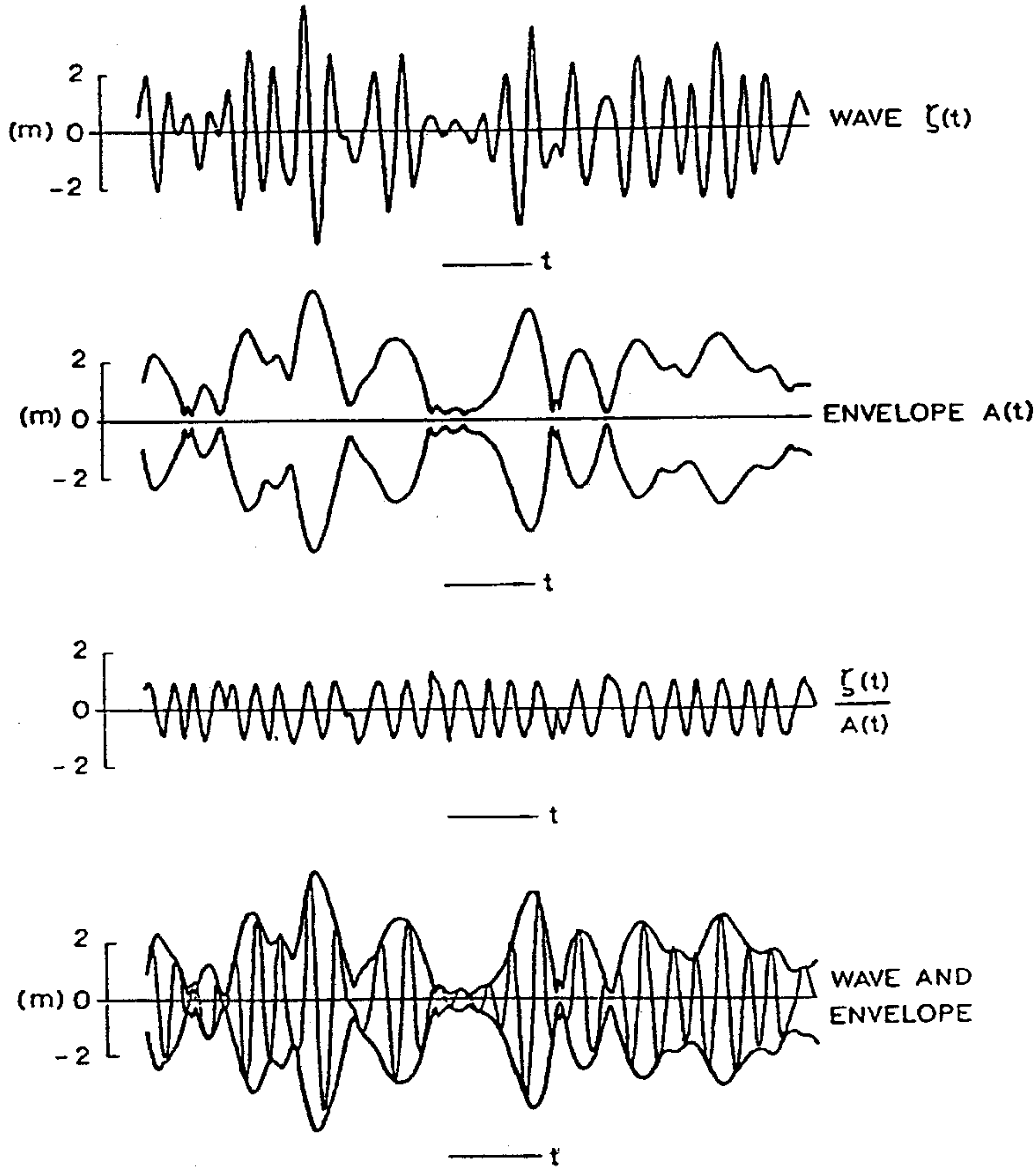
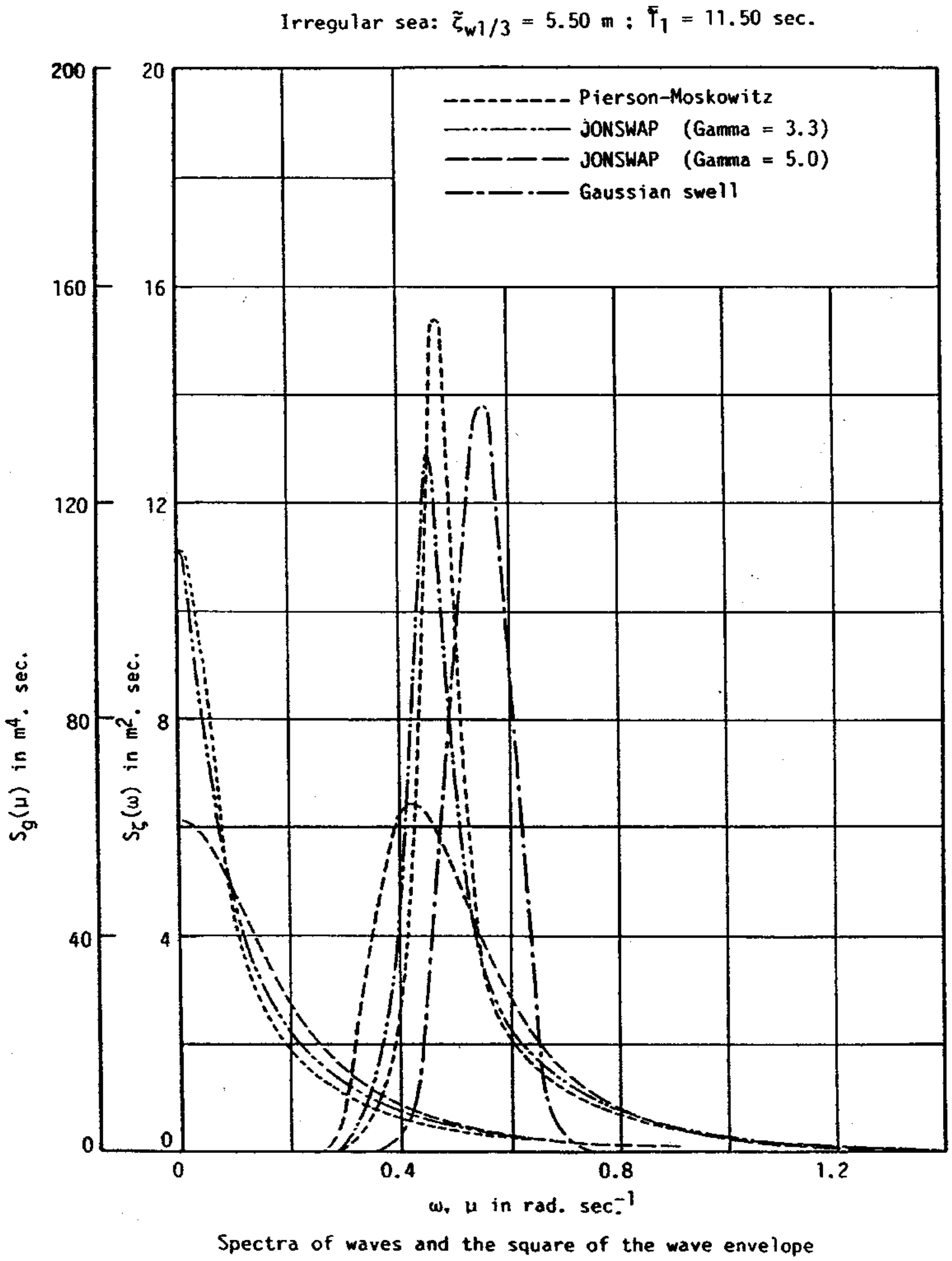


Using the spectral density formulation of A^2 (t), which means the spectrum of the square of the wave envelope or the wave group spectrum according to:

$$S_g(\mu) = 8 \int_0^{\infty} S_\zeta(\omega)\, S_\zeta(\omega + \mu)\, d\omega$$

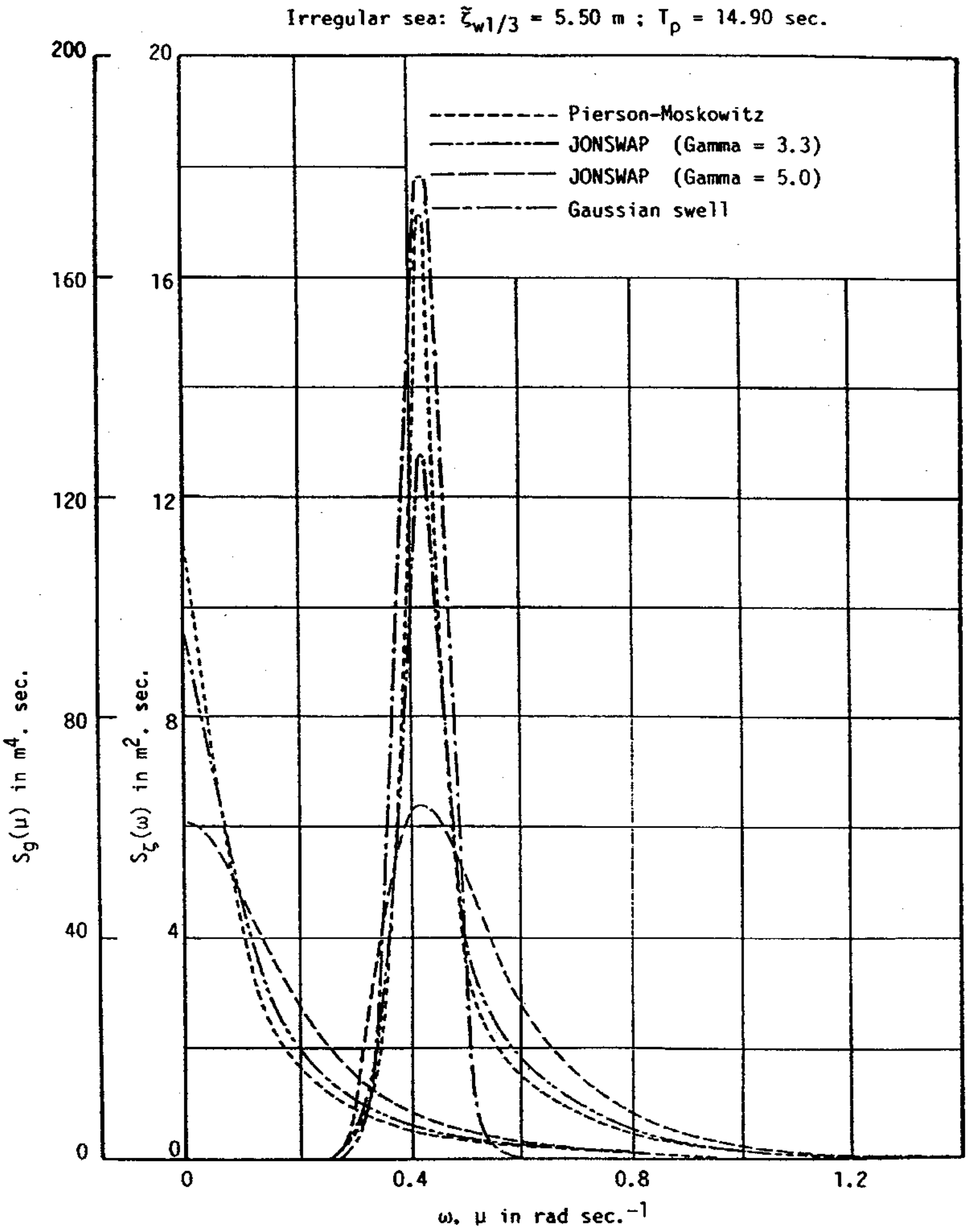
Computations have been carried out on the different afore-mentioned wave spectrum formulations.

In the figure below the wave group spectra have been computed for 5 different wave spectrum formulations each having the same significant wave height $\zeta_{w1/3}$ = 5.5 m and the same average period T_1 = 11.50 s.



Spectra of waves and the square of the wave envelope

In the figure below the wave group spectra have been computed for 5 different wave spectrum formulations each having the same significant wave height $\zeta_{w1/3}$ = 5.5 m and the same peak period T_p = 14.9 s.



Spectra of waves and the square of the wave envelope

From the results it can be concluded that the spectral density of the square of the wave groups will be substantially influenced by the shape of the chosen wave spectrum.

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APPENDIX E04

Wave Calibration Procedure in the Offshore Basin (OB)

Revision	Date	Description of revision	Author
0	May 27, 2009	First version of the appendix	JH
1	February 25, 2010	Review and up-date of the text	JLC

Wave Calibration Procedure in the Offshore Basin (OB)

The requested irregular wave conditions are calibrated prior to the actual model tests, without the model(s) present in the basin. The wave elevations are measured by means of resistance wire wave probes, placed at the centre of the test set-up and at additional (typically 2) reference positions. The reference wave probes remain at their location in the test set-up for the entire duration of the model test project. The irregular waves are calibrated for a duration of 1 hour or 3 hours (prototype value).

The irregular waves are calibrated through the following procedure.

1. The correct current profile is generated in the basin.

2. The required wave spectrum is specified in the wave generation software. Based on this input the software calculates a control file for the wave generators. This file contains motion control information for all individual wave flaps in the basin.

3. After the current has become stationary, the irregular seas are generated, measured and analysed. The measured wave spectrum at the zero position (centre of the test set-up) is compared with the required wave spectrum.

4. If necessary, a correction for the wave generator control file is calculated. This correction is based on the (frequency-by-frequency) ratio between the measured and required spectrum at the zero position. After applying correction to the control file, the sea state is generated, measured and analysed again, until a sufficiently close correspondence is found between the measured and the required wave spectrum. Depending on the spectral shape, this iterative process typically takes 2 or 3 attempts to generate the wave spectrum at the required accuracy.

5. The final version of the wave generator control file is stored, in order to be able to exactly reproduce the calibrated sea state at any time during the project.

APPENDIX F01

Offshore Basin (OB)

Revision	Date	Description of revision	Author
0	March 27, 2017	First version of the appendix	JJS

Offshore Basin (OB)

General

In the Offshore Basin (OB) irregular long and short crested waves can be generated. The OB is 45 m long, 36 m wide and has an adjustable water depth with a maximum of 10 m. The basin is mainly designed for testing models of offshore structures which are fixed, moored or controlled by dynamic positioning, in waves, wind and current.

Figure F01-0-1: Overview of the offshore basin

Sign convention

The figure shows the possible directions of current, swell, local waves and wind that can be modelled in MARIN's Offshore Basin. All directions are defined in the basin-fixed system of axes.

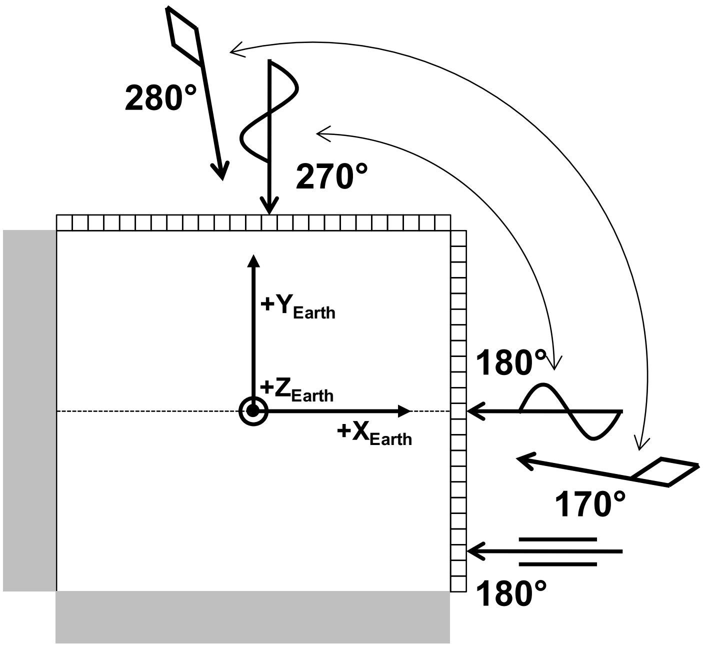

Figure F01-0-2: Representation of the Basin Fixed Coordinate System (BFCS) in the OB

Wave generation

At two adjacent sides of the basin, segmented wave generators consisting of hinged flaps are installed. This implies that waves can be generated in any direction ranging between head seas and beam seas (180 - 270 deg, defined in the basin fixed system of axes). Wave directions between following seas and beam seas can be modeled by changing the vessel heading. Opposite the 270 deg wave generator, passive sinkable wave absorbers are installed.

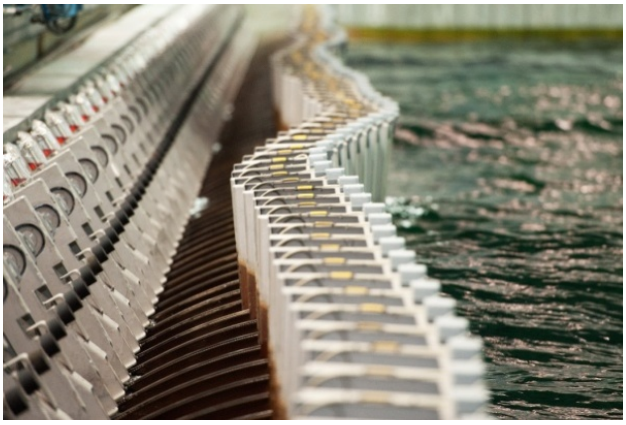

Figure F01-0-3: Overview of the wave flaps (left) and absorbing beaches (right)

The wave generator system is equipped with higher order wave synthesis techniques. The beaches of the OB are designed to minimize wave reflections, even for long period swells. For the generation of irregular seas the wave generator flaps perform (pre-calculated) irregular motions. The signal of the wave flap motions is non-repetitive and contains the same range of frequencies present in the irregular seas to be generated. Each flap is controlled separately by a driving motor and has a width of 40 cm.

The capability of the wave flaps is limited due to power, wave flap angles or wave breaking criteria. Therefore, it may be difficult to calibrate wave spectra which contains energy at low periods, high periods, or with a too high significant wave height. Figure F01-0-4 shows the wave generation capability at model scale. The plot shows the capability of long crested waves from the 180 deg and 270 deg wave maker. The horizontal axis represents the peak period of the wave spectrum in [s] at model scale. The vertical axis represents the significant wave height in [m] at model scale. It should be noted that these plots are indicative and depend on many parameters (spectrum enhancement factor, current, wave direction…).

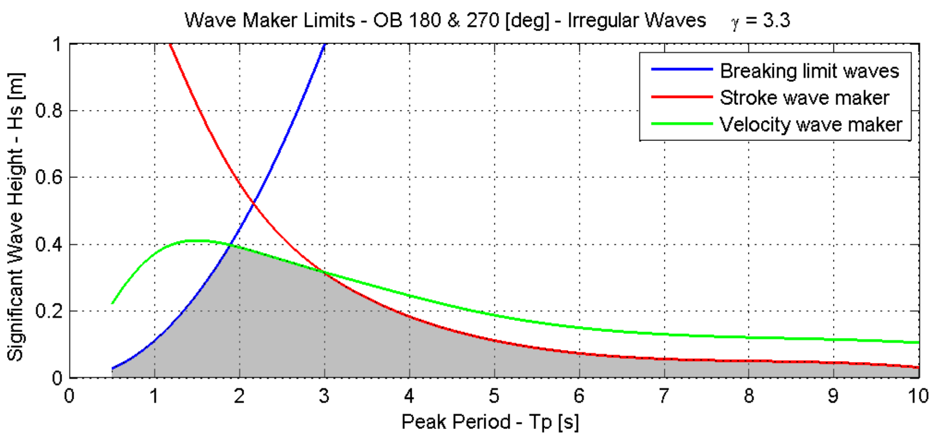

Figure F01-0-4: Wave generation capability in the OB

Wind generation

Wind can be generated by a large number of wind fans. Together they form a wind field of 20 m width. This ensures a constant wind field over the full measurement area, even when using a large test set-up, e.g. in case of tandem offloading tests. Constant wind as well as gusting and squall wind can be generated. It is noted that the wind forces to be modelled will be an important factor to take into account in the choice of the scale, as the maximum wind speed that can be reached in the basin is approximately 6.5 m/s.

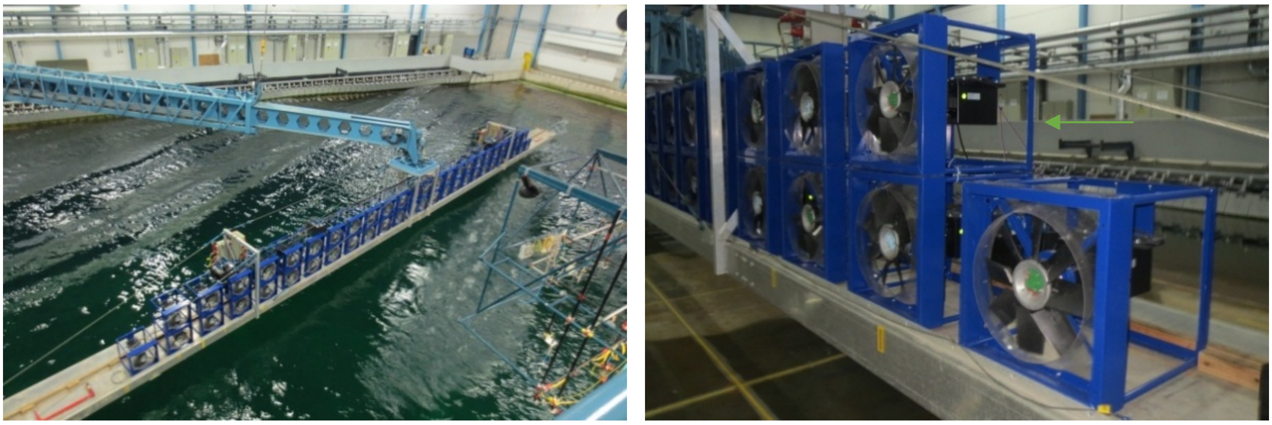

Figure F01-0-5: Overview of the wind fans used in the Offshore Basin

As an alternative to the wind fans, the wind forces can be modelled using a dynamic winch. This is a good option for spread mooring systems as the model heading is relatively constant during a test, which means that a fixed attachment point can be used.

Current generation

The current generation system in the Offshore Basin consists of 6 separate layers, each equipped with its own pump. Current can be generated over the full depth of 10.0 m. The water is re-circulated through a system of channels outside the basin, in order to avoid recirculation in the basin itself. This current generation system enables the adjustment of vertical current profiles with constant speeds. The water is flowing into the basin from one side and flowing out on the opposite side over the full basin width. The water is re-circulated outside the basin through a system of large channels, in order to avoid re-circulation in the basin itself. On Figure F01-0-6 and Figure F01-0-7 both the inlet (left) and the outlet (right) of the six current layers are displayed.

Figure F01-0-6: Current inlet

Figure F01-0-7: Current outlet

The turbulence intensity in the current flow in the Offshore Basin is generally very low (around 5%). However, the turbulence may be somewhat larger in case of a strongly sheared current profile (current profiles with a strong variation in velocity over the water depth). This can be explained as follows. In the Offshore Basin the current is adjusted in 6 separate layers (each with their actual heights) and the natural shear in the current flow will prevent sharp steps in current speed between the different layers. In case of a very high surface current and small (or even zero) velocity for larger depths a strong current gradient may cause an increase in turbulence, which is a natural phenomenon. Therefore, no guarantee can be given about the turbulence that will be measured in the basin.

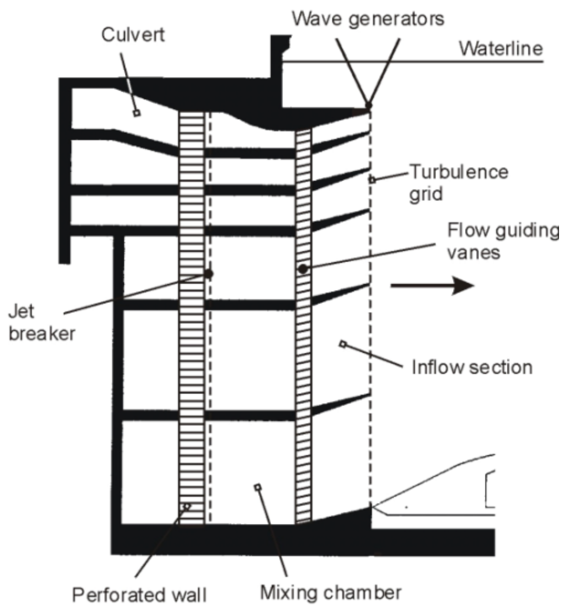

Figure F01-0-8: Side view of the current pump system

Figure F01-0-9 shows the capability of the current generation system. The minimum and maximum current speeds that can be achieved are represented as a function of the basin depth. Model scale values are shown on this Figure. Also, this Figure shows that the current generation system of the Offshore Basin is designed to standard current profiles, i.e. the deeper the water, the lower the current speed. For particular current profiles, the calibration in the bottom layers parts may be more difficult.

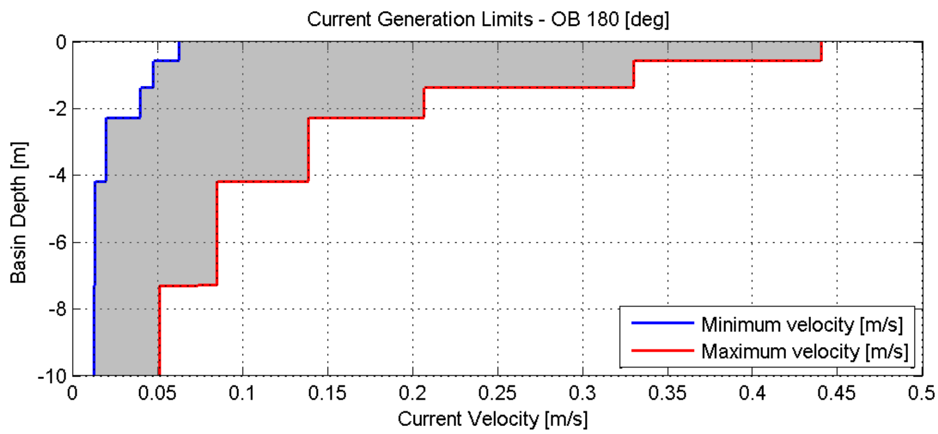

Figure F01-0-9: Capability of the current generation in the OB

APPENDIX M05

Calibration of Model Weight Distribution using Resonic

Revision	Date	Description of revision	Author
0	October 19, 2017	First version of the appendix	JLC
1	October 20, 2017	Reviewed and up-dated	JLC + RvdV
2	October 26, 2017	Measurement accuracies added	JLC

Calibration of Model Weight Distribution using Resonic

Prior to the start of the model tests, the weight distributions of the scale models are calibrated. The calibrated properties include the model mass, the position of the CoG and the moments of inertia about the principal axes. Measurements are performed using a Resonic[8] oscillation table, as shown in the photo below.

Resonic 2000F Oscillation Table

The following weight calibration procedure is applied:

1. The mass of the completed empty model (including all top-sides, instrumentation, cables, measurement equipment and thrusters, but without ballast weights) is carefully measured and the model is placed on the Resonic oscillation table. After the measurement software is started a number of passive oscillations is performed. This process is fully automated. The software derives the inertia properties of the model, based on the measured natural frequencies. The output of the analysis includes the position of the center of gravity (x, y, z) and the moments inertia around the principal axes (I_{xx}, I_{yy}, I_{zz}).

[8] Resonic GmbH, http://www.resonic.de/

2. The weight and positions of all ballast weights to be included in the model are determined. This is than such, that the correct total mass, CoG position and moments of inertia are achieved. In order to avoid any undesired couplings between the different modes of motion, the so-called products of inertia (I_{xy}, I_{xz}, I_{yz}), the ballast weights are placed symmetrical as much as possible.

3. The complete model (including all ballast weights) is placed in the water in the basin harbour. The model draft and trim are checked by the draft marks on the hull. The model GM value is checked by means of a heeling test. The vessel roll period is determined in a roll decay test. If necessary, the position of the ballast weights is changed to achieve the required GM value or roll period. The final positions of the ballast weights inside the model are marked and the modelled weight distribution is documented in the model test report.

4. The complete model is lifted from the water and placed on the Resonic oscillation table. The inertia measurement process is repeated to obtain the inertia properties of the model as it will be used in the model tests. The results are included in the model test report.

5. The model is placed in the water in the model basin. Here, in the test set-up, the final measurements of the GM value and roll natural period are carried out. The results of these measurements are included in the model test report.

Remark

For typical size models used in offshore model tests, the following measurement accuracies are achieved with the Resonic 2000F oscillation table.

Measured Property	**Measurement Accuracy**
Model Mass (M)	+/- 0.5 kg
Position of CoG (x, y, z)	+/- 2 mm
Main diagonal moments of inertia (I_{xx}, I_{yy}, I_{zz})	+/- 1%
Cross moments of inertia (I_{xy}, I_{xz}, I_{yz})	+/- 1% of largest principal moment

APPENDIX P02

Experimental Procedure for Static Load Tests (applied displacement)

Revision	Date	Description of revision	Author
0	September 10, 2009	First version of the appendix	JLC
1	January 31, 2010	Review and up-date of the text	JLC

Experimental Procedure for Static Load Tests (applied displacement)

Pretension Adjustments

Prior to the static load tests the mooring line pretensions are adjusted, according to the following procedure.

1. A set of anchor points is installed on the basin floor. The exact anchor locations are known from the static load-displacement calculations that are carried out during the model preparations.

2. The model is connected to the basin carriage by means of a 6-component force frame. The model orientation can be adjusted to correspond to the mooring system orientation in the basin. The model is placed at the correct draft. Alternatively, the chain table of an FPSO model can be connected to the basin carriage through a 3 component (FX, FY, FZ) force transducer. The vertical position of the chain table corresponds with the required vessel draft.

3. The mooring lines are connected to their anchor points and to the model. The mooring line pretensions are measured and compared to the theoretical (calculated) values.

4. If necessary, the pretension in each mooring line is adjusted by moving its anchor point on the basin floor (no more than a few centimetres). In this manner, the line pretensions are adjusted to values within a few % of the theoretical values.

Static Load Tests (“Applied Displacement”)

The model is connected to the basin carriage, with all mooring lines (and risers, if applicable) connected. Subsequently, static load-displacement tests are carried out using the following procedure.

5. The basin carriage is given a series of displacements in X- and Y-direction. If necessary, also yaw displacements can be applied. After each displacement the mooring line tensions, as well as the total mooring loads FX and FY, are measured.

6. The measured total mooring loads are plotted as a function of the applied displacements. The measured and calculated static-load characteristics are plotted together.

APPENDIX P03

Experimental procedure for motion decay tests

Revision	Date	Description of revision	Author
0	May 27, 2009	First version of the appendix	JH
1	February 1, 2010	Review and up-date of the text	JvdB
2	September 19,2014	Pumping method is added	FJ

Experimental procedure for motion decay tests

The purpose of the motion decay tests is to determine the natural periods and the damping levels for the various modes of motion of the vessel model. Two different methods can be used to performed the decay tests. On one hand, the held-over decay starts with the model at rest and in calm water. On the other hand, the decay with pre-oscillations starts with building up the motion amplitude before releasing the model. The objective is to take into account eventual memory effects due to the presence of vortices generated during the pre-oscillations. These vortices are not present when the decay is started with a static offset. The test procedure applied for the motion decay tests is described below.

Method 1 – Held over decays

1. The vessel model is completely at rest in its equilibrium position in calm water. The model is at the correct draft and correct trim with a zero heel angle.

2. The measurement is started.

3. The model is given an offset by manually moving it away from its equilibrium position in the desired mode of motion (e.g. surge, or roll). Then the model is released.

4. The model motions are measured and recorded. The recorded time traces are analysed using the methods described in Appendix D01.

Method 2 – Decays with pre-oscillations

1. The vessel model is completely at rest in its equilibrium position in calm water. The model is at the correct draft and correct trim with a zero heel angle.

2. The measurement is started.

–

3. The model is excited manually at its natural period for a given degree of freedom (e.g. roll, pitch). The motion is built up on a few periods till a pre-defined amplitude is reached.

4. The model is released.

5. The model motions are measured and recorded. The recorded time traces are analysed using the methods described in Appendix D01.

APPENDIX P04

Experimental procedure for model tests in (current, wind and) waves

Revision	Date	Description of revision	Author
0	May 27, 2009	First version of the appendix	JH
1	June 11, 2010	Reviewed and up-dated text	JLC

Experimental procedure for model tests in (current, wind and) waves

The model tests in environments of combined current, irregular waves and wind are performed according to the procedure described below.

1. The model is completely at rest in its zero position in calm water. The model is at the correct draft and correct trim with a zero heel angle.

2. The signals of all quantities are set to zero. This means that all quantities are measured relative to their values in the equilibrium position. In the data analysis, the mooring line pretensions are again added, so the mooring line tensions can be regarded as absolute tensions (in other words; zero tension is a slack line).

3. The current pumps are started and set at the correct RPMs (if applicable). After approximately 20 minutes (model scale value) the current has become stationary.

4. The wind fans are started and set at the correct RPMs (if applicable). The wind flow is stationary within a few minutes.

5. The wave generators are started, together with the measurement system. The first 30 minutes (1,800 s) of irregular seas are generated to let possible transient phenomena vanish (“start-up time”). Subsequently, irregular seas are generated for the actual duration of the model test (e.g. 3 hours / 10,800 s).

6. The model motions, line tensions, accelerations and all other signals are measured and recorded.