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FPP Marinet2 Tests at Oceanide

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1. Introduction

On July 7th 2017 Floating Power Plant (FPP) received acceptance of a Marinet 2 Phase 1 application with project acronym "FPPMarinet2_MIV_hex" to perform 15 days of testing at the facility Oceanide in France.

The aim of the tests campaign is to obtain data from physical tests to validate FPP's multi-body numerical model for the interaction between the semisubmersible, which moves with 6 Degrees of Freedom (DoF), and the pitching WEC, which moves with 1 DOF.

The platform had up to 6 DoF (depending on the test) to be controlled by the hexapod.

Analysis of experimental measurements will provide coefficients used in models such as wave excitation, wave radiation, motion RAO, power performance coefficients, etc.

This present document is the Model Platform Tests Report including the scope of testing, a description of the model, of its instrumentation and of data that have been recorded.

1.1 FPP Development So Far

Floating Power Plant is the developer of the world's first floating wind platform with integrated Wave Energy Convertors (WECs). FPP successfully offshore tested a 37-m-wide grid connected device in the benign waters of Denmark for 4 tests phases across a 4-year period. FPP's first commercial device will be the P80, an 80-100-m-wide platform designed for the energetic waters of the UK. In order to design the commercial device, advanced numerical models need to be developed in order to accurately predict the loads and motions under the influence of waves, wind and current. As the industry is in its infancy, there is no validated commercial software available that can model FPP's technology (which includes very closely spaced interacting bodies). FPP work's together with partners to develop and validate the necessary numerical models. Key to the model development, is accurate physical test data for simplified cases. The final numerical model will be a hydro-aeroelastic model comprising a wind turbine, a semisubmersible platform, a turret mooring system, and 4 WECs each pitching relative to the semi-submersible platform.

Considering the hydrodynamic modelling without the turbine, already presents a case beyond the current state of the art in numerical modelling. This is because FPP's device is specifically designed to have large interactions between the WECs and platform, using a unique geometry and very small gaps between interacting bodies.

Care is therefore taken to develop and validate the hydrodynamic part of the model in stages, with each stage introducing an extra level of complexity. The validation is performed using experimental tests at small scale in wave basins so that the waves are controlled and known in great detail allowing for accurate numerical model validation.

FPP has to date performed a series of wave flume, wave basin and PTO dry tests to develop the technology and provide the basis for the first versions of the numerical models.

Note that in order to develop the models and design the P80 device, FPP is going back into wave basins and flumes to obtain small scale results for model validation, despite having previously progressed to full scale offshore sea trials (at a benign site) for concept validation.

The following phases are established for the completion of the hydrodynamic model development of the FPP commercial design.

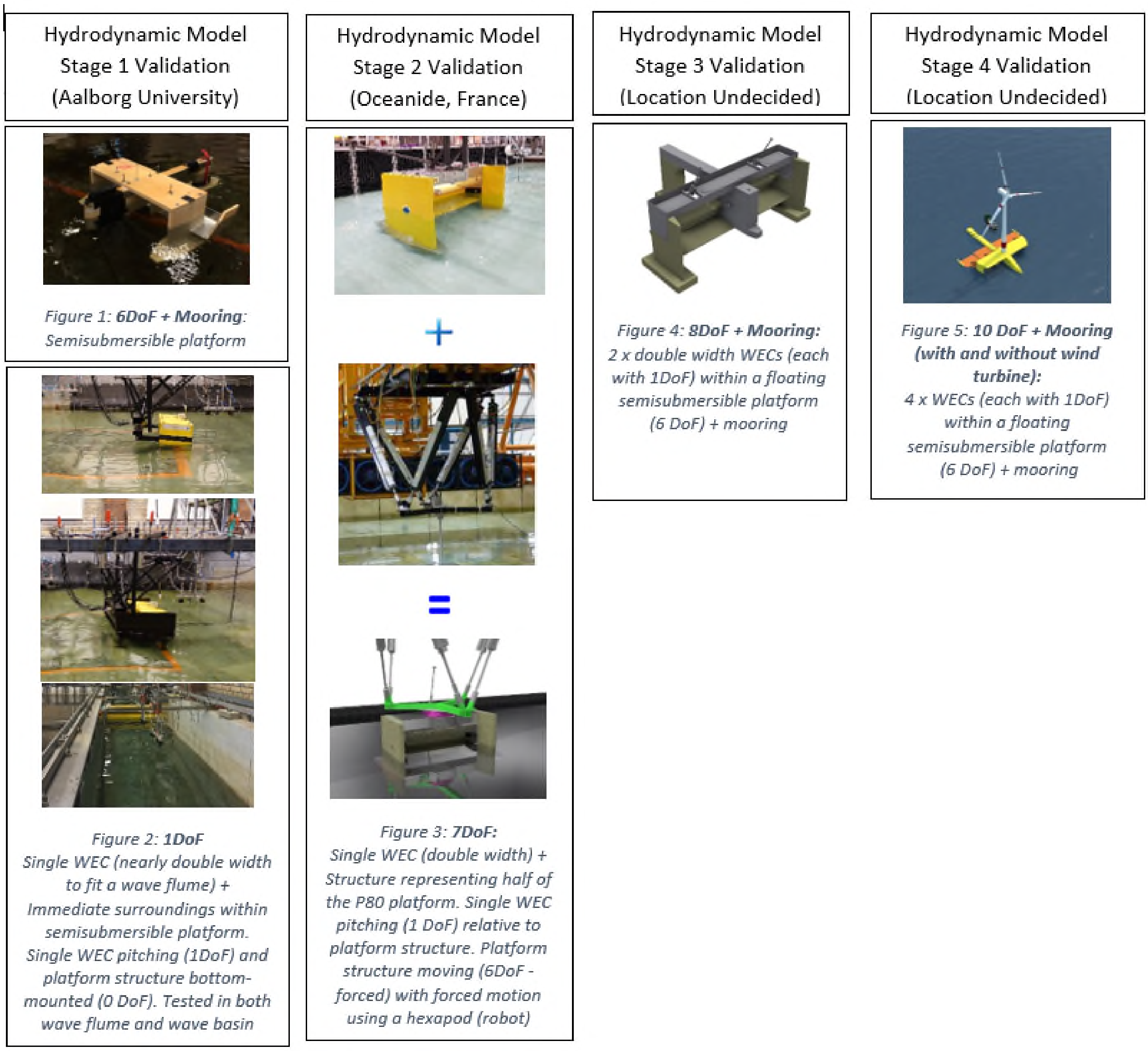


Figure 1: Plan for FPP Hydrodynamic Model Development and Validation

2. Conventions

2.1 Abbreviations

- DOF Degree of Freedom
- FPP Floating Power Plant AS or its affiliates LTD(UK), NUF(NO)
- OCD OCEANIDE

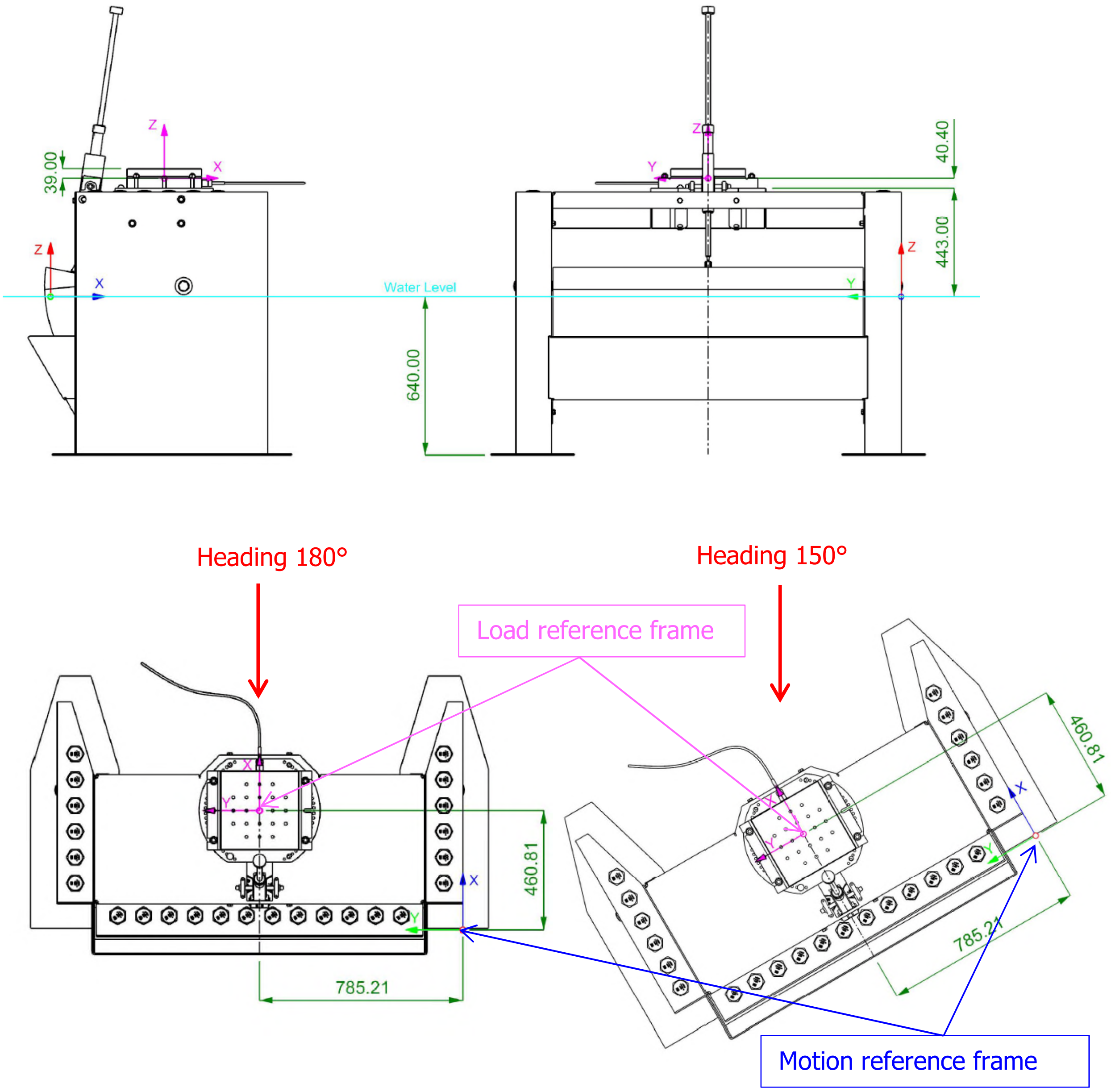
- Hs Significant wave height
- TP Peak period in wave spectrum
- PTO Power Take-Off
- WA Wave Absorber
- WEC Wave Energy Converter
- DAQ OCEANIDE Data Acquisition system

2.2 Definitions

- Actuator (PTO Actuator): The assimilated PTO test rig which absorbs and transfer force from the Model Platform onto the Wave Absorber as dampening in the equation of motion.
- Bottom Plate: Part of Platform which forms the lower structure of the Wave Absorber enclosure. Increases the WA efficiency. See also Spoiler.
- Infrastructure The facility (BGO FIRST) where the tests are performed.
- Model Platform (MPLF): Constitutes the scaled portion of the P80 unit which in this test covers port side section of the P80 platform (from centreline to full breadth) entailing the width of two absorbers, half centre hull section (with centre hull port side wall) and the port side pontoon (less port side partition section). Also described as the Wave Absorber enclosure.
- Partition Section (Stb/Port): Vertical section of the P80 Platform subdividing the inner from the outer Wave Absorber on starboard and port side.
- Platform (PLF): Constitutes the entire floating P80 device intended to carry wind turbine generator and wave energy converters for power production.
- Power Take-Off (PTO): Part of WEC system which transforms Wave Absorber motion into electric power by use of hydraulic pistons, hydraulically driven electric generator and an associated power control system.

2.3 Reference frames

The reference frames used for loads and motions measurements are shown on the following sketch.



sketch 1: Reference frames

3. Scope of testing

The test series has been comprised of:

- Waves calibration without the model
- Check of force and motions measurements
- Check of hexapod displacements
- Slow motion tests with hexapod
- Radiation tests (moving platform with hexapod)
- Tests in waves with fixed platform and with fixed or moving absorber
- Tests in waves with moving platform 1Dof or multi Dof and with fixed or moving absorber

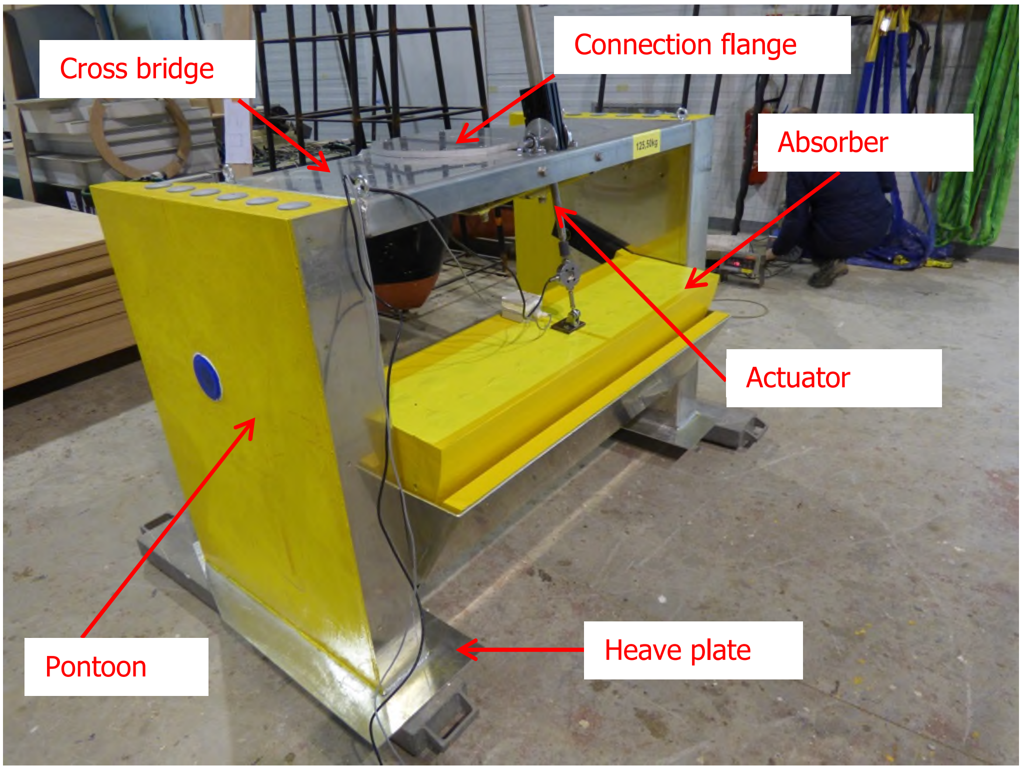
Several PTO damping have been tested for the actuator controlling the waves absorber.

4. Model description

The water depth in the basin was set to 3.333 m.

4.1 Platform Model

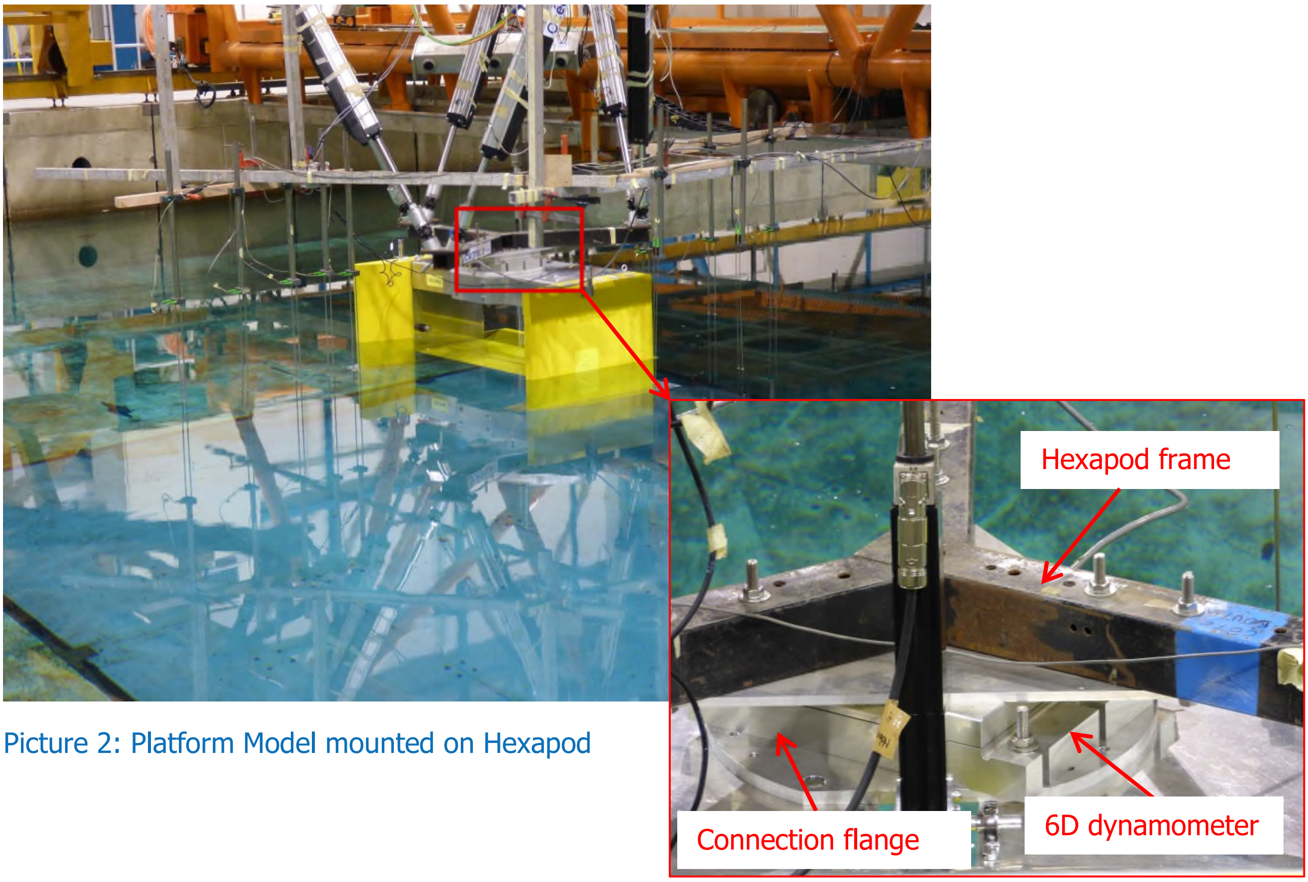
The model has been provided by FPP. It represents one half of a 1:30 scaled P80 device, modified to contain only 1 WEC instead of 2. It briefly consists of a structure representative of the semi-submersible (the "platform" from herein), a wave absorber, and a PTO system. The wave absorber has moved in a single degree of freedom, pitch, relative to the platform. A linear electrical actuator is supported by the platform applying loads to the absorber representative of the PTO system for the WEC.



Picture 1: Platform Model

4.2 Hexapod

The platform model was fixed to the hexapod and the 6D force sensor thanks to the connection flange.



Picture 2: Platform Model mounted on Hexapod

5. Instrumentation

All OCEANIDE sensors were recorded on the Oceanide DAQ system. Two trigger signals for data synchronization were used: one at the start of Oceanide data acquisition which was sent to the FPP system, and one at the wave maker start (if any) which was stored in the Oceanide file. All Oceanide measurements were given to FPP in one data set for each test.

In additional to the data logging, Oceanide also recorded video of most tests. The video recordings were started using the trigger signal.

5.1 FPP sensors

Floating Power Plant had its own data acquisition system for the 2 water level sensors, the electrical actuator and the PTO control system. Synchronization to the signals recorded by OCD was ensured by recording a trigger sent from the DAQ.

5.2 Oceanide sensors

Oceanide has provided the following sensors:

- 3 markers fixed on the model for the 6D platform motions
- 1 marker fixed on the absorber for the 3D absorber motions (see Picture 4)
- A 6D dynamometer to measure the loads between hexapod and the model
- 12 Wave probes to measure the water elevation in basin
- 1 HD video camera to witness all the tests

1.1.1 Motions measurements

The KRYPTON RODYM DMM System performs the motion measurements of the platform model in the 6 degrees of freedom. This contactless tracking system is based on infrared cameras aiming at infrared active markers located on the model. A fourth marker is used to measure the 3 coordinates (x,y,z) of a point on the absorber (see Picture 4), given in the reference frame.

The motions are expressed at reference frames given on sketch *1* for both headings 180° and 150°.

1.1.2 Loads measurements

The loads (Fx, Fy, Fz, Mx, My and Mz) are measured thanks to a 6D dynamometer fixed between platform connection flange and hexapod frame (see Picture 2). The loads reference frame is given on sketch *1*. It was the same for both headings.

1.1.3 Wave probes

Wave probes (see Picture 3) have been used to measure the waves elevation:

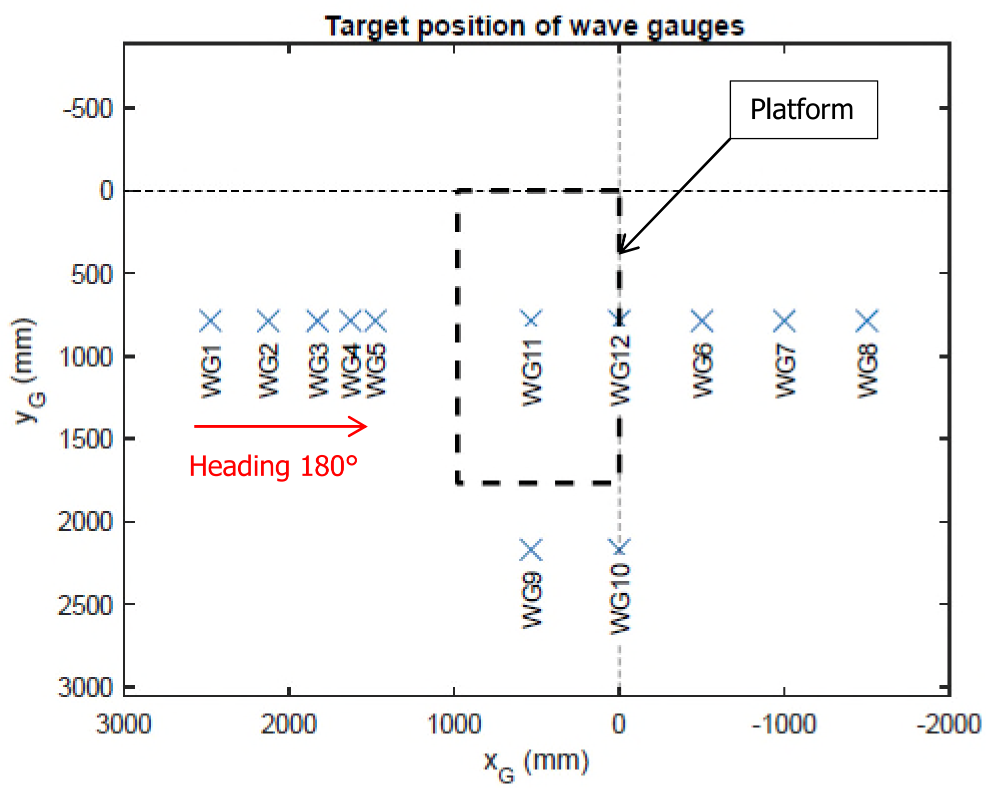
- 12 for waves calibration (including 7 wave probes for incident waves separation)
- 10 for tests with platform.

Their actual locations are given in Table 1 in the motion reference frame at heading 180° as the target locations are illustrated on sketch 2. The locations of the 10 wave probes used for tests with platform didn't change at heading 150°.

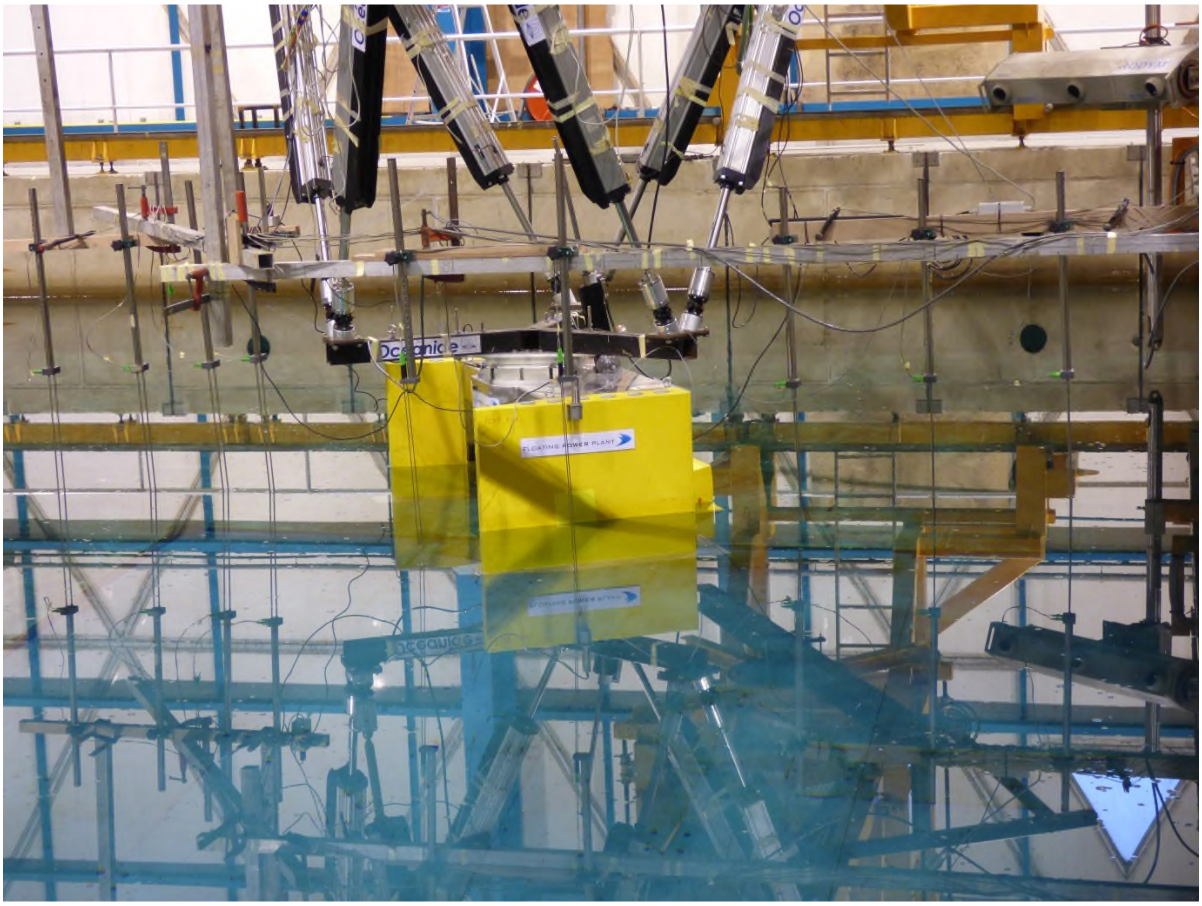
The wave probe n°5 (WG5) has been removed for the tests from 11th December to 14th December to allow the hexapod displacements.

	Waves calibration		Tests with Platform	
	XG	YG	XG	YG
WG1	2413	785	2416	785
WG2	2056	785	2054	785
WG3	1761	785	1764	785
WG4	1570	785	1567	785
WG5	1408	785	1412	785
WG6	-554	785	-560	785
WG7	-1060	785	-1062	785
WG8	-1550	785	-1545	785
WG9	486	2055	488	2050
WG10	-139	2055	-38	2050
WG11	486	897	-	-
WG12	-139	785	-	-

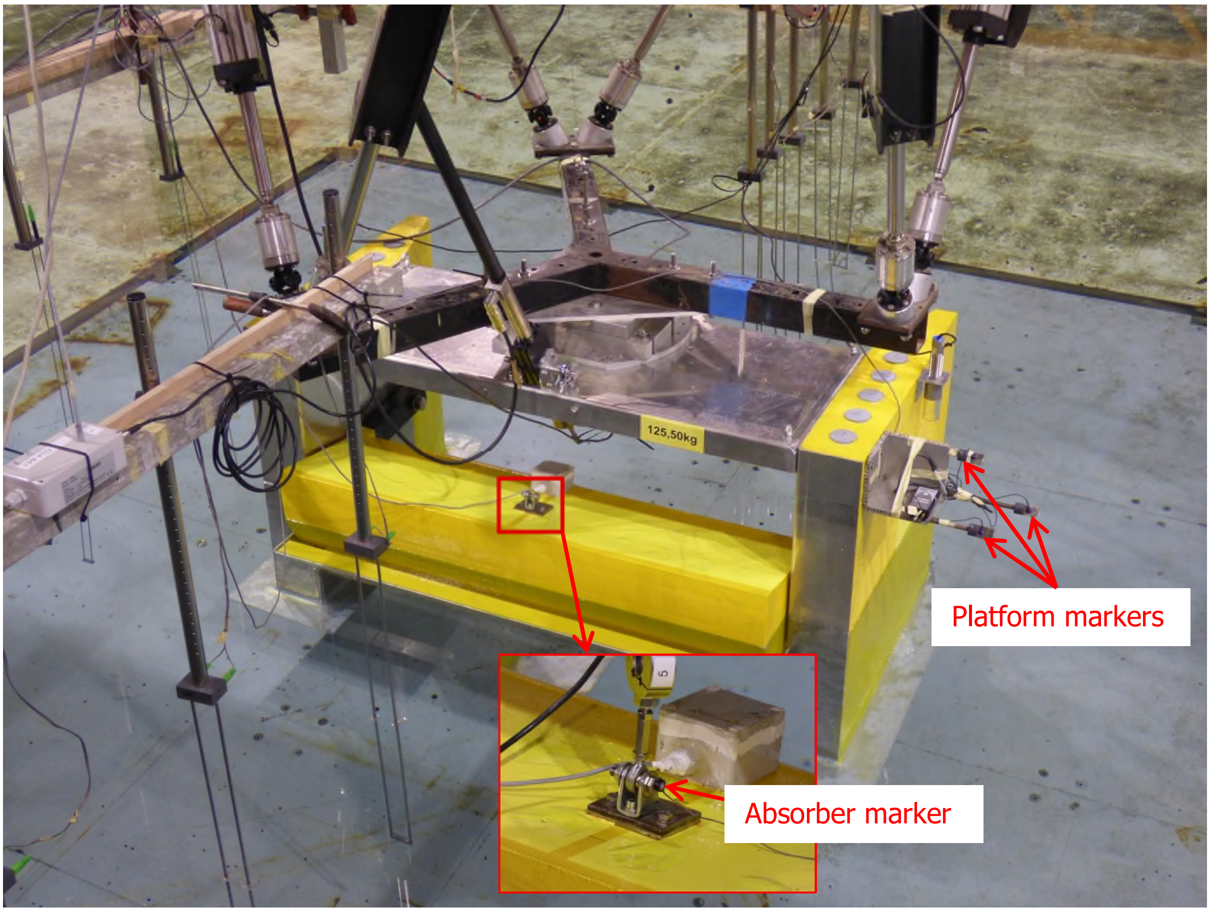
Table 1: Wave probes locations. Measures in mm.



sketch 2: Wave probes location



Picture 3: Wave probes



Picture 4: Markers for motion measurements

6. Tests procedure

6.1 Waves calibration

The sea states have been calibrated without the platform model in the basin. The 7 wave probes (WG1, WG2, WG3, WG4, WG5, WG11 and WG12) have been used for the incident waves separation. The incident waves time series are reconstructed at the location of wave gage n°1: WG1.

6.2 Check tests

Some check tests have been performed at the beginning of the tests campaign to check the loads and motions measurements.

The loads measurements have been checked using a force sensor and pulling on given points of the platform model except for vertical load (Fz) for which lead masses have been put on the platform top.

The motions measurements have been checked thanks to the hexapod to give a motion and controlled by a ruler for translations or by an inclinometer for rotations.

6.3 Static tests

Static tests have been performed to record the different sensors values at rest and to check values after heading change. The test duration is of 30 s.

6.4 Hydrostatic tests

The hydrostatic tests are performed doing very slow motion (T=120s) in calm water to quantify the hydrostatic contribution. The test sequence is defined below:

- t=0 s: Start of OCD data acquisition
- t=~30 s: Start of hexapod trajectory
- the tests duration is given in Table 5

6.5 Decay tests

A decay test has been performed by moving the absorber from its free position with its actuator and then releasing the controlled force in the actuator to let the absorber in free condition. This procedure has been repeated 6 times during the test alternating up and down motion of the absorber. The test sequence is defined below:

- t=0 s: Start of OCD data acquisition
- t=~30 s: Start of the test
- the test duration is of 1500 s

6.6 Waves tests

The waves tests are performed with fixed platform in waves. The test sequence is defined below:

- t=0 s: Start of OCD data acquisition
- t=~30 s: Start of wave makers
- the tests duration are given in Table 7

6.7 Hexapod tests

The hexapod tests are performed in calm water with hexapod playing time series for single or combined motions and for harmonic or white noise type (for a given frequency interval) oscillations. The test sequence is defined below:

- t=0 s: Start of OCD data acquisition
- t=~30 s: Start of hexapod trajectory
- the tests duration are given in Table 8

6.8 Waves and hexapod tests

The waves and hexapod tests combine imposed motions by hexapod and waves. The synchronization between the two is done in the motion time series generation, using the trigger signal for the wave maker start. The test sequence is defined below:

- t=0 s: Start of OCD data acquisition
- t=~30 s: Start of wave makers and hexapod trajectory
- the tests duration are given in Table 9 and Table 10

7. Tests list

7.1 Waves calibration tests

The waves calibration are given in the following table.

Oceanide DAQ file	Wave name	Wave type	Waves Tp / T (s)	Waves Hs / H (m)	Wave maker file
28110951.a17	IRR	Jonswap spectrum (γ=1.5)	1.70	0.060	fpp_h060t170_c1
28111132.a17	WN	White Noise	0.75 - 3.00	0.060	fpp_h060t000_c1
28111330.a17	REG1	Regular waves	3.00	0.100	fpp_a040t300
28111241.a17	REG2	Regular waves	2.85	0.100	fpp_a036t285
28111353.a17	REG3	Regular waves	2.70	0.100	fpp_a058t270
28111423.a17	REG4	Regular waves	2.55	0.100	fpp_a057t255
28111455.a17	REG5	Regular waves	2.40	0.100	fpp_a051t240
28111535.a17	REG6	Regular waves	2.25	0.100	fpp_a053t225
28111550.a17	REG7	Regular waves	2.10	0.100	fpp_a050t210
28111620.a17	REG8	Regular waves	1.95	0.100	fpp_a045t195
28111654.a17	REG9	Regular waves	1.80	0.100	fpp_a042t180
29110826.a17	REG10	Regular waves	1.65	0.085	fpp_a032t165
29110906.a17	REG11	Regular waves	1.50	0.070	fpp_a024t150
29110934.a17	REG12	Regular waves	1.35	0.057	fpp_a018t135
29110957.a17	REG13	Regular waves	1.20	0.045	fpp_a013t120
29111030.a17	REG14	Regular waves	1.05	0.040	fpp_a010t105
29111049.a17	REG15	Regular waves	0.90	0.040	fpp_a009t090
29111106.a17	REG16	Regular waves	0.75	0.040	fpp_a008t075

Table 2: Waves calibration

7.2 Check tests

The check tests performed before the start of the campaign are given in the following table.

Oceanide DAQ file	Check
30111438.a17	Load - Fx
30111425.a17	Load - Fy
30111456.a17	Load - Fz
30111456.a17	Load - Mx
30111456.a17	Load - My
30111448.a17	Load - Mz
30111212.a17	Motion - X
30111212.a17	Motion - Y
30111212.a17	Motion - Z
30111212.a17	Motion - Roll
30111212.a17	Motion - Pitch

Table 3: Check tests

7.3 Static tests

Static tests are given in table below.

Oceanide DAQ file	Absorber	Heading	Motion reference frame
13121421.a17	free	150°	180°
13121627.a17	free	150°	150°
05121348.a17	free	180°	180°

Table 4: Static tests

7.4 Hydrostatic tests

Hydrostatic tests are given in table below.

			Hexapod				
Oceanide DAQ file	Absorber	Heading	Motion DoF	Period	Single amplitude	Duration (s)	Tracking file
30111725.a17	none	180 deg	Heave	120 s	0.1 m	240 s	fpp_heave_120s_100mm
30111736.a17	none	180 deg	Pitch	120 s	3 deg	240 s	fpp_pitch_120s_3deg
05121455.a17	slow motion (T=120s)	180 deg	-	-	-	200 s	-
05121514.a17	free	180 deg	Heave	120 s	0.1 m	240 s	fpp_heave_120s_100mm
05121536.a17	free	180 deg	Pitch	120 s	3 deg	240 s	fpp_pitch_120s_3deg

Table 5: Hydrostatic tests

7.5 Decay tests

A decay test has been performed for the absorber (see table below).

Oceanide DAQ file	Absorber	Heading	Duration
13121107.a17	controled	150 deg	1500 s

Table 6: Decay tests

7.6 Waves tests

The waves tests are described in the table here after.

Oceanide DAQ file	Absorber	Heading	Waves: Name	Tp / T (s)	Hs / H (m)	Duration	Wave maker file
01121013.a17	none	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1
04121158.a17 (*)	without actuator	180 deg	IRR	1.70 s	0.060 m	600 s	fpp_h060t170_c1
04121230.a17 (*)	without actuator	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1
04121346.a17 (*)	without actuator	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300
04121417.a17 (*)	without actuator	180 deg	REG2	2.85 s	0.100 m	285 s	fpp_a036t285
04121439.a17 (*)	without actuator	180 deg	REG3	2.70 s	0.100 m	270 s	fpp_a058t270
04121525.a17 (*)	without actuator	180 deg	REG8	1.95 s	0.100 m	195 s	fpp_a045t195
04121627.a17	without actuator	180 deg	REG8	1.95 s	0.100 m	195 s	fpp_a045t195
04121654.a17	without actuator	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210
06120938.a17	controled (increasing PTO damping)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300
06121020.a17	controled (increasing PTO damping)	180 deg	REG3	2.70 s	0.100 m	270 s	fpp_a058t270
06121049.a17	controled (increasing PTO damping)	180 deg	REG5	2.40 s	0.100 m	240 s	fpp_a051t240
06121119.a17	controled (increasing PTO damping)	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210
06121153.a17	controled (increasing PTO damping)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180
06121215.a17	controled (increasing PTO damping)	180 deg	REG11	1.50 s	0.070 m	150 s	fpp_a024t150
06121415.a17	controled (increasing PTO damping)	180 deg	REG13	1.20 s	0.045 m	120 s	fpp_a013t120
06121440.a17	controled (increasing PTO damping)	180 deg	REG15	0.90 s	0.040 m	90 s	fpp_a009t090
06121632.a17	controled (decreasing PTO damping)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180
06121647.a17	controled (decreasing PTO damping)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180
06121744.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	72 s	fpp_a042t180_40T
06121802.a17	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	120 s	fpp_a040t300_40T
07120920.a17	controled (cc=200)	180 deg	REG3	2.70 s	0.100 m	108 s	fpp_a058t270_40T
07120945.a17	controled (cc=150)	180 deg	REG5	2.40 s	0.100 m	96 s	fpp_a051t240_40T
07121045.a17	controled (cc=200)	180 deg	REG7	2.10 s	0.100 m	84 s	fpp_a050t210_40T
07121106.a17	controled (cc=300)	180 deg	REG11	1.50 s	0.070 m	60 s	fpp_a024t150_40T
07121145.a17	controled (cc=100)	180 deg	REG13	1.20 s	0.045 m	48 s	fpp_a013t120_40T
07121200.a17	controled (cc=100)	180 deg	REG15	0.90 s	0.040 m	36 s	fpp_a009t090_40T
07121311.a17	controled (cc=200)	180 deg	IRR	1.70 s	0.060 m	600 s	fpp_h060t170_c1
07121401.a17	controled (cc=200)	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1
13120912.a17	fixed	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300
13120929.a17 (**)	fixed	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210
13121015.a17	fixed	180 deg	REG13	1.20 s	0.045 m	120 s	fpp_a013t120
13121034.a17	fixed	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1
13121632.a17	fixed	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300
13121651.a17	fixed	150 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210
13121705.a17	fixed	150 deg	REG13	1.20 s	0.045 m	120 s	fpp_a013t120
13121724.a17	fixed	150 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1
14120900.a17	controled (sweep)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300
14120921.a17	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300
14120936.a17	controled (cc=200)	150 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1
14121819.a17	free	150 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180

(*) : For these tests, FPP let the actuator against the hexapod frame when mounting the absorber that could distort the loads measurements

(**): For this test, Actuator gave up (overload) after some time. First part of time series is OK, although the actuator clearly struggles to resist the motion.

Table 7: Waves tests – Heading 180°

7.7 (Waves and) hexapod tests

The hexapod tests are described on Table 8.

The waves and hexapod tests are given in Table 9 for heading 150° and in Table 10 for heading 180°.

			Hexapod				
Oceanide DAQ file	Absorber	Heading	Motion DoF	Period	Single amplitude	Duration (s)	Tracking file
01120948.a17	none	180 deg	Heave	2.1 s	0.056 m	100 s	fpp_heave_a056t210
05121615.a17	fixed	180 deg	Heave	2.1 s	0.056 m	100 s	fpp_heave_a056t210
05121629.a17	free	180 deg	Heave	2.1 s	0.056 m	100 s	fpp_heave_a056t210
12120949.a17	free	180 deg	Heave	0.75 s - 3.00 s	0.06 m	600 s	FPP_HEX_180Heave_WN_201712101342
12121007.a17	controled (cc=200)	180 deg	Heave	0.75 s - 3.00 s	0.06 m	600 s	FPP_HEX_180Heave_WN_201712101342
12121030.a17	fixed	180 deg	Heave	0.75 s - 3.00 s	0.06 m	600 s	FPP_HEX_180Heave_WN_201712101342
12121048.a17	free	180 deg	Heave	3.0 s	0.06 m	300 s	FPP_HEX_180Heave_REG1_201712101342
12121058.a17	controled (cc=200)	180 deg	Heave	3.0 s	0.06 m	300 s	FPP_HEX_180Heave_REG1_201712101342
12121328.a17	controled (sweep)	180 deg	Heave	3.0 s	0.06 m	300 s	FPP_HEX_180Heave_REG1_201712101342
12121116.a17	free	180 deg	mDoF (combined surge, pitch)	0.75 s - 3.00 s	0.06 m	600 s	FPP_HEX_180mDoF_WN_201712111112
12121135.a17	controled (cc=200)	180 deg	mDoF (combined surge, pitch)	0.75 s - 3.00 s	0.06 m	600 s	FPP_HEX_180mDoF_WN_201712111112
12121158.a17	fixed	180 deg	mDoF (combined surge, pitch)	0.75 s - 3.00 s	0.06 m	600 s	FPP_HEX_180mDoF_WN_201712111112
12121222.a17	free	180 deg	mDoF (combined surge, pitch)	3.0 s	0.06 m	300 s	FPP_HEX_180mDoF_REG1_201712111112
12121237.a17	controled (cc=200)	180 deg	mDoF (combined surge, pitch)	3.0 s	0.06 m	300 s	FPP_HEX_180mDoF_REG1_201712111112
14121008.a17 (*)	fixed	150 deg	6DoF (1 DoF at a time)	2.1 s	0.05 m & 5 deg	6 x 21 s	FPP_HEX_6xSingleDof_A_201712140923
14121036.a17	fixed	150 deg	6DoF (1 DoF at a time)	2.1 s	0.05 m & 5 deg	6 x 21 s	FPP_HEX_6xSingleDof_B_201712141013
14121103.a17	fixed	150 deg	6DoF (1 DoF at a time)	2.1 s	0.02 m & 2 deg	6 x 21 s	FPP_HEX_6xSingleDof_C_201712141042
14121123.a17	fixed	150 deg	6DoF (1 DoF at a time)	3.0 s	amplitudes as for Reg1	6 x 30 s	FPP_HEX_6xSingleDof_D_201712141106

(*): Specified motion in surge, sway,heave,roll,pitch,yaw (one dof at a time). Wrong phase of surge/sway and roll/pitch i version A (rotation transformation by -30 degrees)

Table 8: Hexapod tests

			Waves					Hexapod			
Oceanide DAQ file	Absorber	Heading	Name	Tp / T (s)	Hs / H (m)	Duration	Wave maker file	Motion DoF	Period	Single amplitude	Tracking file
14121150.a17 (*)	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Heave	time serie as for REG1		FPP_HEX_150Reg1Heave_Reg01_201712141136
14121220.a17	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Heave	time serie as for REG1		FPP_HEX_150Reg1Heave_Reg01_201712141211
14121337.a17 (**)	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Surge	time serie as for REG1		FPP_HEX_150Surge_Reg01_201712141327
14121416.a17	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Surge	time serie as for REG1		FPP_HEX_150Surge_Reg01_201712141355
14121435.a17	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Roll	time serie as for REG1		FPP_HEX_150Roll_Reg01_201712141358
14121505.a17	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Pitch	time serie as for REG1		FPP_HEX_150Pitch_Reg01_201712141358
14121526.a17	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	mDoF (combined surge, pitch)	time serie as for REG1		FPP_HEX_150mDoF_Reg01_201712141407
14121548.a17	controled (cc=200)	150 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1	mDoF (combined surge, pitch)	time serie as for WN		FPP_HEX_150mDoF_WN_201712141409
14121610.a17	controled (cc=200)	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	mDoF (combined all 6 DoF)	time serie as for REG1		FPP_HEX_150NoWDmDoFall_Reg01_201712141440
14121630.a17	controled (cc=200)	150 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1	mDoF (combined all 6 DoF)	time serie as for WN		FPP_HEX_150NoWDmDoFall_WN_201712141441
14121655.a17	free	150 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	mDoF (combined all 6 DoF)	time serie as for REG1		FPP_HEX_150NoWDmDoFall_Reg01_201712141440
14121716.a17	free	150 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	mDoF (combined all 6 DoF)	time serie as for REG9		FPP_HEX_150NoWDmDoFall_Reg09_201712141627
14121751.a17	free	150 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	mDoF (combined all 6 DoF)	time serie as for REG9		FPP_HEX_150NoWDsurge_Reg09_201712141739
14121804.a17	free	150 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	mDoF (combined all 6 DoF)	time serie as for REG9		FPP_HEX_150NoWDheave_Reg09_201712141739
14121832.a17	free	150 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	mDoF (combined all 6 DoF)	time serie as for REG9		FPP_HEX_150NoWDroll_Reg09_201712141740

(*) : For this test, Wrong input of waves to calculated motion (was specified in global coordinate system, and the platform origin was moved in x when it was rotated)
(**): Wrong input (both surge and sway in motion, as hexaspod was only moving in surge)

Table 9: Waves and hexapod tests – Heading 150°

			Waves					Hexapod			
Oceanide DAQ file	Absorber	Heading	Name	Tp / T (s)	Hs / H (m)	Duration	Wave maker file	Motion DoF	Period	Single amplitude	Tracking file
07121527.a17	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Heave	3.06	0.059	fpp_heave_a059t306
07121613.a17	controled (cc=200)	180 deg	REG3	2.70 s	0.100 m	270 s	fpp_a058t270	Heave	2.75	0.068	fpp_heave_a068t275
07121755.a17	controled (cc=200)	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210	Heave	2.1	0.057	fpp_heave_a056t210
07121730.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	Heave	1.84	0.015	fpp_heave_a015t184
08121028.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	Heave	1.8	0.015	fpp_heave_a015t180_del29s69
08121107.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	Heave	1.8	0.015	fpp_heave_a015t180_del29s865
08121157.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	Heave	1.8	0.015	fpp_heave_a015t180_del30s315
08121231.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	Heave	1.8	0.015	fpp_heave_a015t180_del30s765
08121413.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	Heave	1.8	0.015	fpp_heave_a015t180_del31s215
08121652.a17	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Heave	time serie as for REG1		FPP_HEX_Heave_Reg1_201712081643
11120943.a17	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Heave	time serie as for REG1		FPP_HEX_180Heave_REG1_201712101342
11121037.a17	controled (cc=200)	180 deg	REG3	2.70 s	0.100 m	270 s	fpp_a058t270	Heave	time serie as for REG3		FPP_HEX_180Heave_REG3_201712101342
11121121.a17	controled (cc=150)	180 deg	REG5	2.40 s	0.100 m	240 s	fpp_a051t240	Heave	time serie as for REG5		FPP_HEX_180Heave_REG5_201712101342
11121142.a17	controled (cc=200)	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210	Heave	time serie as for REG7		FPP_HEX_180Heave_REG7_201712101342
11121159.a17	controled (cc=200)	180 deg	REG9	1.80 s	0.100 m	180 s	fpp_a042t180	Heave	time serie as for REG9		FPP_HEX_180Heave_REG9_201712101342
11121414.a17	controled (cc=200)	180 deg	IRR	1.70 s	0.060 m	600 s	fpp_h060t170_c1	Heave	time serie as for IRR		FPP_HEX_180Heave_IRR_201712101342
11121435.a17	controled (cc=200)	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1	Heave	time serie as for WN		FPP_HEX_180Heave_WN_201712101342
11121016.a17 (*)	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	mDoF (combined surge, pitch)	time serie as for REG1		FPP_HEX_180mDoF_REG1_201712101515
11121215.a17	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	mDoF (combined surge, pitch)	time serie as for REG1		FPP_HEX_180mDoF_REG1_201712111112
11121255.a17	controled (cc=200)	180 deg	IRR	1.70 s	0.060 m	600 s	fpp_h060t170_c1	mDoF (combined surge, pitch)	time serie as for IRR		FPP_HEX_180mDoF_IRR_201712111112
11121331.a17	controled (cc=200)	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1	mDoF (combined surge, pitch)	time serie as for WN		FPP_HEX_180mDoF_WN_201712111112
11121507.a17	free	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Heave	time serie as for REG1		FPP_HEX_180Heave_REG1_201712101342
11121531.a17	free	180 deg	IRR	1.70 s	0.060 m	600 s	fpp_h060t170_c1	Heave	time serie as for IRR		FPP_HEX_180Heave_IRR_201712101342
11121609.a17	free	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1	Heave	time serie as for WN		FPP_HEX_180Heave_WN_201712101342
11121636.a17	free	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	mDoF (combined surge, pitch)	time serie as for REG1		FPP_HEX_180mDoF_REG1_201712111112
11121659.a17	free	180 deg	IRR	1.70 s	0.060 m	600 s	fpp_h060t170_c1	mDoF (combined surge, pitch)	time serie as for IRR		FPP_HEX_180mDoF_IRR_201712111112
11121729.a17	free	180 deg	WN	0.75 s - 3.00 s	0.060 m	600 s	fpp_h060t000_c1	mDoF (combined surge, pitch)	time serie as for WN		FPP_HEX_180mDoF_WN_201712111112
12121343.a17	controled (sweep)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Heave	time serie as for REG1		FPP_HEX_180Heave_REG1_201712101342
12121358.a17	controled (sweep)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Surge	time serie as for REG1		FPP_HEX_180Surge_Reg01_201712120903
12121413.a17	controled (sweep)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Pitch	time serie as for REG1		FPP_HEX_180Pitch_Reg01_201712120904
12121428.a17	controled (sweep)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	mDoF (combined surge, pitch)	time serie as for REG1		FPP_HEX_180mDoF_REG1_201712111112
12121450.a17	controled (sweep)	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210	Heave	time serie as for REG7		FPP_HEX_180Heave_Reg07_201712121404
12121507.a17	controled (sweep)	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210	Surge	time serie as for REG7		FPP_HEX_180Surge_Reg07_201712121404
12121528.a17	controled (sweep)	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210	Pitch	time serie as for REG7		FPP_HEX_180Pitch_Reg07_201712121405
12121543.a17	controled (sweep)	180 deg	REG7	2.10 s	0.100 m	210 s	fpp_a050t210	mDoF (combined surge, pitch)	time serie as for REG7		FPP_HEX_180mDof_Reg07_201712121405
12121557.a17	free	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Surge	time serie as for REG1		FPP_HEX_180Surge_Reg01_201712120903
12121617.a17	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Surge	time serie as for REG1		FPP_HEX_180Surge_Reg01_201712120903
12121634.a17	free	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Pitch	time serie as for REG1		FPP_HEX_180Pitch_Reg01_201712120904
12121651.a17	controled (cc=200)	180 deg	REG1	3.00 s	0.100 m	300 s	fpp_a040t300	Pitch	time serie as for REG1		FPP_HEX_180Pitch_Reg01_201712120904

(*) : For this test, Specified motion using time-series WITH WRONG definition of Hexapod DOF (Before update of Hexapod trajectory file to match FPP global coordinate system)

Table 10: Waves and hexapod tests – Heading 180°

8. Data acquisition

All data are given at basin scale in one data set for each test. The sampling frequency for the Oceanide files was set to 100 Hz for all instrumentation, except for the video for which the acquisition frequency is of 25 Hz.

9. Processing

Only for heave harmonic oscillations (hexapod tests with or without waves), the following processing has been performed.

Considering the platform model connected to the hexapod in forced oscillations, the sinusoidal motion in heave can be written as:

$$Z(t) = A \cdot e^{i \cdot \omega \cdot t}$$

Applying the fundamental principle of dynamics on the oscillated model, we can write:

$$m\ddot{Z} = F_{connection} + F_{hydrodynamic}$$

We assume: $F_{hydrodynamic} = -m_a \ddot{Z} - B\dot{Z} - KZ$

Thus, the connection load can be written as: $F_{connection} = (m + m_a)\ddot{Z} + B\dot{Z} + KZ$

With A = amplitude of vertical motion

ω = angular frequency

m = mass of the model (including 14.65 kg for sensitive part of the 6D dynamometer)

m_a = added mass of the model in the considered motion

B = damping

K = hydrostatic stiffness

Noting that $F_{connection} = F_{measured}$ with $F_{measured}$ the total vertical force Fz, described in section 1.1.2.

Finally, the corrected load is:

$$F_{measured}(t) = -(m + m_a) \cdot \omega^2 \cdot Z(t) + B \cdot i \cdot \omega \cdot Z(t) + K \cdot Z(t)$$

By Fourier transformation of the complex number: $\frac{1}{\rho\omega^2}\frac{F_{measured}}{Z}$, we can deduce the following quantity by identifying respectively the real and imaginary part of the first order component as:

$$\mathrm{Re}\left[-\frac{1}{\rho\omega^2}\frac{F_{corrected}}{Z}\right] = \frac{(m + m_a)}{\rho} - \frac{K}{\rho\omega^2} \qquad \mathrm{Im}\left[\frac{1}{\rho\omega^2}\frac{F_{corrected}}{Z}\right] = \frac{B}{\rho\omega}$$

In pdf document, the real part is called "Added mass" (but care should be taken to the fact that it is also including the hydrostatics, see equation above) and the imaginary part is called "Damping".

10. Main Learning Outcomes

10.1 Progress Made

10.1.1 Progress Made: For This User-Group or Technology

The tests performed at Oceanide have proven extremely useful to FPP. Accurate scaled model data had only previously been obtained for a fixed platform with a pitching WEC. The tests performed at Oceanide provided the opportunity to extend FPP's data to include the interaction effects between a moving platform and a pitching WEC. More specifically, the use of a hexapod to force the platform motions has provided FPP with the very precise data, in which the multi-degree of freedom model can be validated where only 1 of the 7 degrees of freedom (the pitching relative to the platform) is free (with modes 1-6 prescribed by the hexapod).

At this early stage, only limited analysis had been made on the data, however it is clear the quality of the data is high, and the ability of the numerical model predict the motion of the absorber is looking promising.

10.1.2 Progress Made: For Marine Renewable Energy Industry

Linear wave theory is still heavily relied upon within the marine renewable energy industry. In some circumstances the theory is entirely suitable, however in many cases non-linearities need to be included within the modelling. The numerical model being developed by FPP and its partners is in the time domain with the inclusion of linear wave theory for some of the hydrodynamic inputs. The data obtained during these tests will directly be used to validate the model for cases including extremely closely spaced bodies, and "generalised modes" (i.e. motions beyond the usual 6 degrees of freedom – in FPP's case, pitching relative to a moving platform). These results will directly feed back into the marine renewable energy industry via the public and opensource publications made within the H2020 funded ICONN project, and the code-to-code comparisons of OES task 10.

10.2 Key Lessons Learned

The tests were overall a complete success, with very accurate data obtained for a large variety of tests. This has provided an excellent basis for numerical model validation, the main purpose of the tests. Outside of this, there are a few lessons learnt which will make our next test regime run a little smoother

1. Only a simple test plan was made before we arrived. It would have been better to agree an exact test plan, including individual tests and specific labelling structure for the tests before we had arrived
2. Procedure for document administration should have been established prior to tests
3. FPP work primarily in MATLAB, and the data from the facility was delivered in text files. In order to read the data files into MATLAB, it would have been more efficient to use the same data structure throughout. It would have been beneficial therefore to have agreed an exact data structure for the text files at the beginning of the access period, including additional blank columns for use in the case that additional channels are added throughout the test period.
4. Internet connection at the facility was unstable and slow. As a consequence, there were difficulties with data sharing and backup. It would be beneficial to check the speed of the internet prior to access, and bringing a portable Wi-Fi router to ensure all parties can access uploaded data instantly.

5. FPP spent 1 week prior to the Oceanide access period performing dry tests. This proved extremely useful and is recommended to anyone performing wave basin tests. The dry tests including taking exact measurements of lengths and masses of all components and updating the drawings accordingly, measuring the centre of gravity of both the platform and the WEC, and measuring the moment of inertia.
6. Further to the dry tests, FPP was in the privileged position to have access to a smaller wave basin for 1 day prior to the tests. This proved extremely useful to ensure everything was connected correctly and the WEC was able to move freely. During this day, it turned out that minor errors had been made in the building of the model, so minor modifications needed to be made to allow the WEC to move freely.