anemometer to measure wind speed and direction, the current direction and speed, and the mean wave statistics . The measurements are stored in 10 minute intervals, with most measurements recorded every 0.03 seconds (35 Hz sampling frequency), but some, such as the wave statistics, recording only a mean value for each 20 minute interval.

The platform contains 10 pitching wave absorbers, whose motion is closely integrated to the hydraulic PTO system. The floaters are each partially enclosed by the platform, resulting in complex hydrodynamic properties. A separate numerical model is under development for the floaters, but at this stage is not coupled to the HAWC2-WAMIT model. For this paper therefore, a measurement period where the floaters are fixed (vertically upwards) is required, to avoid the complex interactions of the waves, the floater motions, the PTO unit and the rest of the platform. The HAWC2-WAMIT model is theoretically able to model multiple wind turbines in turbulent wind conditions, and include their influence on the motion of the floating platform together with the mooring forces. At this preliminary stage of comparison, a more simplified case is required, however, in order to understand the comparisons between the simulations and offshore measurements in detail. The measurement period is therefore also required to have the wind turbines not in operation. Further simplifying the comparison case, the measurement period would ideally have a low current and wind speeds.

The third and fourth test phases contain around 2000 hours of data. As with all test data, however, there are often uncertainties in the recordings. A verification and filtering strategy was applied by DTU during post processing, comparing signals to each other to ensure their accuracy ([8]).

Using a this strategy, the measurement period selected as the most suitable period for this first stage of simulation comparison is a one hour period starting at 11:40 on 5th December 2012. During this period, nine out of ten of the floaters were in the storm position (fixed vertically upwards), the turbines were not operating and the current speed was low (0.4 m/sec). The average significant wave height was, $H_{m0} = 0.61$ m , the peak period was $T_p = 3.4$ seconds and the misalignment between the waves and the platform was an average of 15 degrees. Although the effects of wind will not be included in the simulations in this paper, the mean wind speed during the selected measurement period was relatively high at 9.7 m/s, which is likely to have influenced the platform even with the wind turbines non-operational.

5.3 Defining a Spectrum

The wave statistical measurements recorded at the P37 site are averaged over 10 minute intervals. As no time series data exists for waves at this site, it is impossible to know which theoretical spectrum would better represent the waves at the site. An irregular wave field can be approximated by summing component regular waves with a range of phases, amplitudes and frequencies [6]. The distribution of energy between these component waves can be defined by a theoretical spectrum, with different distributions of energy resulting in the same overall statistical wave properties. Common theoretical spectra include the Pierson Moskowitz and the Jonswap spectra. The Pierson Moskowitz spectrum was originally developed based on measurement data from the North Atlantic (open sea) and the Jonswap from the north sea (limited fetch). The two theoretical spectra are similar in definition, with the Jonswap including a peak enhancement factor, γ. A Jonswap spectrum with $\gamma = 1$ exactly represents the Pierson Moskowitz spectrum, however increasing the γ value, increases how pronounced the peak of the spectrum is, hence decreases the energy in the low and high frequency ranges. Where the exact specifications of the energy distribution are not known, a standard γ value of 3.3 can be applied.

In this paper both the Pierson Moskowitz and Jonswap with $\gamma = 3.3$ will be applied. Whilst the spectrum defines the distribution of energy between the component waves, it does not define the phases of the waves, hence these must be defined randomly. Three 'seeds' of each of the two spectra are therefore applied with different random phases in each seed.

6 Preliminary Results of Simulations

Comparing time series data from simulations and measurements is not straight forward. There are many statistical measures that can be used, as well as visual comparisons of the data. Table 1 shows some basic statistics, which can be used as an initial indicator. Further statistical comparisons will however be included in future iterations.

	Offshore	JS1	JS2	JS3	**Mean Js**	PM1	PM2	**Mean PM**
Mean value	**0.52**	-0.1	-0.1	-0.1	**-0.10**	-0.1	-0.1	**-0.10**
Mean Amplitude	**0.50**	0.45	0.45	0.4	**0.43**	0.85	0.84	**0.85**
Mean of highest 1/3 of amplitudes	**0.69**	0.57	0.58	0.52	**0.56**	1.06	1.04	**1.05**

(a) Pitch (degrees)

	Offshore	JS1	JS2	JS3	**Mean Js**	PM1	PM2	**Mean PM**
Mean value	**-0.28**	0	0	0	**0.00**	0.01	0.01	**0.01**
Mean Amplitude	**0.29**	0.1	0.1	0.1	**0.10**	0.18	0.15	**0.17**
Mean of highest 1/3 of amplitudes	**0.41**	0.12	0.13	0.12	**0.12**	0.23	0.19	**0.21**

(b) Roll (degrees)

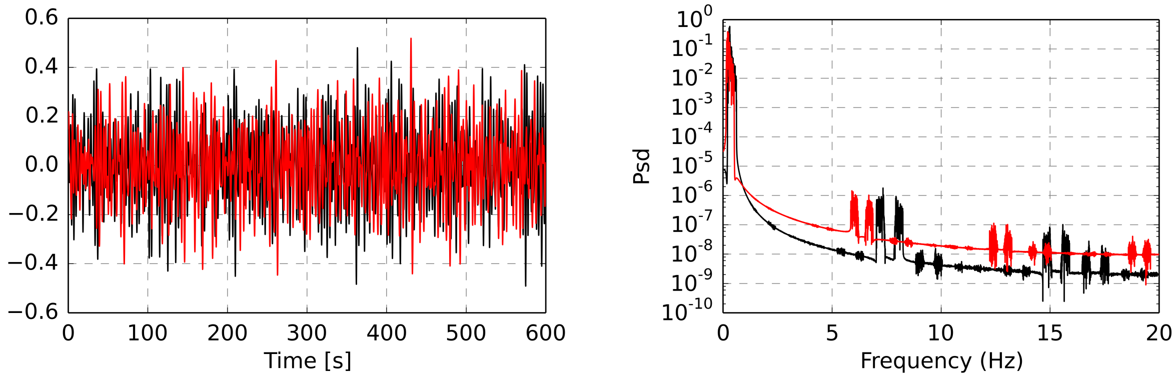
	Offshore	JS1	JS2	JS3	**Mean Js**	PM1	PM2	**Mean PM**
Mean value	**2.98**	3.04	3.04	3.04	**3.04**	3.03	3.03	**3.03**
Mean Amplitude	**0.25**	0.21	0.20	0.19	**0.20**	0.20	0.17	**0.19**
Mean of highest 1/3 of amplitudes	**0.36**	0.27	0.28	0.25	**0.27**	0.28	0.25	**0.27**

(c) Mooring Load on mooring line 1 (Tonnes)

Table 1: Initial statistical comparison between offshore data from P37 (averaged over one hour) and HAWC2-WAMIT results with the Jonswap spectrum (seeds titled JS1, JS2 and JS3) and Pierson Moskowitz spectrum (seeds titled PM1 and PM2)

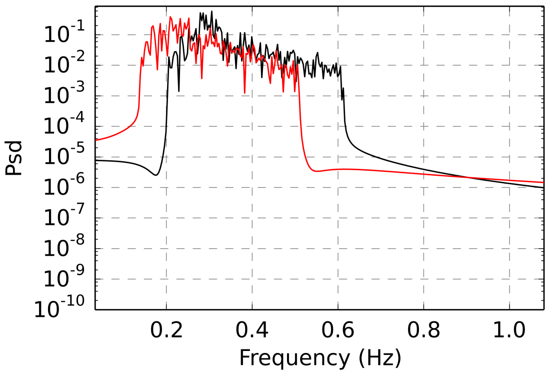
6.0.1 Pierson Moskowitz Compared to Jonswap

The mean amplitudes of the pitch and roll motions are approximately doubled in the Pierson Moskowitz spectra compared to the Jonswap spectra. This is due to the shift in the wave spectrum towards lower frequencies, resulting in a wider PSD peak in the pitch motion, as seen in Figures 7 and 8.



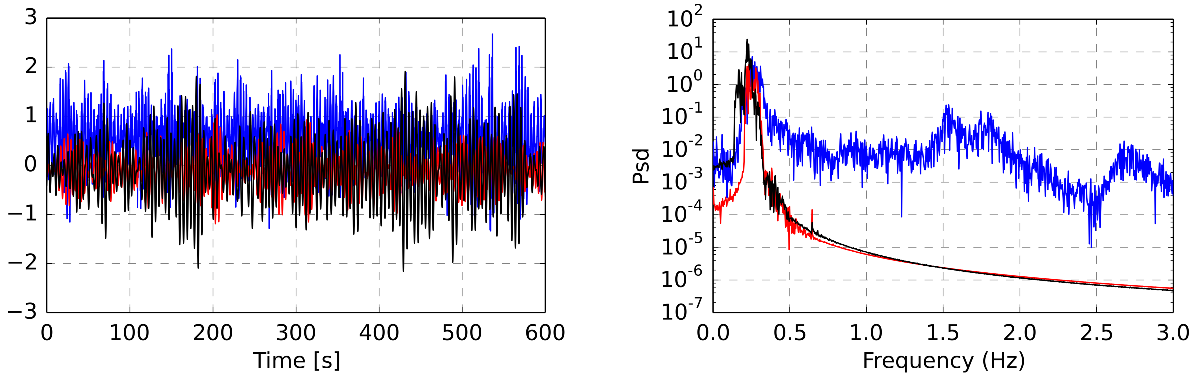
(a) Time series of free surface elevation (m)

(b) PSD of free surface elevation, all frequencies



(c) PSD of free surface elevation, low frequencies

Figure 7: Time series and spectra of the free surface elevation Jonswap and Pierson Moskowitz spectra, JS1 = red and PM1 = black



(a) Time series of platform pitch (deg)

(b) PSD of platform pitch

Figure 8: Time series and spectra of the free surface elevation and the pitch platform motion with the Jonswap and Pierson Moskowitz spectra, JS1 = red and PM1 = black, and measured data = blue

The amplitudes of pitch motion are too small in the simulations with the Jonswap spectra and too large in Pierson Moskowitz spectra compared to the offshore measurements. This indicates that neither theoretical spectra accurately models the P37 site, and perhaps a third spectrum could give better results.

6.1 Mooring Loads on Mooring Line One

The mooring loads are similar in the simulated result to the measured data, however the amplitudes are slightly too small. The high frequency behaviour of the mooring lines is not captured in the simulations. This needs further investigation, together with application to other measurement periods where offshore data is available for more than one mooring line.

6.2 Limitations

In the selected offshore measurement period, the waves come from an average of 15 deg misalignment, hence platform yaws about its mooring turret at the front of its hull. The hydrodynamic input to HAWC2-WAMIT is from WAMIT with the loads given about the centre of flotation. As the platform moves about its mooring turret, the input from WAMIT is not modified to account for the new position.

As the P37 is a test platform, designed for research and development purposes, many measurements were taken, but also many things were changed throughout its test periods. One such variation is the ballasting of the platform, which varies its centre of gravity. Both a centre of gravity calculated for a single ballasting condition, and second centre of gravity calculated in attempt to match the ballasting situation offshore applied in this paper. It is shown the choice of centre of gravity impacts the results. Further work therefore needs to be performed, therefore, to cross-check all records to accurately determine the centre of gravity for each measurement period in order to perform future model validations.

In order to validate the numerical model, the meteorological conditions seen offshore need to be replicated in the model. The statistical wave data recorded at the P37 offshore test site does not contain enough information to accurately repeat the conditions within the model. Two theoretical spectra are applied in this paper, however they result in significantly different results in both the platform motions and mooring loads, due to their difference in energy distribution at high and low frequencies. Further investigation is therefore needed to determine the most appropriate theoretical spectrum to replicate the wave conditions seen by the P37 device.

The method by which the hydrodynamic module is currently integrated to the mooring and aerodynamic modules does not accurately model yaw motion. For this purpose, the comparisons in this paper have focused on the pitch and roll motion of the platform and the mooring loads. Once corrected, further validation can be made to offshore data when considering the yaw motion. It is difficult to draw conclusions on the mooring line simulation based on only one measurement period and one mooring line. Once the potential to model the yawing motion about the mooring turret is included, further validation cases must also be identified in which data is available from multiple mooring lines.

7 Conclusion

One of the key challenges facing the development of floating wind devices is the development of reliable numerical models to predict the loads and motions on the devices under different sea and wind conditions. HAWC2-WAMIT is a code under development by DTU which models complex wind conditions, wind turbines loads and motions combined with the loads and motions of a floating foundation and the mooring system. Floating Power Plant is the developer of a floating hybrid wind and wave energy device, and has 2 years of offshore operational data. In this paper, the challenges of applying the numerical model to the offshore data are explored with a view to validating the numerical model. The comparisons performed in this paper are the first iteration, with a view to identifying the areas which need clarifying to perform detailed validations in the future.

Despite a significant amount of data, a large amount of post-processing and quality checking must be performed on the data to identify suitable periods. As well as good quality data, it is also crucial to identify areas where the complexity is minimised for early stage model validations. A test period with the wind turbines and wave energy devices non-operational is applied as a preliminary simple test case.

Based on the comparisons made in this paper, three key areas have been identified for improvement before the next stage of model validation. Firstly, it is deemed necessary to carefully cross-reference all offshore records and measurements to establish the exact centre of gravity of the platform at all times. Secondly, studies need to be performed on the test site to identify the most suitable theoretical wave spectra to accurately represent the wave climate associated with the measurements. Thirdly, the method in which the hydrodynamic loads and forces are integrated into the model needs to be modified to account for platform yawing motions resulting from misalignment of the platform with the waves.

Further validation stages will include identifying offshore testing periods with high quality data, with increasing complexity (such as with wind turbines operational).

A separate model is also under development within Floating Power Plant for the combination of a single wave energy converter with their hydraulic PTO system. This is currently undergoing similar validation studies. Once validated separately, this model will be integrated into the HAWC2-WAMIT model to give a fully integrated model of the P37 platform with both wind turbines and wave energy convertors in operation

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