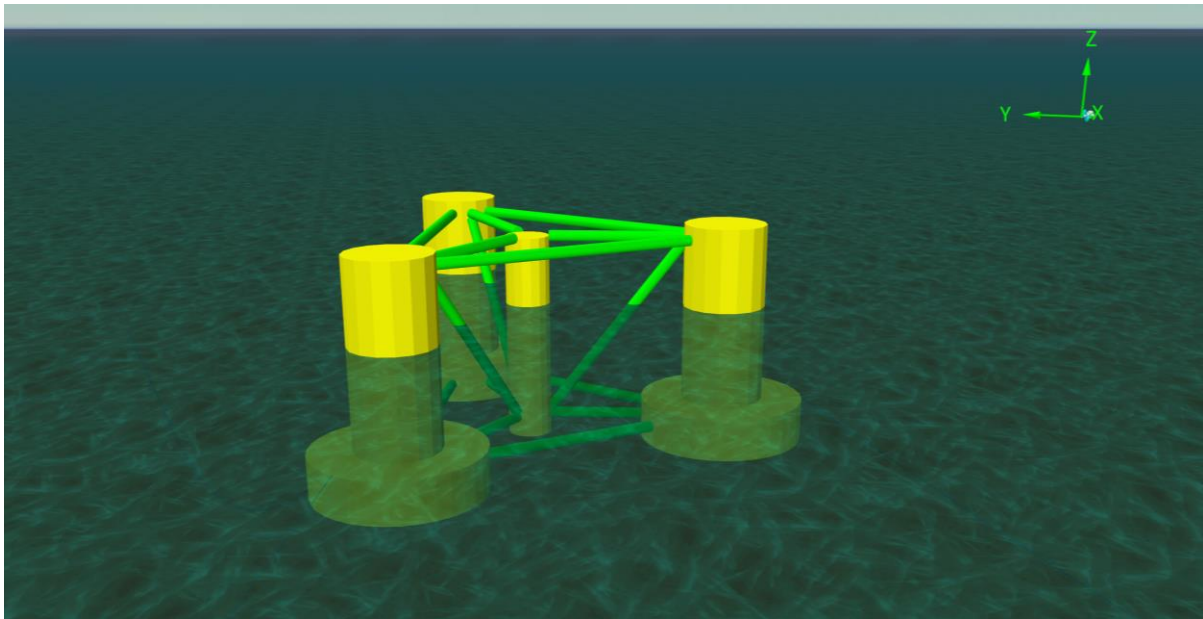# L02 OC4 Semi-sub

Introduction

In this example we use OrcaWave to perform a diffraction analysis of a semi-submersible floating wind turbine platform. This example demonstrates the importance of doing a mesh sensitivity study and explains how to handle the situation where a relatively large superstructure is modelled explicitly in OrcaFlex.

The semi-sub being modelled here is based on the DeepCwind platform. The properties of this platform are publicly available and well documented in the Offshore Code Collaboration study OC4, phase II.

The turbine, nacelle and tower used in this example are taken from our K01 5MW spar FOWT example, which in turn is based on the OC3 Hywind spar.

Note: *The properties applied in these examples are based on our interpretation of the data provided in the OC3/OC4 studies and are not necessarily correct. If you use these models, or any part of them, for your own analysis purposes, you <u>must</u> first satisfy yourself that they are correct and appropriate for the scenario being analysed.*
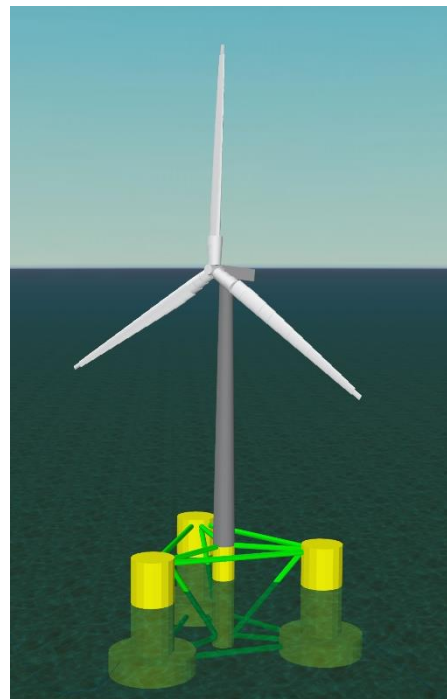
OrcaWave diffraction analysis

Mesh

The starting point for doing a diffraction analysis is to generate a suitable mesh of the vessel's hull form. OrcaWave does not currently include a mesh generation or editing tool, therefore a suitable meshing tool is needed to generate a mesh file. OrcaWave accepts various mesh formats including WAMIT .gdf, AQWA .dat and Hydrostar .hst formats. For a full list, please see the Mesh file formats page of the OrcaWave help.

In this example we have used Rhino to generate and edit meshes in the WAMIT .gdf format, but other tools are available.
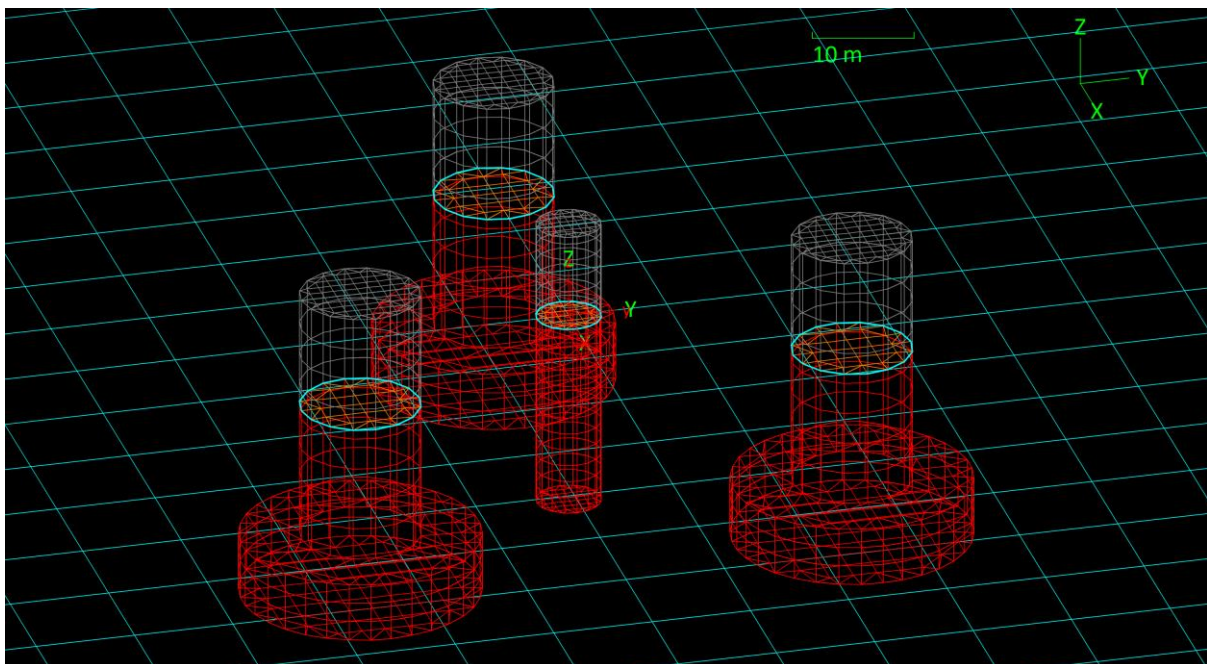

Figure 1: Panel mesh

The OrcaWave data input and results outputs are covered in more detail in the example L01 Default vessel.

In this example we use OrcaWave to generate 1st order wave load data (load RAOs), 2nd order drift loads (in the form of Newman QTFs) plus stiffness, added mass & damping data. Displacement RAOs will also be output, however because our OrcaFlex analysis will use a vessel in 'fully calculated' mode, we will not be using these.

Semi-sub modelling

The platform consists of a main central column attached to three larger offset columns via a series of smaller diameter cross members (also referred to as 'pontoons'). For this example, the platform is assumed to be a rigid body.

Open the OrcaWave results file *L02 OC4 Semi-sub.owr*. On the *mesh view* page, you can see the meshed main and offset columns, along with some green lines connecting them. It is assumed that the cross members are small enough to contribute only Morison drag to the platform's loading. They are therefore not present in the mesh file (shown in Figure 1 above) but are added to the model as *Morison elements*, drawn as green lines in the *mesh view*. In addition, the definition

document required the viscous drag associated with the main central column and three offset columns to also be modelled by the addition of Morison elements. Further discussion about Morison elements is offered later in this document.

The origin of the platform is on the centreline, 20m above the base. This corresponds with the still water level of the complete turbine and platform assembly, in its moored condition.

We want to evaluate the platform's motion when it has the full wind turbine and tower arrangement mounted on it, therefore the properties applied in OrcaWave must be representative of the complete system: platform + tower + nacelle + rotor. Collectively, these items are referred to as the platform's 'superstructure'. These properties are applied on the *inertia* page and in this case, we have used the following data:

Item	Mass (te)	Centre of mass (CoM) relative to origin (0,0,0) (m)			Mass moments of inertia about object's CoM (te.m^2)		
		x	y	z	Ixx	Iyy	Izz
Platform	13473	0.000	0.000	-13.460	6.827E+06	6.827E+06	1.226E+07
Tower	249.718	0.000	0.000	43.322	1.206E+05	1.206E+05	1818.395
Nacelle	240	1.900	0.000	89.343	350.024	5409.870	2607.890
Rotor (inc hub)	110	-5.452	0.000	90.040	19549.619	19549.619	39060.238
Total	14072.718	-0.010	0	-9.890	11.33E+06 0 13.18E+03	0 11.32E+06 0	13.18E+03 0 12.29E+06

Table 1: Mass and inertia properties

On the *bodies* page the file containing the mesh has been identified as *L02 OC4 Semi-sub mesh.gdf*. The contents of this can be viewed on the *mesh view* page.

Note that we have ticked the option to *add interior surface panels…* on the *bodies* page. The results of this action can be seen in the *mesh view*. If you rotate the view and ensure that the *interior lid panels* view option is ticked in the *view options* panel, the interior surface panels can be seen (drawn with an orange pen). In this instance the *triangulation method* creates the most suitable mesh on the interior surface.

Environment

On the *environment* page you can see that the considered water depth is 200m. The OrcaWave analysis considers 32 wave periods, ranging from 3.75s through to 30s, and 9 wave headings between 0 and 180 deg, spaced at 22.5 deg intervals.

Accounting for the mooring

In the OrcaFlex model we will be modelling the platform in its moored condition, as a 'fully calculated' vessel. This means that the displacement RAOs are not used directly in the OrcaFlex model, but if we include 2nd order wave loading then they are used indirectly, because of their use in the OrcaWave QTF calculation.

For this reason, the displacement RAOs generated must reflect the vessel in its moored condition and should include any additional damping. Therefore, on the *constraints* page, some data has been added to the external stiffness and damping tables. Again, the data applied on this page

affects the displacement RAOs, and consequently the QTFs, which are calculated from the displacement RAOs.

A mooring stiffness matrix has been applied as an *external stiffness matrix* in OrcaWave. In this case the details of the mooring system are known, so we can apply the mooring stiffness matrix to generate displacement RAOs for the platform in its moored condition. This can be achieved by following the steps below:

1. Perform an initial calculation in OrcaWave with no external stiffness (the *diffraction solve type* in OrcaWave can be *potential formulation only*).
2. Import the OrcaWave results to OrcaFlex and add the three mooring lines, using the properties provided in the OC4 documentation. It is also important to ensure that each mooring line is connected between the platform and the seabed. The superstructure (rotor, tower, etc.) should be omitted from the model during this stage because its mass and inertia are already included as part of the vessel type data.
3. The OC4 documentation states that the platform's draught of 20m is achieved when the platform and its moorings are in still water. The same documentation states that the displaced volume of the platform in its equilibrium position is 13917m^3. However, the diffraction analysis mesh file does not include the small diameter cross members. This, along with the discretisation of the mesh itself, leads to OrcaWave calculating a *lower* volume of water displaced by the body (13372m^3). In turn, this will affect the accuracy of the mooring stiffness matrix calculated by OrcaFlex. So, before calculating the mooring stiffness matrix, the *displaced volume* must be manually adjusted to the appropriate value of 13917m^3. This needs to be set on the *vessel type* data form, *stiffness, added mass and damping* page.
4. On the *vessel* data form, select the *calculation* page and make sure the *included in static analysis* setting is set to *6DOF*. That ensures that the presence of the moorings will affect the response of the platform in statics and vice versa.
5. On the same vessel data form, select the *inertia compensation* page and make sure that all data are set to zero.
6. Run a static analysis and use OrcaFlex to calculate the mooring stiffness matrix (see the Modelling, data and results | Vessels | Vessel mooring stiffness calculation page of the OrcaFlex help for further details). In this case, the mooring stiffness should be calculated for the platform in its undisplaced position i.e. in equilibrium and with no environmental loads applied.
7. Apply the mooring stiffness matrix in a further OrcaWave analysis – with the *diffraction solve type* in OrcaWave set to *potential and source formulations* – to calculate the displacement RAOs and QTFs for the moored condition.

Much of the OrcaWave calculation will not change with the addition of constraints, meaning there is no need to recalculate *all* of the results again. Instead, we can choose to output intermediate results, from the first calculation, for subsequent use in the second. This accelerates the second calculation considerably, meaning it is particularly useful for analysing bodies with a large number of panels, or where multiple calculations are performed using e.g. different inertia or QTF calculation options.

In this case the calculation runs very quickly, so we have simply run the same model twice, once without the constraints and once with them included.

External damping

Some data has also been applied as an *external damping matrix,* to account for additional linear damping. The data applied in this example comes from comparison against tank test free-decay results (as part of the Offshore Code Collaboration study OC6 phase I work) and may not be appropriate for other situations.

Morison elements

As discussed previously, Morison elements have been added to the OrcaWave model to account for viscous drag. On the *Morison elements* page, there are 4 types of Morison element defined, each with associated drag diameters and coefficients. In the lower table these element types are used, along with position and orientation information, to add elements to the body.

Note that a clear *pen style* has been used for three of the four element types is set so that they don't show in the mesh view. The mesh itself provides the visualisation of the central and offset columns in this case, so we don't need the additional visualisation that the Morison elements would give us.

Number of Morison element types: 4

		Pen		
Name	Width	Style	Colour	
UC morison	1	Clear		
BC morison	1	Clear		
MC morison	1	Clear		
Pontoon morison	1	Solid		

Since Morison drag is quadratic, stochastic linearisation is performed to obtain a linearised drag model which can contribute to the first-order equation of motion. Linearisation is performed for a given sea state, defined by a wave spectrum. The wave spectrum to be used is defined on the *wave spectrum* page, and in this case, we have used the same spectrum as we intend to use in our OrcaFlex analysis.

The linearised drag will affect results for displacement RAOs (and quantities dependent on them, such as QTFs). Drag does not affect results for load RAOs, added mass or damping.

Viewing the results

After familiarising with the OrcaWave model, the results of the OrcaWave analysis can be viewed on the *graphs* and *tables* pages. For further details about viewing results, please refer to the example L01 Default vessel.

Mesh sensitivity results

To check that the considered mesh was refined enough to give accurate results without being unnecessarily dense (which would increase the calculation time), a basic sensitivity study was done. In this case, the full set of periods and headings was included, however a reduced set could be used for efficiency. This analysis was repeated with 3 different mesh densities (ranging from ~900 up to ~5000 panels), so that the results could be compared.

Further details about working with OrcaWave meshes, please see our document available on the papers and technical notes page of the Orcina website.

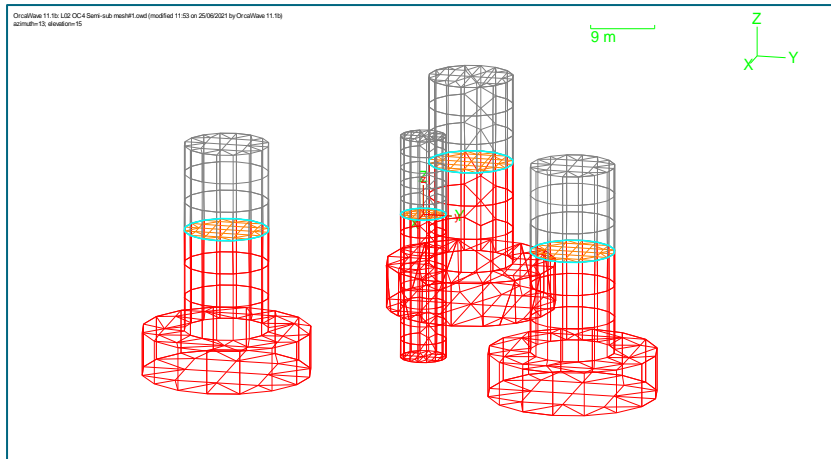**Figure 2: Mesh #1, 864 panels**

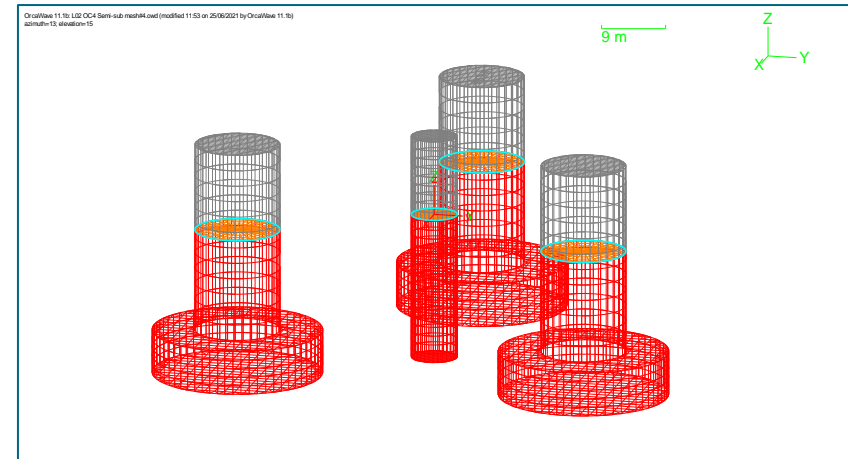**Figure 4: Mesh #3, 5140 panels**
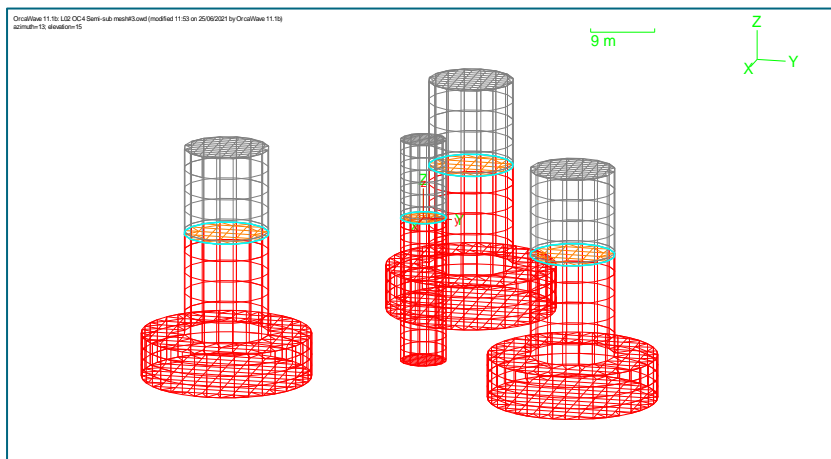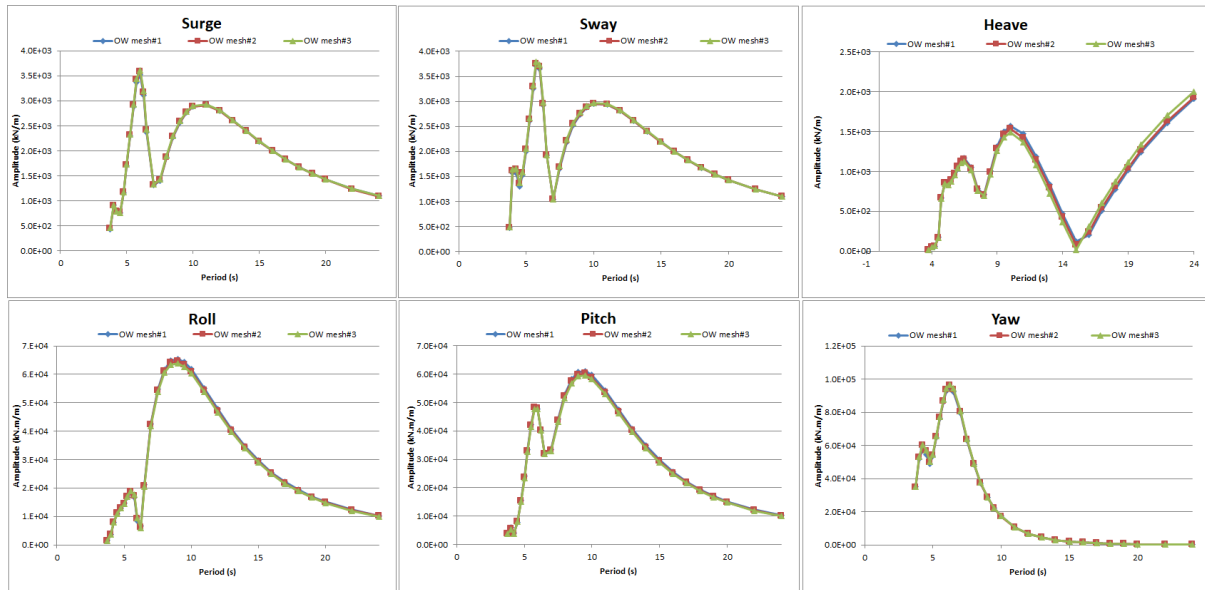

Figure 3: Mesh #2, 1710 panels

Figure 5: Load RAO amplitude plots for different mesh densities, 45° direction
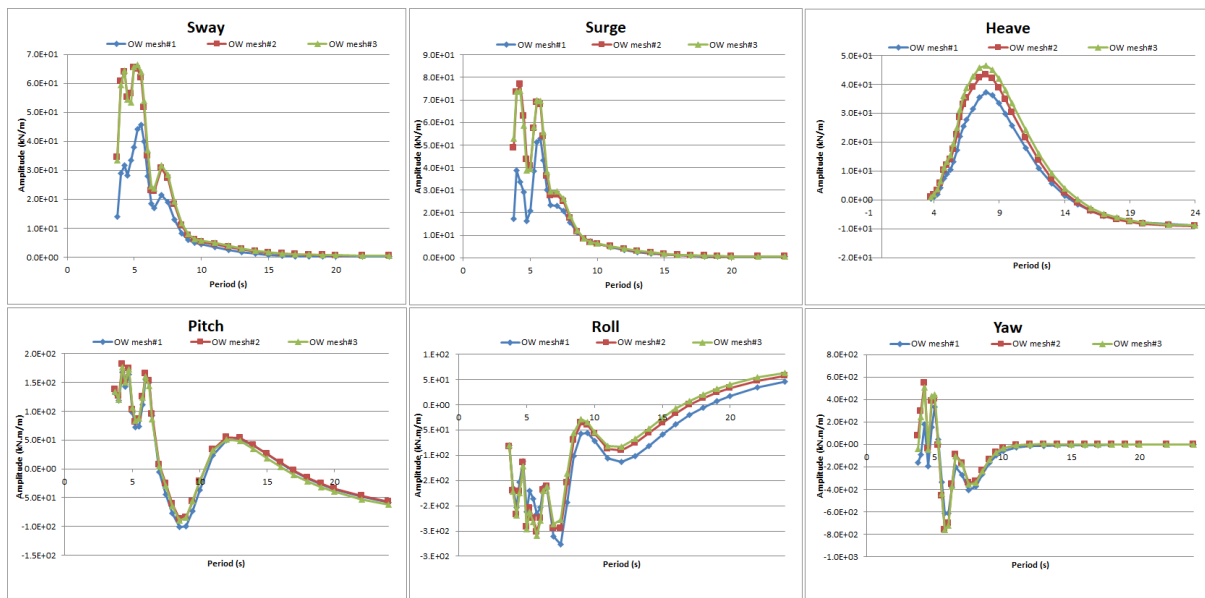

Figure 6: Mean drift load plots for different mesh densities, 45 deg direction
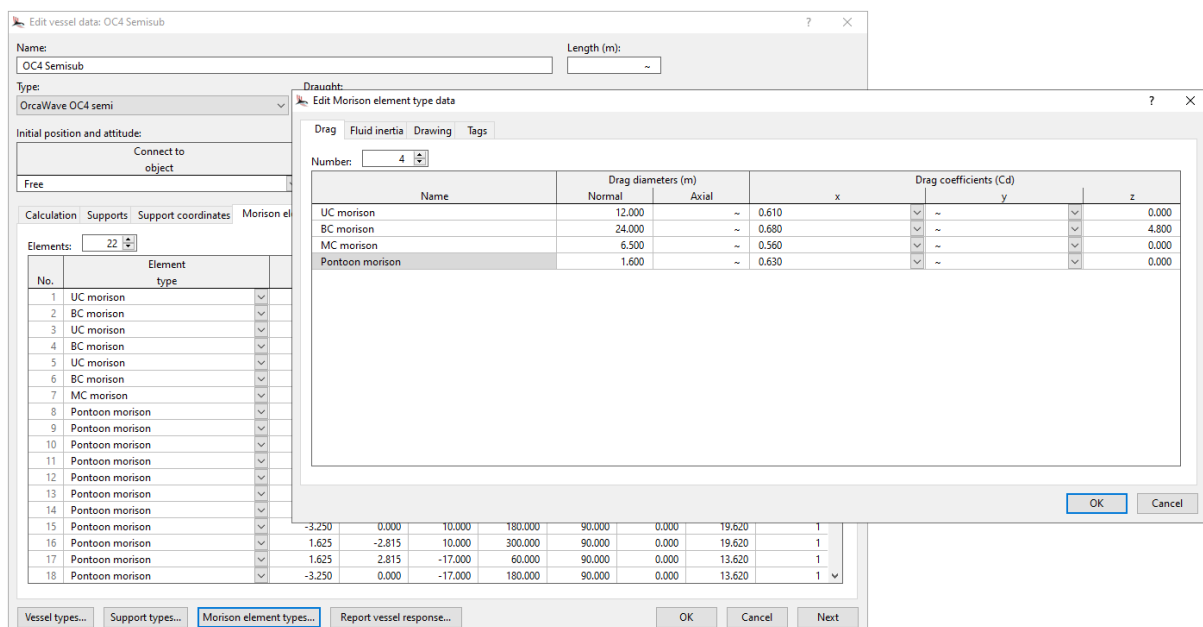
OrcaFlex dynamic analysis

Setting up the OrcaFlex model

Open the OrcaFlex model *L02 OC4 Semi sub.sim*.

The data created by the OrcaWave analysis has been imported into OrcaFlex as a vessel type named *OrcaWave OC4 semi*. Note that if this import is done by opening the OrcaWave results file (*.owr*) in OrcaFlex then the *Morison elements* are also imported, along with various other data.

Note that importing the data via the import hydrodynamic data process, in an existing OrcaFlex model, will not import the Morison elements; meaning they would need to be added separately. However, this is a relatively straightforward task because you can copy and paste the data directly from OrcaWave to OrcaFlex.

For further details about the import process, please refer to the Modelling, data and results | Vessels | Importing hydrodynamic data | OrcaWave page of the OrcaFlex help.
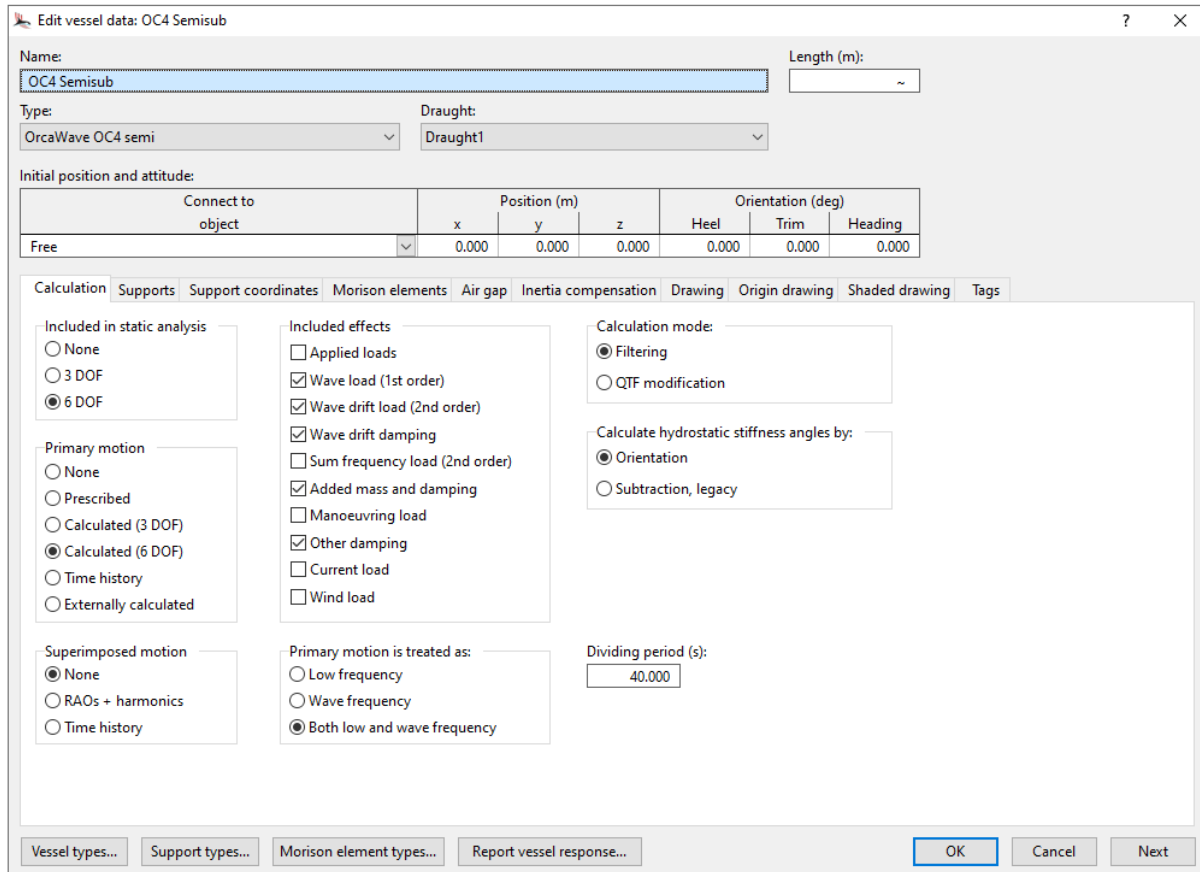

In this example, there are some additional pieces of data to set before we can run an OrcaFlex analysis.

Again, the displaced volume of the platform in its equilibrium position is specified in the OC4 documentation as 13917 m^3, so we have manually adjusted the *displaced volume* on the *stiffness, added mass and damping* page of the *vessel type* data form to match this value.

In the model we have added the three mooring lines, using the properties provided in the OC4 documentation, and connected each mooring line between the platform and the seabed.

On the *calculation* page of the *OC4 Semisub*'s data form, the calculation method used for the vessel is set. In this case we want the analysis to be fully coupled i.e. we want the presence of the moorings to affect the response of the semi-sub and vice versa. To enable this, the *included in static analysis* and *primary motion* options are both set to *6 DOF*. The *superimposed motion* option is set to *None*.

In the list of *included effects*, we have ticked the required options, as shown by the screen shot below.

The primary motion includes contributions from *both low and wave frequency* motion, therefore we have also set the *dividing period* to filter the motion into its low and wave frequency components. This is necessary because the included effects that depend only on the low frequency motion (in this case, the wave load, the wave drift load, and the wave drift damping) use only the low frequency part of the primary motion in their calculation. Please see the vessel modelling overview page of the OrcaFlex help for further details on these options.

The *dividing period* should ideally be well above the highest period of the significant wave frequency response of the vessel and, at the same time, well below the lowest period of significant slow drift response (usually given by the vessel's surge, sway and/or yaw natural periods).

A modal analysis showed that, in this case, the shortest of the above-mentioned natural periods is in yaw at ~64s. In this case, a JONSWAP wave spectrum is applied, with Hs =7m and Tp = 8s, which has most of its energy in the frequency range >0.05 Hz (<20s period). The wave frequency spectrum provides some visibility on this. You can view this by clicking on the *view frequency spectrum* button on the *waves* page of the *environment* data form.

In this case, a choice of 40s for the *dividing period* – which is roughly midway between these two values – is considered reasonable.

Note that a further use is made of the mesh file to provide some visuals of the platform. Both the wire frame and shaded graphics views of the platform use the panels defined in the mesh file, which can be automatically imported along with the other OrcaWave data.

Modelling the superstructure

In systems where there is a superstructure that is relatively large and represents a significant proportion of the total mass and inertia of the floater, you may wish to model the superstructure in detail. Typical examples of this requirement are installation analysis of heavy topsides, or analysis of floating wind turbines.

In the case of floating wind turbine systems, if we want to include the rotation of the rotor and flexing of the tower & blades in our OrcaFlex model, then we need to model them explicitly. In the OrcaFlex model we have therefore added a turbine object, 6D buoy and line to represent the rotor, nacelle, and tower respectively. These objects have been copied directly from the K01 5MW spar FOWT example model.

Recall that our OrcaWave analysis included the mass and inertia of the platform *and* the superstructure. This means that the vessel type imported into OrcaFlex contains the total mass and inertia of the turbine rotor, nacelle and tower. As we have now added these items as separate objects in the OrcaFlex model – each with their own mass and inertia properties – we need to make sure that we don't double-count the mass and inertia of these objects!

So, when we model these items explicitly, we need to remove their contribution from the mass and inertia properties of the vessel type. In addition, it is also necessary to modify the vessel type's hydrostatic stiffness matrix.

OrcaFlex can do this calculation automatically, provided that you apply the *mass*, *moment of inertia tensor* and *centre of mass* of the superstructure on the *inertia compensation* page of the *vessel* data form. If the superstructure comprises multiple parts (as is the case here, with the rotor, nacelle and tower) then OrcaFlex can also calculate the combined properties of these objects so that you can easily add the data to the *inertia compensation* page.

To do this, you need to first add the superstructure components to the model, as we have done. Then, in the *model browser*, multi-select those objects, right-mouse click and select *properties* from the pop-up menu to open the compound properties report (pictured below).

Note that we want the compound properties to be reported relative to the platform's origin, therefore we select the platform (*OC4 Semisub*) from the *report relative to:* drop-down box at the top of the compound properties report. The mass, centre of mass and mass moment of inertia matrix can all then be copied and pasted directly into the *inertia compensation* page of the *vessel* data form. OrcaFlex will then be able to make the necessary subtractions.

Further details about this feature can be found on the Theory | Vessel theory | Inertia compensation page of the OrcaFlex help.
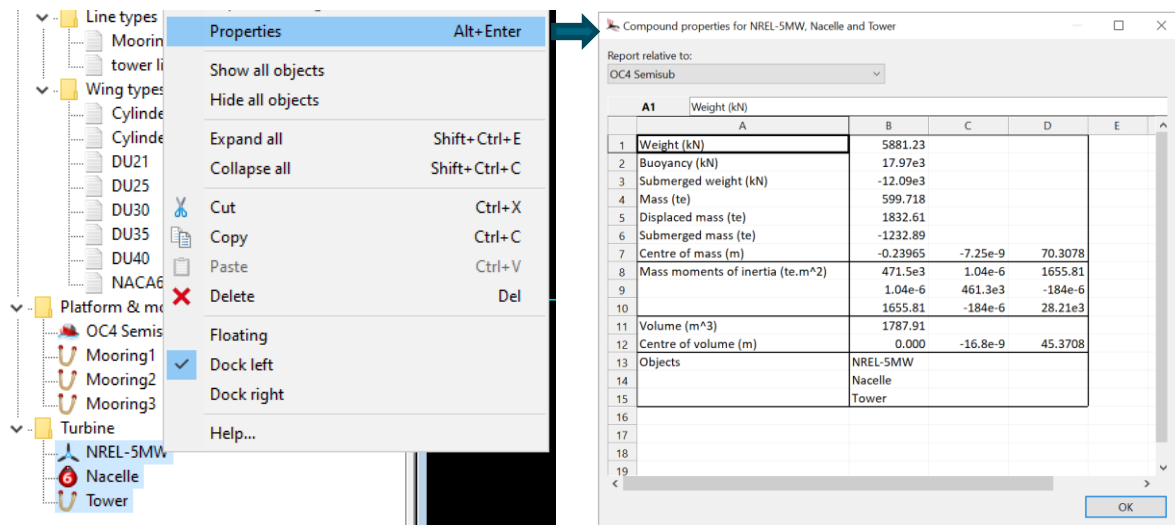
Wind turbine controllers

For simplicity, the turbine in this example does not use sophisticated control algorithms to control the blade pitch and the generator torque. Therefore, Python is not required to run this model. For examples of modelling such controllers, please refer to the turbine examples in the K Renewables examples set.

For this example, the following settings are considered for the *NREL-5MW* turbine object:

- On the *generator* page, the *generator control mode* has been set to *specified rotation*, with an *angular velocity* of 6 rad/s.
- On the *blades* page, the blade *pitch controller* has been switched off (set to *(none)*) and the *blades DOFs* set to *fixed*.

The simulation has been run with a constant wind speed of 15m/s, and a JONSWAP wave spectrum with a significant wave height (*Hs*) of 7m and a zero-crossing wave period (*Tz*) of 8s.