

Technical Report

**Description of the Load Cases  
and Output Sensors to be Simulated in  
the OC4 Project under IEA Wind Annex  
30**

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## Content

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Symbols	2
<b>2</b>	<b>Load cases</b>	<b>3</b>
2.1	Eigenanalysis	5
2.2	Rigid offshore wind turbine	6
2.3	Land based turbine	7
2.4	Flexible offshore structure	8
2.5	Fully-flexible offshore wind turbine	9
<b>3</b>	<b>Support structure outputs</b>	<b>11</b>
	<b>Bibliography</b>	<b>15</b>
	<b>Appendix</b>	<b>15</b>
A	Column numbers, column headers and sensor descriptions	17
B	Coordinate system definition	18
B.1	Global coordinate system	18
B.2	Blade coordinate system	19
B.3	Blade coordinate system that pitches	20
C	Wavelets definition	22
D	Wavelets generation	23



# 1 Introduction

This document defines the load cases and the results outputs ('sensors' in the following) for the code comparisons in the course of the Offshore Code Comparison Collaboration Continuation (OC4) project operated under IEA Wind Annex 30<sup>1</sup>. The approach is based on the OC3 project, IEA Wind Task 23<sup>2</sup>, as described in detail in Jonkman and Musial (2010). The model of the rotor-nacelle assembly (RNA) and the controller to be used are defined in Jonkman et al. (2009). The model of the support structure (tower and jacket) and the global coordinate system (whenever is referred to a global coordinate system in this document) are given in Vorpahl et al. (2011).

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<sup>1</sup>[http://www.ieawind.org/task\\_30/task30\\_Public.html](http://www.ieawind.org/task_30/task30_Public.html)

<sup>2</sup>[http://www.ieawind.org/task\\_23.html](http://www.ieawind.org/task_23.html)

## 1.1 Symbols

Symbol	Unit	Description
$\alpha$	-	power law exponent for the normal wind profile
$\mu_b$	-	Wöhler material exponent for blades
$\mu_s$	-	Wöhler material exponent for welded elements
$\Omega$	rpm	rotor speed
$\Phi$	deg	blade azimuth position measured clockwise looking downwind from blade 1 pointing upwards
$\sigma_x$	m/s	standard deviation of longitudinal wind speed at hub height
$\sigma_y$	m/s	standard deviation of lateral wind speed at hub height
$\sigma_z$	m/s	standard deviation of vertical wind speed at hub height
$\Theta$	deg	pitch angle
$c_x$	-	aerodynamic drag coefficient for structure
$c_d$	-	drag coefficient in Morison's equation
$c_m$	-	inertia coefficient in Morison's equation
$g$	m/s <sup>2</sup>	gravitational acceleration
$F_x$	kN	force component in x-direction
$F_y$	kN	force component in y-direction
$F_z$	kN	force component in z-direction
$H$	m	wave height
$H_5$	m	significant wave height
$L_c$	m	isotropic integral parameter of the wind speed component
$L_{k,x}$	m	integral length parameter of x component of the wind speed
$L_{k,y}$	m	integral length parameter of y component of the wind speed
$L_{k,z}$	m	integral length parameter of z component of the wind speed
$M_x$	kNm	moment component in x-direction
$M_y$	kNm	moment component in y-direction
$M_z$	kNm	moment component in z-direction
$N_{ref}$	-	reference number of cycles for the damage equivalent load (DEL) calculation
$\Delta t$	s	time step for data output
$\Delta t_{wave}$	s	time step for the wave data generation
$\Delta t_{wind}$	s	time step for the wind data generation
$T$	s	wave period
$T_{det}$	s	simulation time for deterministic cases
$T_{stoch}$	s	simulation time for stochastic cases
$T_p$	s	peak period of the sea state
$V_{hub}$	m/s	wind speed at the hub height
$V_r$	m/s	rated wind speed
$x$	m	coordinate
$y$	m	coordinate
$z$	m	coordinate

## 2 Load cases

As in the OC3 project, load case sets with increasing complexity are defined to allow for stepwise comparisons of results and to enable OC4 participants to trace back possible discrepancies in the results. The load case sets and individual load cases are given in the following sections.

The parameters mentioned in the following paragraphs are defined in Table 2.1 or given directly with the load case definitions in sections 2.1 to 2.5. In all load cases with aerodynamics enabled, the turbine is facing perfectly upwind (no yaw error), towards the negative global x-axis. The turbulence description is based on the Kaimal spectrum and the Normal Turbulence Model (NTM) with the values for the standard deviation<sup>1</sup>. The integral length parameter of velocity component  $L_k$  is calculated according to IEC (2005).

Turbulent wind datasets generated with a grid resolution of 32 x 32 are supplied by Risø DTU. These datasets already include wind shear and may be used directly. As an alternative, the wind datasets may be generated individually as well with the specifications given herein. In this case, the minimum resolution for the individually generated turbulence wind fields shall be 10 x 10 with at least 10 m of grid spacing. A time step of  $\Delta t_{\text{wind}}$  is to be used.

The wind shear with a power law profile is to be applied in accordance with the offshore requirements specified in GL (2005) to all load cases with the stochastic wind model. The wind shear shall be superimposed within the aeroelastic code.

Wind load on a structure is neglected by specifying the aerodynamic drag coefficient as  $c_x = 0$ .

The Wheeler stretching method is applied to all regular Airy waves and irregular wavetrains based on Airy wavelets. The time step of  $\Delta t_{\text{wave}}$  shall be used for the time history of the deterministic and stochastic waves.

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<sup>1</sup>The model of standard deviation proposed in IEC (2005) was found too conservative for the UpWind site, whereas IEC (2009) values were found to be too optimistic. Based on the actual site data, values in between the values derived from the two standards were defined in Fischer et al. (2010).

The stochastic wave data description is based on the Normal Sea State (NSS) model from IEC (2009). The NSS is defined as an irregular sea state described by the linear Airy theory and the Pierson-Moskowitz spectrum with the significant wave height  $H_s$  and the peak spectral period  $T_p$  being the input parameters. Irregular waves may be generated based on the spectral input defined herein or the time history data may be reproduced. For the latter possibility, 50 wavelets with defined wave number, amplitude, phase angles and angular frequencies are attached in Appendix C. Supplementary information concerning the wavelets can be found in Appendix D. However, this information is not necessary for the use of the provided input.

Wind and waves are aligned in all load cases. This results in a wave direction normal and parallel to the sides of the jacket.

Marine growth shall be applied in all the simulations independently on presence of water. In the load cases defined in the following 'No water' means that wave loads, but also all other effects resulting from water surrounding a structure, such as buoyancy or hydrodynamic added mass, are disabled in the simulations. Only in Load Case 2.1 this is not the case, here 'still water' is included as described in section 2.2. The same accounts for 'No air', meaning that no effects from the surrounding air are included in the simulations.

Start-up transients are cut using a 'pre-simulation time'  $T_{pre}$  which is simulated but cut from the results files in all simulations. A 'pre-simulation time' value is not defined. It should be chosen individually by each participant in order to satisfy the initial conditions of the proper simulation.

The stochastic cases are run with one seed and a simulation time of  $T_{stoch} = 3600$  s to get statistically comparable results. The time step for data output is set for all load cases and participants to avoid difficulties during post processing of the results. Hydrodynamic loads calculation is based on Morison's equation with standard values for inertia and drag coefficients. The Wöhler material exponents to be used for the structure (welded steel parts) and the blades (glass fiber reinforced plastic) are taken from GL (2005). This is different compared to the approach in OC3 where outputs of all components were post-processed with two different Wöhler material exponents. A standard value is used as reference number of cycles for the damage equivalent load (DEL) calculation.

The load cases with deterministic input are compared in terms of time-series output and the stochastic cases are compared in terms of probability density functions (PDF) and damage equivalent loads (DEL).

Symbol	Value	Description
$\mu_b$	10	Wöhler material exponent for rotor blades
$\mu_s$	4	Wöhler material exponent for welded elements
$c_x$	0	aerodynamic drag coefficient for structure
$c_d$	1	drag coefficient in Morison's equation
$c_m$	2	inertia coefficient
$g$	9.80665 m/s <sup>2</sup>	standard gravity acceleration
$N_{ref}$	2E8	reference number of cycles for the DEL calculation corresponding to 20 years turbine lifetime
$\Delta t$	0.05 s	time step for data output
$\Delta t_{wave}$	0.1 s	time step for the wave data generation
$\Delta t_{wind}$	0.1 s	time step for the wind data generation
$T_{det}$	30 s	simulation time for deterministic load cases
$T_{pre}$	User defined	'Pre-simulation time' to be cut off from the simulation
$T_{stoch}$	3600 s	simulation time for stochastic load cases

Table 2.1  
General settings

## 2.1 Eigenanalysis

In Load Case set 1, Eigenanalyses in the absence of water are performed. In Cases 1.0a and 1.0c, only the support structure (tower and jacket) degrees of freedom (DOF) are enabled, meaning that the Rotor Nacelle Assembly (RNA) is rigid or the complete RNA is represented by a point mass including inertia. In load Cases 1.0b and 1.0d, all DOF are enabled, the turbine is stationary but fully flexible. Blade 1 is pointing straight up and the high speed shaft is completely locked at the generator side (a brake is applied). Load Cases 1.0a and 1.0b do not include damping, Cases 1.0c and 1.0d include structural damping as defined in Vorpahl et al. (2011) and critical damping for blades defined in Jonkman et al. (2009). Table 2.2 gives an overview of the load cases in Load Case set 1.

Load Case	Enabled DOF	Wind Conditions	Wave Conditions	Analysis Type	Initial Conditions
1.0a	Support structure	No air	No water	Eigenanalysis, no gravity or damping, natural frequencies and mode shapes	
1.0b	All	No air	No water	Eigenanalysis, no gravity or damping, natural frequencies and mode shapes	$\Omega = 0$ rpm $\Phi = 0$ deg $\Theta = 0$ deg brake applied
1.0c	Support structure	No air	No water	Eigenanalysis, gravity and structural damping included, damped frequencies and mode shapes	
1.0d	All	No air	No water	Eigenanalysis, gravity and structural damping included, damped frequencies and mode shapes	$\Omega = 0$ rpm $\Phi = 0$ deg $\Theta = 0$ deg brake applied

Table 2.2  
Load Case Set 1



## 2.2

### **Rigid offshore wind turbine**

Load Case Set 2 deals with a completely rigid offshore wind turbine. Different load sources are enabled dependent on the individual load case. In Case 2.1, gravity and buoyancy outputs are checked in still water without aerodynamic loads. Load Case 2.2 allows for comparison of basic aerodynamic loading as the wind field is as simple as possible and water is not included. In Load Case 2.4a and 2.4b, loads resulting from stochastic winds are simulated for rated (highest rotor thrust) and over-rated wind speeds (supplementary check of pitch controller functions), respectively. Load Case 2.3a, 2.3b and 2.5 are meant to verify wave load calculation for a linear and a nonlinear regular wave and an irregular linear train, respectively. Table 2.3 defines the load cases in Load Case Set 2 in detail.

Load Case	Enabled DOF	Wind Conditions	Wave Conditions	Analysis Type	Initial Conditions
2.1	None	No air	Still water	Static simulation including gravity and buoyancy to MSL	
2.2	None, Rotor speed and blade pitch via controller	Steady, uniform, no shear, $V_{hub} = 8$ m/s	No water	Periodic time-series solution	$\Omega = 9$ rpm $\Phi = 0$ deg $\Theta = 0$ deg
2.3a	None	No air	Regular Airy: $H = 6$ m, $T = 10$ s	Periodic time-series solution	Wave simulation starts from crest at $x = 0, y = 0$ (global system)
2.3b	None	No air	Regular stream function (Dean, 9th): $H = 8$ m, $T = 10$ s	Periodic time-series solution	Wave simulation starts from crest at $x = 0, y = 0$ (global system)
2.4a	None, Rotor speed and blade pitch via controller	NTM (Kaimal): $V_{hub} = V_r = 11.4$ m/s $\sigma_x = 1.68$ m/s $\sigma_y = 1.34$ m/s $\sigma_z = 0.84$ m/s $L_{k,x} = 340.20$ m $L_{k,y} = 113.40$ m $L_{k,z} = 27.72$ m $L_c = 340.20$ m Wind shear: $\alpha = 0.14$	No water	PDF, DEL, power spectra	$\Omega = 12.1$ rpm $\Phi = 0$ deg
2.4b	None, Rotor speed and blade pitch via controller	NTM (Kaimal): $V_{hub} = 18$ m/s $\sigma_x = 2.45$ m/s $\sigma_y = 1.96$ m/s $\sigma_z = 1.23$ m/s $L_{k,x} = 340.20$ m $L_{k,y} = 113.40$ m $L_{k,z} = 27.72$ m $L_c = 340.20$ m Wind shear: $\alpha = 0.14$	No water	PDF, DEL, power spectra	$\Omega = 12.1$ rpm $\Phi = 0$ deg
2.5	None	No air	Irregular Airy: $H_s = 6$ m, $T_p = 10$ s, Pierson-Moskowitz wave spectrum	PDF, DEL, power spectra	

Table 2.3  
Load Case Set 2

## 2.3 Land based turbine

In the load cases being part of Load Case Set 3, a Land based turbine under deterministic (Load Case 3.2) and stochastic (Load Case 3.4a) wind loads is investigated. The support structure to be used with this turbine is the tower for the land based turbine defined by Jonkman et al. (2009). In order to compensate the

difference of the hub height<sup>2</sup>, the tower shall be placed on the top of a rigid, cylindrical element characterized by the following parameters: 0.55 m height, 6 m diameter and 0.1 m thickness. As basic aerodynamics and control behavior are verified in Load Case Set 2, only two load cases are simulated here. The turbine is fully flexible (RNA and tower) but water and respective effects – such as water added masses, wave loads or buoyancy - are not included (Cf. Table 2.4).

Table 2.4  
Load Case Set 3

Load Case	Enabled DOF	Wind Conditions	Wave Conditions	Analysis Type	Initial Conditions
3.2	All, Rotor speed and blade pitch via controller	Steady, uniform, no shear: $V_{hub} = 8$ m/s	No water	Periodic time-series solution	$\Omega = 9$ rpm $\Phi = 0$ deg $\Theta = 0$ deg
3.4a	All, Rotor speed and blade pitch via controller	NTM (Kaimal): $V_{hub} = V_r = 11.4$ m/s $\sigma_x = 1.68$ m/s $\sigma_y = 1.34$ m/s $\sigma_z = 0.84$ m/s $L_{k,x} = 340.20$ m $L_{k,y} = 113.40$ m $L_{k,z} = 27.72$ m $L_c = 340.20$ m Wind shear: $\alpha = 0.14$	No water	PDF, DEL, power spectra	$\Omega = 12.1$ rpm $\Phi = 0$ deg

## 2.4 Flexible offshore structure

Load Case Set 4 tests a model of a flexible offshore structure. This means that the flexible support structure (Tower and jacket) supports a rigid RNA or a tower top mass including inertias instead of the RNA. Therefore only hydrodynamic loads are included and two load cases (Load Case 4.3b with regular wave and Load Case 4.5 with irregular sea state) are sufficient. Details are given in Table 2.5.

Table 2.5  
Load Case Set 4

Load Case	Enabled DOF	Wind Conditions	Wave Conditions	Analysis Type	Initial Conditions
4.3b	Support structure	No air	Regular stream function (Dean, 9th): $H = 8$ m, $T = 10$ s	Periodic time-series solution	Wave simulation starts from crest at $x = 0$ , $y = 0$ (global system)
4.5	Support structure	No air	Irregular Airy: $H_s = 6$ m, $T_p = 10$ s, Pierson-Moskowitz wave spectrum	PDF, DEL, power spectra	

<sup>2</sup>The yaw bearing elevation was changed from  $z = 87.6$  m (OC3 project) to  $z = 88.15$  m (OC4 project) as described in Vorpahl et al. (2011). The height of the onshore tower defined in Jonkman et al. (2009) is 87.60 m. Therefore, it is decided to place it on the top of a rigid, cylindrical element in order to compensate the missing height and to correct the wind shear effect influence. Stretching of the tower from 87.60 m to 88.15 m is not applied since it may influence the distribution of mass and thus dynamics of the support.

## 2.5 Fully-flexible offshore wind turbine

The most complicated load cases are part of set 5 dealing with the fully-flexible offshore wind turbine. In the cases defined here, both, aerodynamic and hydrodynamic loads are enabled in one deterministic Load Case 5.6 and one stochastic Load Case 5.7 as shown in Table 2.6.

Load Case	Enabled DOF	Wind Conditions	Wave Conditions	Analysis Type	Initial Conditions
5.6	All, Rotor speed and blade pitch via controller	Steady, uniform, no shear: $V_{hub} = 8 \text{ m/s}$	Regular stream function (Dean, 9th): $H = 8 \text{ m}, T = 10 \text{ s}$	Periodic time-series solution	$\Omega = 9 \text{ rpm}$ $\Phi = 0 \text{ deg}$ $\Theta = 0 \text{ deg}$ wave simulation starts from crest at $x = 0, y = 0$ (global system)
5.7	All, Rotor speed and blade pitch via controller	NTM (Kaimal): $V_{hub} = 18 \text{ m/s}$ $\sigma_x = 2.45 \text{ m/s}$ $\sigma_y = 1.96 \text{ m/s}$ $\sigma_z = 1.23 \text{ m/s}$ $L_{k,x} = 340.20 \text{ m}$ $L_{k,y} = 113.40 \text{ m}$ $L_{k,z} = 27.72 \text{ m}$ $L_c = 340.20 \text{ m}$ Wind shear: $\alpha = 0.14$	Irregular Airy: $H_s = 6 \text{ m}, T_p = 10 \text{ s},$ Pierson-Moskowitz wave spectrum	PDF, DEL, power spectra	$\Omega = 12.1 \text{ rpm}$ $\Phi = 0 \text{ deg}$

Table 2.6  
Load Case Set 5



### 3 Support structure outputs

The sensors that were defined for the OC3 project for the turbine are to be used in OC4 Phase I as well. Additionally, the sensors described in the following are in scope of interest. The placement of these load sensors is shown in Figure 3.1. The support structure output signals ought to be recorded with respect to the global coordinate system defined by Vorpahl et al. (2011) except the axial outputs. The signal outputs of the turbine shall be presented according to the respective coordinate systems specified in table in Appendix A and described in Appendix B<sup>1</sup>.

Axial outputs are to be calculated in the local member axis; positive values mean tension forces and negative values mean compression forces respectively. The force output must be chosen from the beam element located below the given node.

Sensor for wave elevation at the jacket centerline (relative to SWL) (**1 output**).

Sensors placed at the top central node of the transition piece (see 'TP' in Figure 3.1) provide translational and rotational displacements (**6 outputs**).

Sensors placed at nodes located at two legs diagonal to each other (see 'K1L1' and 'K1L4' in Figure 3.1) provide axial forces (**2 outputs**).

Sensors placed at nodes located at the centers of X-Joints (see 'X2S2', 'X2S3', 'X4S2' and 'X4S3' in Figure 3.1) provide out-of-plane deflections parallel to the axis of the global coordinate system (**4 outputs**). Please note that the jacket sides are slightly inclined, thus the plane created by X-braces is also inclined from the vertical position. This plane is not taken as the reference plane for the out-of-plane deflections, but the vertical plane. The problem is illustrated in Figure 3.2.

Sensors placed at nodes located in the center of a brace between a K-joint and the center of the very bottom X-Joints ('B59' and 'B61' in Figure 3.1). Axial forces (**2 outputs**) shall be recorded and out-of-plane shear forces with respect to the

<sup>1</sup>The appendix content is based on a memo note describing the coordinate systems used within the OC3 project. The note was prepared by Thomas Krogh from Risø Wind Energy Department, 24.11.2005.

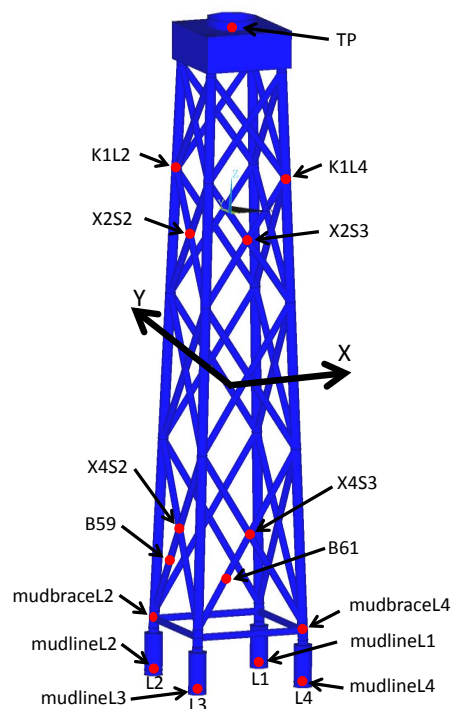
vertical plane whereas the plane is defined as in the above case of the centers of the X-Joints (**2 outputs**).

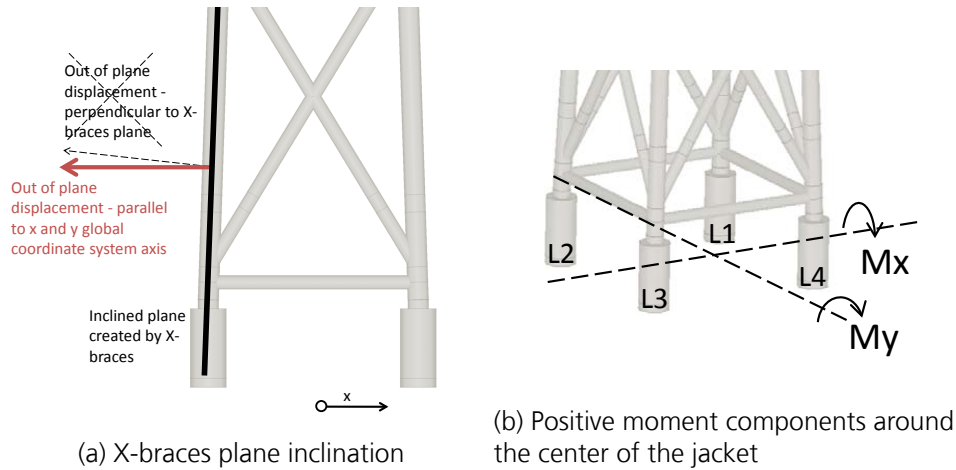
Sensors placed at mudbraces nodes located at two legs diagonal to each other (see 'mudbraceL2' and 'mudbraceL4' in Figure 3.1) provide axial forces (**2 outputs**).

The six combined loads at the jacket base (mudline level). In detail, the base shear in terms of sums of  $F_x$  and  $F_y$  force components from 4 piles. The overturning moments  $M_x$  and  $M_y$ , calculated at mudline in the tower centerline from the vertical forces in the 4 piles, as shown in Figure 3.2. The global torsion at mudline calculated with the  $F_x$  and  $F_y$  force components from 4 piles and the global vertical Force summed from the four  $F_z$  force components (**6 outputs**).

This leads to a total number of **25 outputs** additional to the turbine outputs.

Figure 3.1  
Placement of sensors  
in the jacket



Figure 3.2  
System convention

The structure of the data output file generated by each OC4 participant must be the same for post processing. The output files start with line (the 8th row in the spreadsheet) reserved for general comments, followed by a line with the column headers (row 9). Then, there is a line, which stores units (row 10). The column data starts at line 11 at time  $t = 0$  and the following lines contain the results for the fixed output time step as defined in Table 2.1. The convention for the column-wise sensors data placement, the headers naming and units in the output file is specified in Appendix A. Herein, turbine outputs and support structure outputs are listed. The output file should consist of 58 columns separated by tabulation, each one with unique header naming. Additionally, the naming convention of the output files must be introduced. The output file ought to be named in the following way: *OrganizationName\_CodeName\_WorkPackage\_LoadCase.txt*



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## A Column numbers, column headers and sensor descriptions

Column No.	Column Header	Unit	Sensor description	Convention
1	Time	s	Simulation time	Starts at 0s
2	WindVxi	m/s	Longitudinal wind speed	Measured at the hub height in a free stream
3	WindVyi	m/s	Lateral wind speed	
4	WindVzi	m/s	Vertical wind speed	
5	WaveElev	m	Wave elevation at tower centerline	Relative to SWL
6	GenPwr	kW	Electrical generator power	Positive when generating power, negative when motoring
7	GenTq	kNm	Electrical generator torque	
8	OoPDefl1	m	Blade 1 out-of-plane tip deflection	Blade coordinate system that does not pitch
9	IPDefl1	m	Blade 1 in-plane tip deflection	
10	TwstDefl1	deg	Blade 1 tip twist	
11	BldPitch1	deg	Blade 1 pitch angle	positive towards feather
12	Azimuth	deg	Blade 1 azimuth angle	Positive clockwise when looking downwind
13	RotSpeed	rpm	Low speed shaft speed	
14	GenSpeed	rpm	High speed shaft speed	
15	TTDspFA	m	Tower top fore-aft deflection	Global coordinate system
16	TTDspSS	m	Tower top side-to-side deflection	
17	TTDspTwst	deg	Tower top twist	
18	Spn2MLxb1	kNm	Blade 1 edgewise bending moment at 50% span	Blade coordinate system that pitches
19	Spn2MLyb1	kNm	Blade 1 flapwise bending moment at 50% span	
20	RootFxc1	kN	Blade 1 out-of-plane shear force at root	Blade coordinate system that does not pitch
21	RootFyc1	kN	Blade 1 in-plane shear force at root	
22	RootFzc1	kN	Blade 1 axial force at root	
23	RootMxc1	kNm	Blade 1 in-plane bending moment at root	
24	RootMyc1	kNm	Blade 1 out-of-plane bending moment at root	
25	RootMzc1	kNm	Blade 1 pitching moment at root	
26	RotTorq	kNm	Low speed shaft torque	Positive when generating power, negative when motoring
27	LSSGagMya	kNm	Low speed shaft 0-deg bending at main bearing	Coordinate system that rotates with shaft
28	LSSGagMza	kNm	Low speed shaft 90-deg bending at main bearing	
29	YawBrFxp	kN	Tower top fore-aft shear force	Global coordinate system
30	YawBrFyp	kN	Tower top side-to-side shear force	
31	YawBrFzp	kN	Tower top vertical force	
32	YawBrMxp	kNm	Tower top side-to-side bending moment	
33	YawBrMyp	kNm	Tower top fore-aft bending moment	
34	YawBrMzp	kNm	Tower top yawing moment	
35	TPX	m	Transition piece fore-aft deflection	
36	TPY	m	Transition piece side-to-side deflection	
37	TPZ	m	Transition piece top-down deflection	
38	TPRotX	deg	Transition piece rotation around global x-axis	
39	TPRotY	deg	Transition piece rotation around global y-axis	
40	TPRotZ	deg	Transition piece vertical rotation	
41	K1L2	kN	Axial force in Leg 2 at K-joint level 1	Local element coordinate system
42	K1L4	kN	Axial force in Leg 4 at K-joint level 1	

Column No.	Column Header	Unit	Sensor description	Convention
43	X2S2	m	Out-of-plane deflection at center of X-joint at level 2 on side 2	Global coordinate system
44	X2S3	m	Out-of-plane deflection at center of X-joint at level 2 on side 3	
45	X4S2	m	Out-of-plane deflection at center of X-joint at level 4 on side 2	
46	X4S3	m	Out-of-plane deflection at center of X-joint at level 4 on side 3	
47	B59Ax	kN	Axial force in center of Brace 59	Local element coordinate system
48	B59Sh	kN	Out-of-plane shear force in center of Brace 59	Global coordinate system
49	B61Ax	kN	Axial force in center of Brace 61	Local element coordinate system
50	B61Sh	kN	Out-of-plane shear force in center of Brace 61	
51	MudbraceL2	kN	Axial force in Leg 2 at mudbrace level	Global coordinate system
52	MudbraceL4	kN	Axial force in Leg 4 at mudbrace level	
53	BSX	kN	Fore-aft base shear	
54	BSY	kN	Side-to-side base shear	
55	OTMX	kNm	Overturning moment around global x-axis	
56	OTMY	kNm	Overturning moment around global y-axis	
57	MudMz	kNm	Moment around global z-axis at mudline	
58	MudFz	kN	Summed force along global z-axis at mudline	

## B Coordinate system definition

The set of coordinate systems used in the OC4 project corresponds to the coordinate systems used within the IEA Annex 23 OC3 project. The most important definitions of coordinate systems are described within this appendix.

### B.1 Global coordinate system

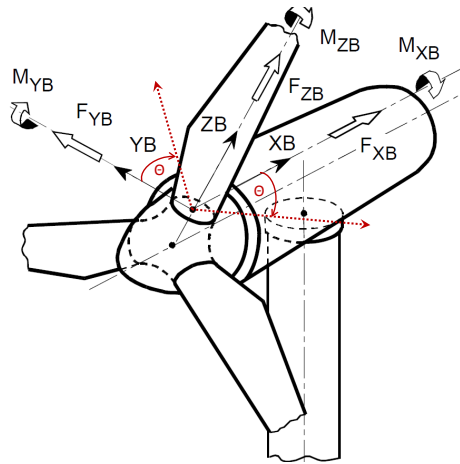
The global coordinate system (Figure B.1) has its origin at the MSL, at the center of the jacket sub-structure. The z-axis points upward, the x-axis points downwind and the y-axis is perpendicular to the plane created by x and z-axis according to the right hand Cartesian coordinate system.



### B.3 Blade coordinate system that pitches

The pitching blade coordinate system (Figure B.3) rotates with the rotor and has its origin at the center of the blade root. The z-axis points towards the blade tip along the pitch axis, the x-axis is perpendicular to the z-axis and points downwind when the blade pitch angle is 0 deg, y-axis creates the right hand Cartesian coordinate system. The coordinate system rotates clockwise around the z-axis looking down from the blade tip, when the blade pitches out.

Figure B.3  
Blade coordinate system that pitches (GL, 2010)



## Appendix

## C Wavelets definition

Table C.1  
Wavelets data

Number	Wave number [1/m]	Frequency [rad/s]	Phase [deg]	Amplitude [m]
1	2.44E-2	0.4487	0.0056	0.2997
2	2.73E-2	0.4850	94.7072	0.2997
3	2.90E-2	0.5048	184.0358	0.2997
4	3.04E-2	0.5201	330.2281	0.2997
5	3.16E-2	0.5332	23.5924	0.2997
6	3.27E-2	0.5449	157.6506	0.2997
7	3.37E-2	0.5557	33.8721	0.2997
8	3.48E-2	0.5659	128.7826	0.2997
9	3.57E-2	0.5757	129.0934	0.2997
10	3.67E-2	0.5851	312.9789	0.2997
11	3.77E-2	0.5942	276.1215	0.2997
12	3.87E-2	0.6032	13.9798	0.2997
13	3.97E-2	0.6121	238.295	0.2997
14	4.07E-2	0.6209	24.8919	0.2997
15	4.17E-2	0.6296	38.4924	0.2997
16	4.27E-2	0.6384	21.3841	0.2997
17	4.38E-2	0.6472	123.2276	0.2997
18	4.49E-2	0.6561	5.5427	0.2997
19	4.60E-2	0.6650	276.0593	0.2997
20	4.72E-2	0.6741	48.1264	0.2997
21	4.84E-2	0.6834	300.5899	0.2997
22	4.96E-2	0.6928	134.4764	0.2997
23	5.09E-2	0.7024	64.0632	0.2997
24	5.23E-2	0.7123	309.9143	0.2997
25	5.37E-2	0.7225	249.2402	0.2997
26	5.52E-2	0.7329	19.3887	0.2997
27	5.68E-2	0.7438	66.2147	0.2997
28	5.85E-2	0.7550	110.8217	0.2997
29	6.02E-2	0.7667	299.5195	0.2997
30	6.21E-2	0.7789	144.8572	0.2997
31	6.41E-2	0.7916	295.431	0.2997
32	6.63E-2	0.8051	188.7826	0.2997
33	6.86E-2	0.8192	188.9662	0.2997
34	7.11E-2	0.8342	34.1744	0.2997
35	7.38E-2	0.8502	169.979	0.2997
36	7.68E-2	0.8674	236.3286	0.2997
37	8.01E-2	0.8858	95.4998	0.2997
38	8.37E-2	0.9058	184.6155	0.2997
39	8.78E-2	0.9276	353.5469	0.2997
40	9.24E-2	0.9517	263.0438	0.2997
41	9.77E-2	0.9786	177.868	0.2997
42	1.04E-1	1.0089	347.4362	0.2997
43	1.11E-1	1.0437	160.3155	0.2997
44	1.20E-1	1.0843	182.4162	0.2997
45	1.31E-1	1.1331	109.0934	0.2997
46	1.45E-1	1.1939	52.3338	0.2997
47	1.65E-1	1.2734	94.777	0.2997
48	1.96E-1	1.3866	276.9891	0.2997
49	2.53E-1	1.5756	196.3512	0.2997
50	4.59E-1	2.1212	314.2162	0.2997

## D Wavelets generation

This is only supplementary information, giving a background of the attached wavelets, which were calculated in ASAS software. This information is not required for the reconstruction of the irregular sea state. The wavelets data, given in the Appendix C, shall be used directly by the project partners.

The wavelets are based on the Airy theory and are described by the following equation:

$$\eta(x,t) = A \cos(\kappa x - \omega t + \phi) \quad (1)$$

where:

$\eta$  – water surface elevation [m]

$A$  – amplitude (half wave height) [m]

$\kappa$  – wave number =  $2\pi/\lambda$  [1/m],  $\lambda$  – wave length [m]

$\phi$  – phase shift [deg]

$\omega$  – angular frequency =  $2\pi/T$  [rad/s],  $T$  – wave period [s]

All the wavelets are generated with a constant amplitude method assuring that the area (energy content) of each frequency stripe under the spectrum graph is always the same. The frequency range in the Pierson-Moskowitz spectrum is limited by start and cut-out values, which are calculated as follows:

$$\omega_{\text{start}} = 0.001526 \omega_{\text{peak}} \quad (2)$$

$$\omega_{\text{cut-out}} = 5.11 \omega_{\text{peak}} \quad (3)$$

The wave numbers shown in Appendix C are inversely proportional to the wave length. The wavelength is calculated iteratively according to the following equation:

$$\lambda_i = \lambda_i^d \tanh(2\pi d / \lambda_i) \quad (4)$$

where:

$\lambda_i$  – wave length [m]

$\lambda_i^d = g\tau_i^2 / 2\pi$  – deep water wave length [m],  $\tau_i$  – wave period [s]

$g$  – gravitational acceleration [m/s<sup>2</sup>]

$d$  – water depth [m]