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Hydrodynamic response of a floating offshore wind turbine (1st FOWT Comparative Study Dataset)

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Hydrodynamic response of a floating offshore wind turbine (1st FOWT Comparative Study)

Test Case ID: 015
Date of Experiments: April 2022
Dynamics of Fluids: Focused waves
Structures, Devices & Obstacles: Floating Structures
Project: Extreme loading on FOWT under complex environmental conditions
Institution: University of Plymouth
Facility: COAST
Contacts: Dr Edward Ransley

Description

These test cases consider the hydrostatic and hydrodynamic response of a 1:70 scale model of the IEA 15MW reference wind turbine (IEA-15-240-RWT) (Gaertner, et al. 2020) and UMaine VolturnUS-S semi-submersible platform (Allen, et al. 2020). The test cases consist of static equilibrium load cases, free decay tests (in heave, surge and pitch) and a pair of focused wave cases (one 'operational' and one 'extreme'). Note: only hydrodynamic loading is considered in this comparative study, i.e. there is no aerodynamic loading on the floating offshore wind turbine (FOWT).

Experimental Set-up

Experiments were performed in the COAST Laboratory Ocean Basin (35m long X 15.5m width) at the University of Plymouth, UK. The basin has 24 flap-type, force feedback controlled wave makers with a hinge depth of 2m. The water depth at the wave makers is 4m and there is a linear slope to the working area where the water depth, h, was set to 2.86m. At the far end of the basin there is a parabolic absorbing beach (Figure 1). The water in the basin is 'fresh' water (approximate density, ρ = 998.2072 kg/m3 and viscosity, μ = 0.001002 Pa·s [at 20°C])

The global coordinate system is defined with the z-axis running vertically (positive z upwards) with z = 0 corresponding to the still water level. The x-axis runs in the direction of wave propagation (from the wave makers to the beach). The y-axis is defined according to the right-hand-rule. The origin of the global coordinate system is located 17.3m downstream of the wave makers (near the centre of the device when at rest with no environmental loading) (Figure 1).

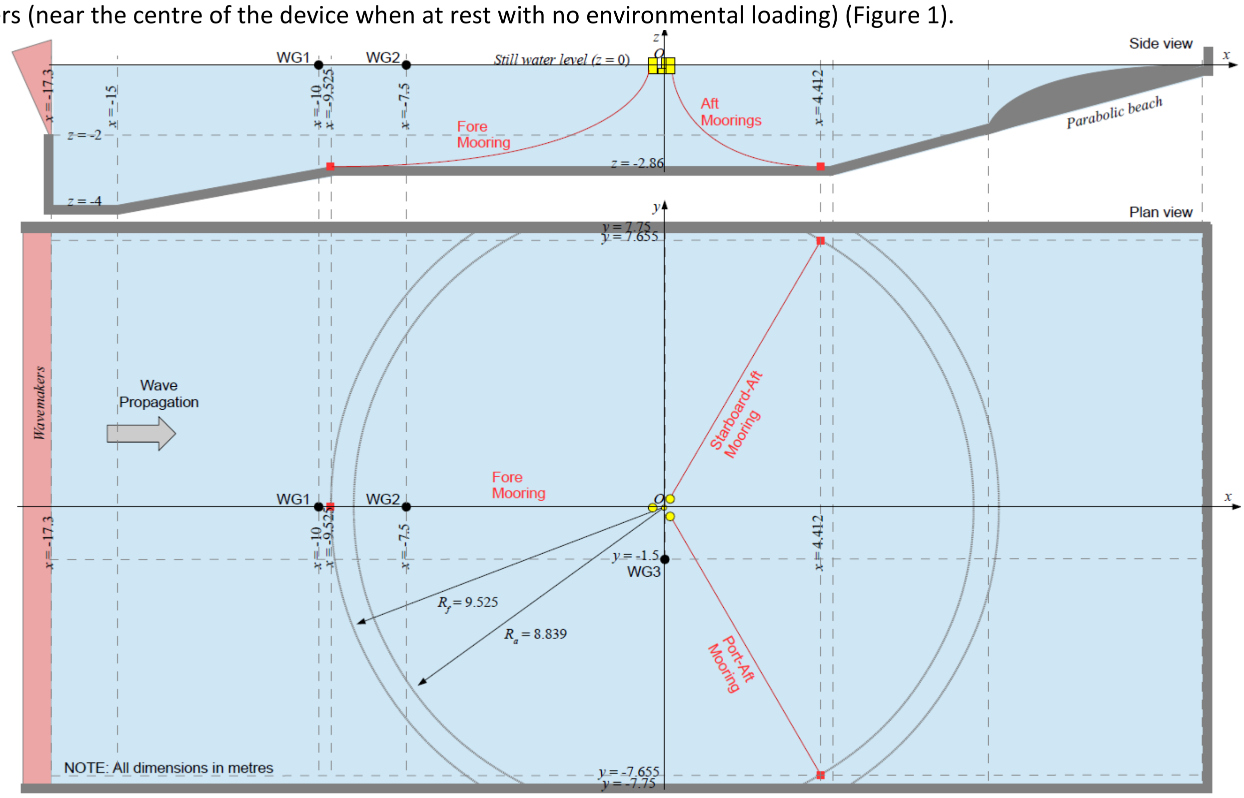

Figure 1: COAST Laboratory Ocean Basin dimensions, experimental set-up and definition of global coordinate system

Experimental Layout

A plan view of the experimental layout is presented in Figure 1. The locations of the wave gauges (WG) and mooring anchors (in the global coordinate system) are indicated by the black circles and red squares respectively, and given in Table 1. The fore mooring anchor is located at the start of the working region of the Ocean Basin. The 3 mooring lines, and their reference names, are indicated with red lines/text. The anchor radii are indicated by dotted arcs (NOTE: unlike the reference document for the VolturnUS-S (Allen, et al. 2020), the fore and aft moorings have different anchor radii since they are truncated to fit in the basin [further information can be found in the mooring description below]).

Table 2: Coordinates of wave gauges and mooring anchors in global coordinate system (NOTE: all values in metres) [see Figure 1 for coordinate system definition]

	WG1	WG2	WG3	Fore anchor	Starboard-Aft anchor	Port-aft anchor
x coordinate	-10.0	-7.5	0.0	-9.525	4.412	4.412
y coordinate	0.0	0.0	-1.5	0.0	7.655	-7.655
z coordinate	-	-	-	-2.86	-2.86	-2.86

Scaled Model

The device considered in these tests is a 1:70 scale model of the IEA Wind 15-Megawatt Offshore Reference Wind Turbine (IEA-15-240-RWT) (Gaertner, et al. 2020) mounted on the UMaine VolturnUS-S semi-submersible platform (Allen, et al. 2020). NOTE: The geometry of the scale model differs slightly compared to a true scaled-version of the references and the mass properties have been adjusted to retain approximately the correctly scaled reference draft, i.e. 20m at full-scale, in the fresh water basin. The geometry of the rotor-nacelle-assembly (RNA) has not been modelled precisely (as, in cases with wind, the aerodynamic loading on the turbine is included using a hybrid testing system consisting of two on-board drone propellers). Figure 2 shows the key dimensions of the device and the positions of the centre of mass and mooring fairleads in the body-fixed coordinate system. The body-fixed coordinate system is defined with the model upright, i.e. the axis of the tower vertically upwards, the x-axis parallel to a vector from the fore fairlead to the tower axis and the origin at the base of the platform (see Figure 2). The key dimensions of the device and the definition for the body-fixed coordinate system are provided in Figure 2 and summarised, along with the mass properties of the model, in Table 2.

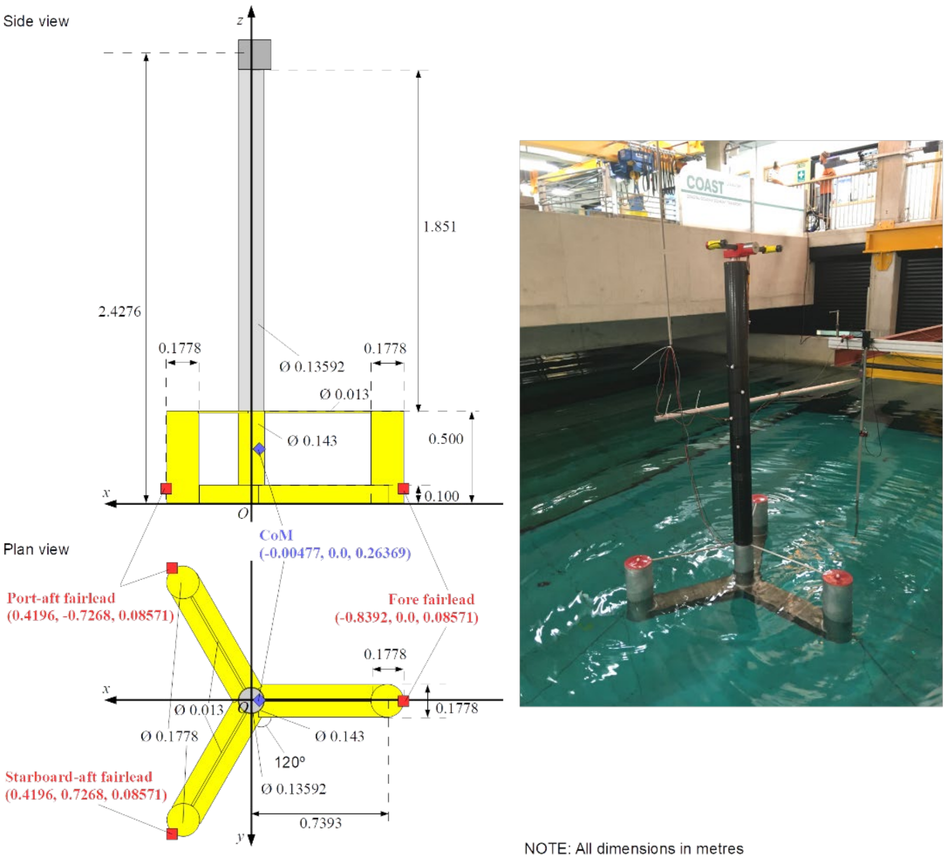

Figure 2: Model dimensions, definition of body-fixed coordinate system and position of CoM and mooring fairleads (in body-fixed system)

Table 2: Key dimensions, mass properties and positions of mooring fairleads in body-fixed coordinate system [see Figure 2]

	Model values
Diameter of central column [m]	0.143
Diameter of outer columns [m]	0.1778
Height of columns [m]	0.500
Distance between central and outer column axes [m]	0.7393
Width of pontoons [m]	0.1778
Depth of pontoons [m]	0.100
Mass [kg]	56.3
CoM position (x, y, z) coordinate [m]	(-0.00477, 0.0, 0.26369)
Ixx [kg m^2]	26.68
Iyy [kg m^2]	26.68
Izz [kg m^2]	14.18
Fore fairlead position (x, y, z) coordinate [m]	(-0.8392, 0.0, 0.08571)
Aft-Port fairlead position (x, y, z) coordinate [m]	(0.4196, -0.7268, 0.08571)
Aft-Starboard fairlead position (x, y, z) coordinate [m]	(0.4196, 0.7268, 0.08571)

Mooring Description

The device is kept on station using a three point mooring system constructed from '3mm long-link' stainless chain. Some links were added in parallel to the chain to achieve the correctly scaled dry line linear density. Due to the finite width of the working region, the laboratory moorings had to be truncated to fit the Ocean Basin. Key details on the mooring properties are given in Table 3 (see Tables 1 and 2 for the anchor and fairlead positions respectively).

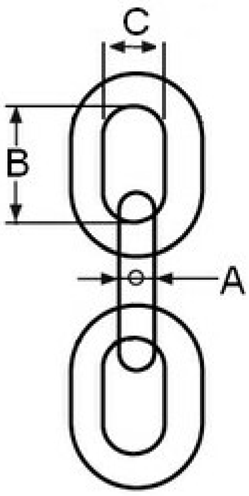

Figure 3: Mooring chain geometry schematic

Table 3: Mooring properties [see Tables 1 and 2 for the anchor and fairlead positions respectively]

	Model values
Fore mooring length [m]	9.685
Aft-starboard mooring length [m]	9.017
Aft-Port mooring length [m]	9.017
Dry mass/length [kg/m]	0.144
Bar diameter (A in Figure 3) [m]	0.00282
B in Figure 3 [m]	0.0263
C in Figure 3 [m]	0.0065
Submerged mass/length [kg/m] (0.872*dry density)	0.125568

Thruster Cable Bundle Description

The thruster cables were not attached for these tests.

Experimental Test Programme (Load Cases)

For the physical model, and set-up, described above, a number of 'load cases' are considered in this comparative study. Initially static equilibrium is considered (both with and without the moorings attached). Due to the complexity of the model/system, particularly the off-centre CoM, these equilibrium cases are deemed necessary to ascertain the equilibrium position/orientation of the model in advance of the dynamic load cases. There are then a series of decay tests considering the heave, surge and pitch degrees of freedom. Finally there are a pair of focused wave interactions with the moored floating structure.

Static Equilibrium

Measurements have been taken with the model at rest. Initially, such a 'static equilibrium' test has been conducted without the mooring system attached (to reduce uncertainty associated with the mooring system parameters/modelling). Then another static equilibrium test has been performed with the moorings attached. For these cases, the position of the centre of mass (in the global coordinate system) and the pitch angle of the model (about the centre of mass) are given in Table 4. For the case with the moorings attached, Table 4 also gives the measured positions of the mooring fairleads (in the global coordinate system) and the measured mooring line tensions (at the fairleads) for the equilibrium position.

Table 4: CoM position (in global coordinate system), model pitch angle (about CoM) and mooring fairlead positions (in global coordinate system) and tensions for static equilibrium load cases with and without the moorings attached

	No moorings	With moorings
FOWT Comparative Study ID	FOWT1_EQ_unmoored	FOWT1_EQ_moored
Equilibrium CoM position [m]	(-0.00477*, 0.0*, -0.00126)	(-0.02038, 0.0, -0.02386)
Equilibrium pitch angle about CoM [°]	-1.729	-1.502
Fore fairlead position (x, y, z) coordinate [m]	n/a	(-0.84956, 0.0, -0.22338)
Aft-Port fairlead position (x, y, z) coordinate [m]	n/a	(0.40880, -0.7268, -0.19065)
Aft-Starboard fairlead position (x, y, z) coordinate [m]	n/a	(0.40880, 0.7268, -0.19065)
Fore mooring line tension (at fairlead) [N]	n/a	7.6
Aft-Port mooring line tension (at fairlead) [N]	n/a	7.2
Aft-Starboard mooring line tension (at fairlead) [N]	n/a	7.2

*values somewhat arbitrary for the unmoored case

Decay tests

The next set of load cases consider decay tests in the three principle degrees of freedom (heave, surge and pitch). Due to the coupled nature of the system no degrees of freedom can be considered in isolation but each decay test is identified by the primary degree of freedom, i.e. the one with the greatest offset from equilibrium.

For each decay test, Table 5 provides the initial vertical/z offset of the centre of mass, the initial horizontal/x offset of the centre of mass and the initial pitch offset about the centre of mass. NOTE: values in Table 5 are offsets relative to the equilibrium position/orientation of the device (with moorings) and it is requested that participants in the Comparative Study perform these decay tests using these offsets relative to their equilibrium position/orientation found in the static equilibrium load case described above. Furthermore, the offsets in the other degrees of freedom have been omitted from Table 5 as, for simplicity, we suggest participants assume these are zero (the true offset in these other degrees of freedom can be found from the physical data if necessary).

Table 5: Initial COM offsets from equilibrium position/orientation for the three decay tests

	Heave Decay	Surge Decay	Pitch Decay
FOWT Comparative Study ID	FOWT1_Decay_heave	FOWT1_Decay_surge	FOWT1_Decay_pitch
Original ID*	Heave_decay_ABP1_3	Surge_decay_ThrIt2_NC_1	Pitch_decay_AW2_2
Initial z offset [m]	-0.1472	-0.0017	-0.0277
Initial x offset [m]	-0.0149	0.3825	-0.0031
Initial pitch offset [°]	0.4719	-0.7657	-9.7980

*for administration only

Focused wave cases

The final load cases in the 1st FOWT Comparative Study consist of a pair of focused wave interactions with the FOWT. The waves are generated using the EDL wave synthesiser and paddle control software. The displacement of the paddles is calculated using linear wave maker theory. 112 'fronts' (components) evenly spaced between frequencies of 0.15 and 2Hz (spacing = 0.05/3 Hz) are supply to the paddle control software based on a theoretical wave description. In these cases, the theoretical wave descriptions are crest-focused (i.e. zero phase at focus location, x_{focus}, at the focus time, φ_{focus}) NewWaves based on the 50 year conditions in the Gulf of Maine (NOAA 44005) and a Pierson-Moskowtiz spectrum. The two waves have similar steepness but vary in terms of the peak frequency, T_p, and the significant wave height, H_s. Both wave cases have a theoretical focus time, t_{focus} = 50s, and a theoretical focus location in the global coordinate system, x_{focus} = 0m, i.e. 17.3m upstream of the wavemakers. The crest amplitude, A_{cr}, for the two wave cases has been calculated according to $A_{cr} = \sqrt{2m_0 \ln 1000}$, where m_0 is the zeroth spectral moment and can be approximated according to $m_0 = \left(\frac{H_S}{4}\right)^2$. Table 6 summarises the theoretical parameters in the wave descriptions used for wave generation in two wave cases. A file containing the parameters describing the 112 fronts in each case (e.g. FOWT1_FW1_fronts.txt) can be found in the 'Resources' section below.

Table 6: Theoretical wave parameters for each of the wave load cases (at laboratory scale – 1:70)

FOWT Comparative Study ID	**FOWT1_FW1**	**FOWT1_FW2**
Original ID*	Benign_Focus_0deg_ThrusterIter2_3	Extreme_Focus_0deg_ThrusterIter2_3
Water depth [m]	2.86	2.86
Theoretical peak period, T_p [s]	1.3831	1.9380
Theoretical significant wave height, H_s [m]	0.069	0.139
Theoretical crest elevation, A_{cr} [m]	0.064	0.127
Theoretical focus location, x_{focus} [m]**	0.0	0.0
Theoretical focus time, t_{focus} [s]	50	50
Theoretical focus phase, φ_{focus} [°]	0	0

*for administration only

**NOTE: x_{focus} given in global coordinate system

As well as the information about the fronts used in the wave generation, an empty tank test (i.e. without the device present) was performed for each of the wave cases. The surface elevation, in these empty tank tests, measured at the positions in Table 7 are available in the 'Resources' section below (e.g. FOWT1_FW1_empty.txt). These wave cases were then repeated with the FOWT initially at rest, in its equilibrium position.

Table 7: Coordinates of wave gauges, in empty tank tests, in global coordinate system (NOTE: all values in metres) [see Figure 1 for coordinate system definition]

	WG1	**WG2**	**WG3**	**WG4**	**WG5**	**WG6**	**WG7**	**WG8**	**WG9**
x coordinate	-10.0	-7.5	0.0	-0.4	-0.2	0	0.2	0.4	0.75
y coordinate	0.0	0.0	-1.5	0	0	0	0	0	0

Physical Measurement Data

The experimental data will be provided according to the details in the submission procedure below.

<u>Decay tests</u>

For the decay tests, the experimental data is provided in an individual text file for each of the cases and is arranged as follows:

- The text files FOWT1_Decay_heave_Experiment.txt; FOWT1_Decay_surge_Experiment.txt, and; FOWT1_Decay_pitch_Experiment.txt contain time series data for the motion and mooring load the three decay tests (FOWT1_Decay_heave; FOWT1_Decay_surge, and FOWT1_Decay_pitch respectively).
- In each file, the first row is a header row (incl. units) and begins with a '%' for (MATLAB) post-processing purposes. From the second row onwards is the time series data
- Column 1 of the data is the time, in seconds, since the release of the structure.
- Columns 2-4 are the x, y and z positions, respectively, of the structure's centre of mass, in the global coordinate system, in metres.
- Columns 5-7 are the rotational displacements of the structure, in degrees, about the body-fixed x, y and z axes (i.e. roll, pitch and yaw) respectively (using the 'right-hand rule').
- Columns 8-10 are the mooring line tensions, in Newtons, at the fairlead position of the fore, port and starboard mooring respectively. The mooring load measurements have been filtered using a zero-phase digital filter based on a twelfth-order low pass IIR Butterworth filter with a normalised 3-dB frequency of 0.005π rad/sample. The mooring load measurements have also been interpolated onto the same time vector as the position/orientation measurements. [NOTE: the starboard mooring data has been omitted due to an issue with the load cell output]

Focused wave cases – incl. the FOWT

For the focused wave cases (including the FOWT), the experimental data is provided in an individual text file for each of the cases and is arranged as follows:

- The text files FOWT1_FW1_Experiment.txt, and; FOWT1_FW2_Experiment.txt, contain time series data for the motion, mooring load and surface elevation measurements for the two focused wave cases (FOWT1_FW1, and FOWT1_FW2 respectively).
- In each file, the first row is a header row (incl. units) and begins with a '%' for (MATLAB) post-processing purposes. From the second row onwards is the time series data
- Column 1 of the data is the time, in seconds, with time = 0s corresponding to the start time of the wave makers.
- Columns 2-4 are the x, y and z positions, respectively, of the structure's centre of mass, in the global coordinate system, in metres.
- Columns 5-7 are the rotational displacements of the structure, in degrees, about the body-fixed x, y and z axes (i.e. roll, pitch and yaw) respectively (using the 'right-hand rule').
- Columns 8-10 are the mooring line tensions, in Newtons, at the fairlead position of the fore, port and starboard mooring respectively. The mooring load measurements have been filtered using a zero-phase digital filter based on a twelfth-order low pass IIR Butterworth filter with a normalised 3-dB frequency of 0.005π rad/sample. The mooring load measurements have also been interpolated onto the same time vector as the position/orientation measurements. [NOTE: the starboard mooring data has been omitted due to an issue with the load cell output]
- Columns 11-13 are the surface elevation measurements, in metres, at WG1, WG2 and WG3 (Figure 1) respectively.

Submission Procedure

To participate in the 1st FOWT Comparative Study we kindly ask participants to submit their simulation data based on the following submission procedure. The 1st FOWT Comparative Study is an 'open' comparative study, i.e. the physical measurements for the test cases are available so participants have the opportunity to compare their results with the experiments in order to help identify potential problems in the numerical implementation etc.

Schedule

The 1st FOWT Comparative Study is being run in conjunction with the ISOPE 2023 conference and the findings of the Study will be presented during a special session at ISOPE 2023. We are presently limiting participation, and release of the physical data, to those contributing to the ISOPE 2023 technical programme, i.e. those submitting papers and presenting their results at ISOPE 2023 (all data will be made publicly available shortly after the Study is complete). It is our intention to contribute to a feature issue of the International Journal of Offshore and Polar Engineering with the papers corresponding to the individual contributions from the participants and a main paper detailing the main findings from the Comparative Study (but individual contribution to the IJOPE feature issue is not mandatory for participation in the Comparative Study). Please note, all participants in the 1st FOWT Comparative Study will be included as co-authors on the main paper. As a result, the schedule follows the schedule of the ISOPE 2023 as below:

19th Oct. 2022	Release of the 1st FOWT Comparative Study description (official start of the Study)
31st Oct. 2022	ISOPE abstract deadline and EoI sent to Edward.ransley@plymouth.ac.uk and L.Qian@mmu.ac.uk *
20th Jan. 2023	ISOPE manuscript (for review) deadline
30th Mar. 2023	ISOPE manuscript final deadline
30th Mar. 2023	Deadline for submission of numerical solutions to the Comparative Study
19-23 June 2023	1st FOWT Comparative Study special session at ISOPE 2023, Ottawa, Canada
31st Aug. 2023	(proposed) Submission of papers (for review) to IJOPE feature issue**
31st Oct. 2023	(proposed) Final submission of papers to IJOPE feature issue*
31st Oct. 2023	Public release of all test case data (official close of the Comparative Study)

*physical measurement data will be supplied to those who have submitted an ISOPE abstract and sent an EoI

**individual contribution to the IJOPE feature issue is not mandatory for participation in the 1st FOWT Comparative Study

Static equilibrium

It is requested that each participant first simulate the FOWT in still water, both with and without the mooring included, until static equilibrium is reached. The information given in Table 4 can be used to position the FOWT close to equilibrium at the beginning of the simulation, however, it should be noted that the mass properties given in Table 2 are given in the body-fixed coordinate system and will need transformation to begin from a rotated position. Alternatively, participants can begin the static equilibrium simulations with the model/tower vertical, however due to relatively low pitch damping the required simulation length is >60s.

For the static equilibrium cases, it is requested that time series data be submitted for the six degrees of freedom motion of the FOWT and the mooring line tensions at the fairleads (in the moored case). For the unmoored static equilibrium case, please submit:

- A single, tab-delimited text file:
  - filename: FOWT1_EQ_unmoored_<institution> (e.g. FOWT1_EQ_unmoored_Plymouth)
  - column 1: Time (in secs, i.e. 0 – 60s, please simulate as much time as necessary)
  - column 2: Horizontal/x-coordinate (surge) of the CoM, in metres, in global coordinate system
  - column 3: Horizontal/y-coordinate (sway) of the CoM, in metres, in global coordinate system
  - column 4: Vertical/z-coordinate (heave) of the CoM, in metres, in global coordinate system
  - column 5: Roll about CoM, in degrees, relative to upright position, i.e. with tower vertical
  - column 6: Pitch about CoM, in degrees, relative to upright position, i.e. with tower vertical
  - column 7: Yaw about CoM, in degrees, relative to upright position, i.e. with tower vertical

For the moored static equilibrium case, please submit:

- A single, tab-delimited text file:
  - filename: FOWT1_EQ_moored_<institution> (e.g. FOWT1_EQ_unmoored_Plymouth)
  - columns 1-7: Same as for unmoored case above
  - columns 8-10: Tension in fore, port and starboard fairleads respectively, in N

Decay tests

As described above, it is requested that each of the decay tests be performed by applying the offsets in Table 5 to the moored equilibrium position/orientation found in the static equilibrium test (described above) [NOTE: roll, sway and yaw are assumed to be zero at time = 0]. Again, please note that the mass properties of the device, given in Table 2, will need to be transformed according to the initial position/orientation of the FOWT.

For each of the decay tests (heave, surge and pitch) it is requested that time series data be submitted for the six degrees of freedom motion of the FOWT and the mooring line tensions at the fairleads. For the analysis we request at least 180s be simulated in each case (but the more time the better) with time = 0s as the 'release' time of the FOWT. For decay test, please submit:

- A single, tab-delimited text file:
  - filename: FOWT1_Decay_<primaryDOF>_<institution> (e.g. FOWT1_Decay_heave_Plymouth)
  - column 1: Time (in secs, i.e. 0 – 180s, please simulate as much time as you can)
  - column 2: Horizontal/x-coordinate (surge) of the CoM, in metres, in global coordinate system
  - column 3: Horizontal/y-coordinate (sway) of the CoM, in metres, in global coordinate system
  - column 4: Vertical/z-coordinate (heave) of the CoM, in metres, in global coordinate system
  - column 5: Roll about CoM, in degrees, relative to upright position, i.e. with tower vertical
  - column 6: Pitch about CoM, in degrees, relative to upright position, i.e. with tower vertical
  - column 7: Yaw about CoM, in degrees, relative to upright position, i.e. with tower vertical
  - columns 8-10: Tension in fore, port and starboard fairleads respectively, in N

Focused wave cases – empty tank

It is requested that, for each of the focused wave cases, a corresponding empty tank simulation is also conducted (with a numerical mesh equivalent to that used in the cases with the structure included) and the data submitted as part of the Study. NOTE: Please remember that the physical measurements from corresponding empty tank experiments are available in the 'Resource' section.

For the empty tank submissions, it is requested that time series data be submitted for surface elevation recorded at the positions of wave gauges 1-9 (see Table 7 for WG positions in empty tank). For each empty tank case please submit:

- A single, tab-delimited text file:
  - filename: <caseID>_empty_<institution> (e.g. FOWT1_FW1_empty_Plymouth)
  - column 1: Time (in secs relative to beginning of empty tank data, i.e. 0 – 64s)
  - columns 2-10: Surface elevation measurements (in metres)
    - WG 1, 2, 3, 4, 5, 6, 7, 8, 9

Focused wave cases – incl. the FOWT

For the focused wave cases including the FOWT structure, it is requested that time series data be submitted according to the following:

- A single, tab-delimited text file:
    - filename: <caseID>_<institution> (e.g. FOWT1_FW1_Plymouth)
    - column 1: Time (in secs relative to beginning of empty tank data, i.e. 0 – 64s)
    - column 2: Horizontal/x-coordinate (surge) of the CoM, in metres, in global coordinate system
    - column 3: Horizontal/y-coordinate (sway) of the CoM, in metres, in global coordinate system
    - column 4: Vertical/z-coordinate (heave) of the CoM, in metres, in global coordinate system
    - column 5: Roll about CoM, in degrees, relative to upright position, i.e. with tower vertical
    - column 6: Pitch about CoM, in degrees, relative to upright position, i.e. with tower vertical
    - column 7: Yaw about CoM, in degrees, relative to upright position, i.e. with tower vertical
    - columns 8-10: Tension in fore, port and starboard fairleads respectively, in N
    - columns 11-13: Surface elevation measurements (in metres)
        - WG 1, 2, 3

Relevant references

The details, and all corresponding physical data, for the 1st FOWT Comparative Study are published by the University of Plymouth and deposited in the PEARL Research Repository (under embargo until completion of the 1st FOWT Comparative Study) with the citation and doi:

Ransley, E., Brown, S., Edwards, E., Tosdevin, T., Monk, K., Reynolds, A., Greaves, D., Hann, M. (2022). "Hydrodynamic response of a floating offshore wind turbine (1st FOWT Comparative Study Dataset)". PEARL Research Repository. https://doi.org/10.24382/71j2-3385

We request that contributions to the 1st FOWT Comparative Study special session at ISOPE 2023 use this as the present source of the test case description and physical data. Once published, citation of the main paper (presenting the findings from the study) will also be expected when using this data.

Allen, C., Viselli, A., Dagher, H., Goupee, A., Gaertner, E., Abbas, N., Hall, M. and Barter, G. (2020). "Definition of the UMaine VolturnUS-S Reference Platform Developed for the IEA Wind 15-Megawatt Offshore Reference Wind Turbine". *Golden, CO: National Renewable Energy Laboratory*. NREL/TP-5000-76773. https://www.nrel.gov/docs/fy20osti/76773.pdf

Gaertner, E., Rinker, J., Sethuraman, L., Zahle, F., Anderson, B., Barter, G., Abbas, N., Meng, F., Bortolotti, P., Skrzypinski, W., Scott, G., Feil, R., Bredmose, H., Dykes, K., Shields, M., Allen, C., and Viselli, A. (2020). "Definition of the IEA 15-Megawatt Offshore Reference Wind". *Golden, CO: National Renewable Energy Laboratory*. NREL/TP-5000-75698. https://www.nrel.gov/docs/fy20osti/75698.pdf

Resources

Accompanying documents:

filename	Description
FOWT1_FW1_fronts.txt	Wave fronts supplied to wave maker for wave generation in FOWT1_FW1 (and FOWT1_FW1_empty); tab-delimited text file (lines 1-3 – headers; column 1 – frequency (Hz); column 2 – amplitude (m); column 3 – angle (rad); column 4 – phase (rad)
FOWT1_FW2_fronts.txt	Wave fronts supplied to wave maker for wave generation in FOWT1_FW2 (and FOWT1_FW2_empty); tab-delimited text file (lines 1-3 – headers; column 1 – frequency (Hz); column 2 – amplitude (m); column 3 – angle (rad); column 4 – phase (rad)
FOWT1_FW1_empty.txt	Empty tank test surface elevation data and paddle displacement for FOWT1_FW1 wave case (and FOWT1_FW1_empty); tab-delimited text file (line 1 - header; column 1 – Time (s); columns 2-10 – surface elevation at wave gauges WG1-WG9 (m)); column 11 – paddle displacement (flap-type) in degrees
FOWT1_FW2_empty.txt	Empty tank test surface elevation data and paddle displacement for FOWT1_FW2 wave case (and FOWT1_FW2_empty); tab-delimited text file (line 1 - header; column 1 – Time (s); columns 2-10 – surface elevation at wave gauges WG1-WG9 (m)) ; column 11 – paddle displacement (flap-type) in degrees