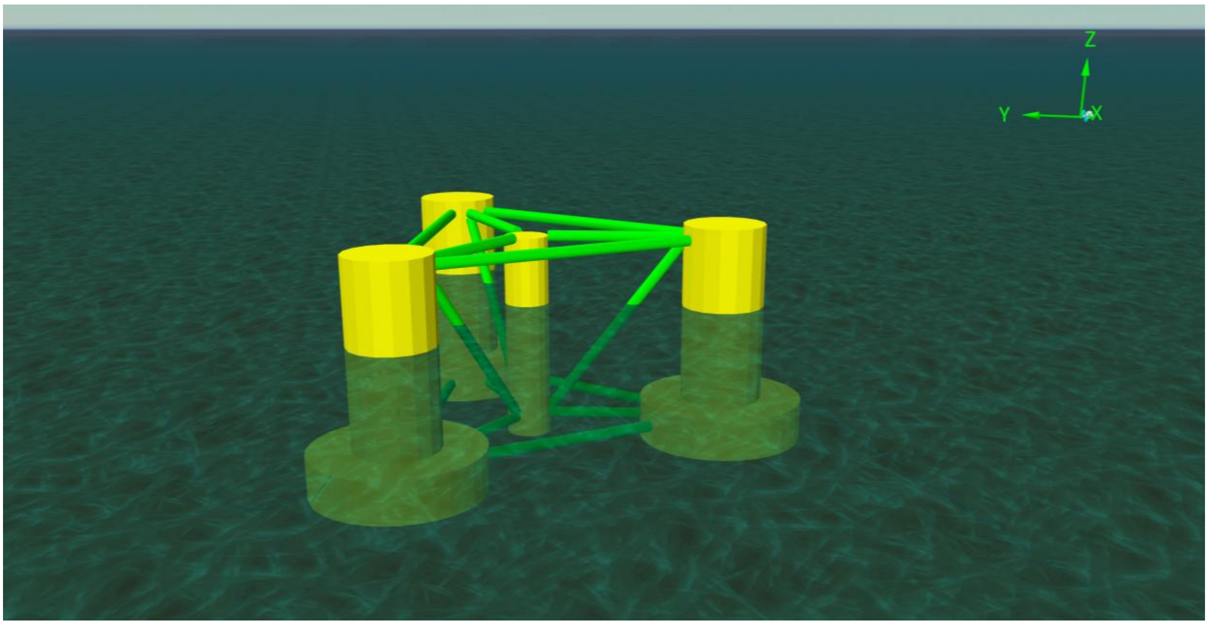
L02 OC4 Semi-sub

Introduction

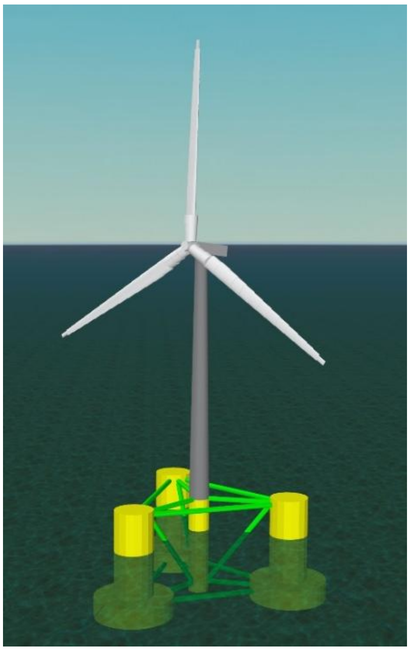
In this example we use OrcaWave to perform a diffraction analysis on a semi-submersible floating wind turbine platform. We demonstrate OrcaWave's ability to build a control surface mesh for the calculation of quadratic loads. We also demonstrate a procedure for modelling the influence of a mooring system in a diffraction analysis. Finally, we discuss the inclusion of Morison elements in diffraction analysis and explain how to deal with the mass and inertia properties of objects representing the platform's superstructure (rotor, nacelle and tower), where the object properties were initially part of the diffraction system but are later explicitly modelled 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 must first satisfy yourself that they are correct and appropriate for the scenario being analysed.*



OrcaWave diffraction analysis

Calculation preferences

In this example we intend to model a vessel object in OrcaFlex subject to 1st order wave loads (load RAOs), 2nd order wave drift loads (in the form of Newman QTFs) plus hydrostatic stiffness, and added mass & damping data. When building a diffraction analysis model, selection of an appropriate *diffraction solve type* is required to ensure the data calculated compliments our intentions for global analysis in OrcaFlex.

We have chosen to use the 'Potential formulation only' *diffraction solve type* since it demands the smallest peak memory requirement whilst still being capable of calculating all the vessel type data we require. Similarly, we have chosen to use the 'Control surface method' for calculation of mean drift loads. Based on our experience, the control surface method provides results of similar quality – with significantly less computational effort – compared to the pressure integration *quadratic load calculation method*. For further details, please refer to the technical note, OrcaWave working with meshes available on the papers and technical notes page of the Orcina website. The momentum conservation method is also effective but is only capable of calculating quadratic loads in 3 degrees of freedom (surge/sway/yaw).

Other *diffraction solve types* exist. The 'Potential and source formulation' option typically demands more memory but allows the user to access the 'Pressure integration' *quadratic load calculation method* as well as calculation of panel velocities. The 'Full QTF calculation' *diffraction solve type* is more extensive and more computationally demanding. It is capable of calculating a full set of sum and difference frequency QTFs.

Mesh

In a diffraction analysis, the form of the body is described using a panel mesh. 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.

The body mesh (*L02 OC4 Semi-sub mesh.gdf*) is specified on the *bodies* page and can be viewed on the *mesh view* page. In this particular case the body mesh includes several dry body panels that exist above the waterline. OrcaWave truncates the mesh at the waterline for diffraction analysis, so these panels are neglected. We have used the *add interior surface panels...* feature on the *bodies* page to place mesh panels inside the body on the water plane. Interior surface panels are used to suppress irregular frequency effects (Theory | Irregular frequencies) which could otherwise lead to irregular results. The interior surface panels can be viewed in the *mesh view*, drawn in orange by default. Please ensure the *interior surface panels* view option is ticked.

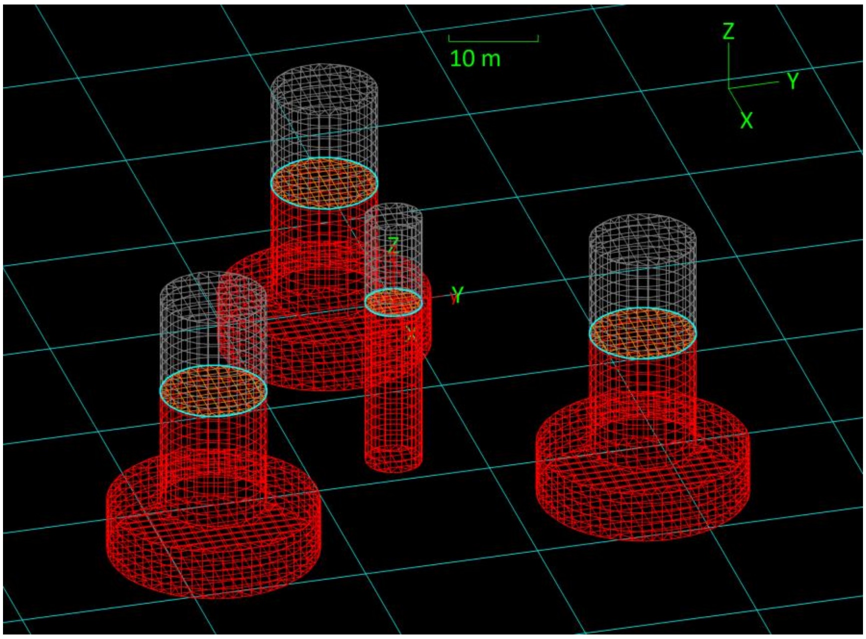


Figure 1: Panel mesh

When choosing to use the 'Control surface' *quadratic load calculation method*, an additional mesh is required. The control surface mesh often takes the form of a cuboid, enclosing a finite volume of water around the body.

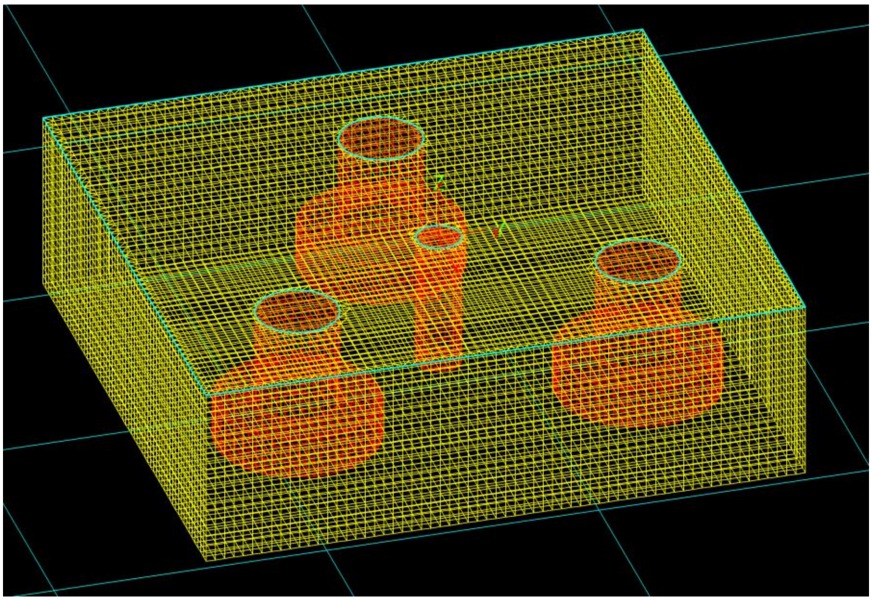
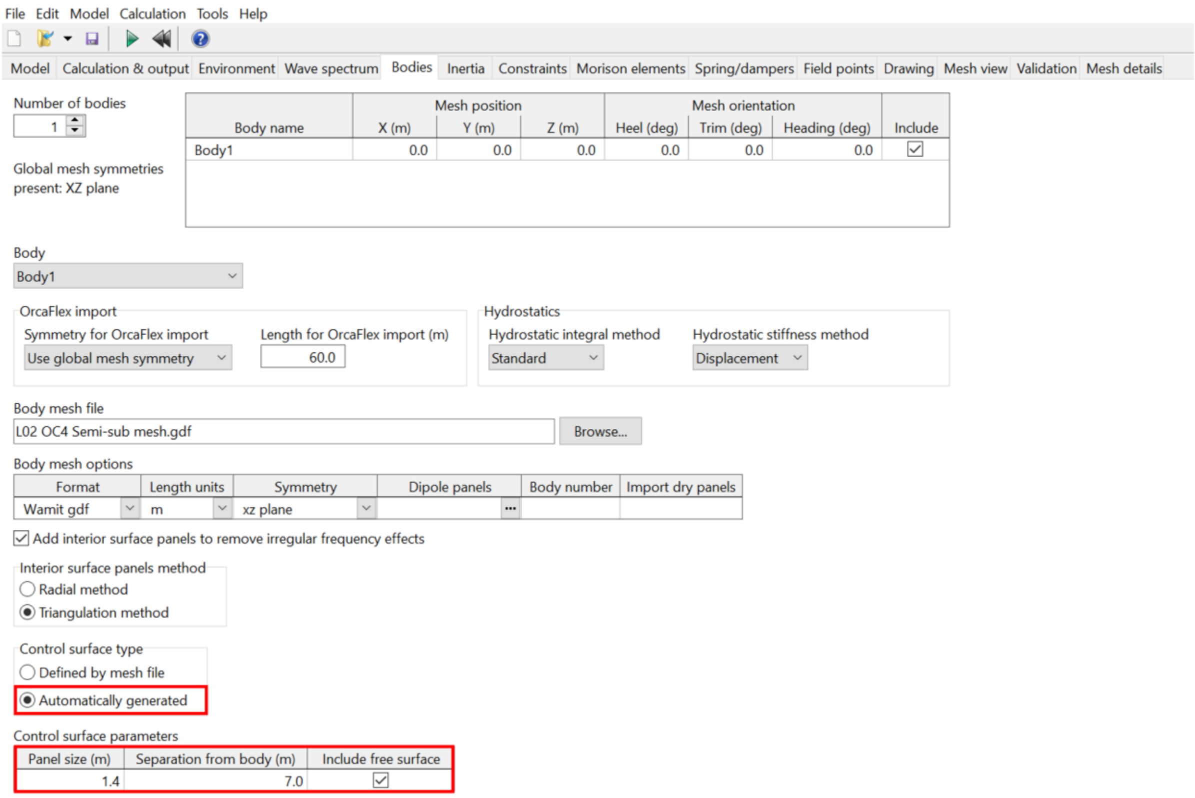


Figure 2 – Auto generated control surface mesh (yellow panels)

The control surface mesh is also defined on the *bodies* page. The user can construct the control surface mesh in a meshing tool and reference the file path. Alternatively, as shown in this example, we have selected the convenient option to instruct OrcaWave to 'automatically generate' a control surface mesh. Under this configuration, the user must define a *panel size* and *separation from the body*. OrcaWave will construct and draw the mesh, accordingly, taking into account body symmetry.



Generally, the control surface panels should be of similar size to the panels used in the body mesh. Provided that the control surface and body meshes do not collide, the separation is arbitrary. In this example we have used a value equivalent to the length of approximately 5 panels. We have also chosen to *include free surface* control surface panels. Omitting the free surface panels will limit the calculation of quadratic loads to the surge, sway & yaw degrees of freedom.

The body mesh and control surface mesh (when included) have significant influence over the quality of the results reported in a diffraction analysis. If the meshes are constructed from panels which are too large, the body form will be poorly approximated. Furthermore, there will be too few panels to adequately resolve the effect of waves of shorter wavelength. Although OrcaWave performs basic mesh validation checks, the program cannot assess whether the mesh discretisation is sufficient to ensure accurate results. Therefore, it is common practice to run a mesh convergence study to prove that the diffraction analysis results have converged.

For further details, please refer to the technical note, OrcaWave working with meshes.

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, the tower, nacelle and rotor 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

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 OrcaFlex we intend to model the platform in its moored condition. A mooring system has the effect of limiting vessel motion to some degree. Some diffraction analysis results such as load RAOs are calculated assuming the body is still. Others, like mean drift loads and full QTFs are influenced by the motion described by the displacement RAOs. Therefore, it is in the user's best interest to ensure that the motion described by the displacement RAOs is representative of the real system. To help in this task, external stiffness and external damping can be specified on the *constraints* page.

In this case the details of the mooring system are known, and a mooring stiffness matrix has been applied as an *external stiffness matrix* in OrcaWave, according to the following procedure:

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.) could 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 an under estimate of displaced volume in OrcaWave. In turn, this will influence the static equilibrium position of the system and the mooring stiffness matrix calculated by OrcaFlex. So, before calculating the mooring stiffness matrix, the *displaced volume* has been manually adjusted to the reference 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. Revisit the OrcaWave analysis from step 1 and copy & paste the mooring stiffness matrix into the *external stiffness matrix* on the *constraints* page. Rerun the diffraction analysis.

Inclusion of the mooring stiffness matrix will only influence a small subset of the OrcaWave results. Rather than recalculating all the diffraction results for a second time (step 7), we can make use of a concept known as intermediate results. Intermediate results are associated with the first OrcaWave analysis in a chain (step 1) and can be called upon for use in a related OrcaWave analysis (step 7), e.g. when a mooring stiffness matrix has been included. Intermediate results are enabled using the check box on the calculation & output page. This feature has the potential to accelerate any related analyses considerably, meaning it is particularly useful when 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 quickly, so we have simply run the same model twice, once without the constraints and once with them included.

External damping

Additional damping may also be specified in an effort to improve the quality and accuracy of the displacement RAO motion. In this example additional linear damping has been applied as an *external damping matrix*. 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.

External damping will affect displacement RAOs (and quantities dependent on them, such as mean drift loads and full QTFs). External damping will not affect results for load RAOs, added mass or wave radiation damping.

Morison elements

As discussed previously, Morison elements have been added to the OrcaWave model to account for viscous drag, otherwise neglected in an inviscid diffraction analysis. 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 so that they don't show in the mesh view. The mesh itself provides the geometry for the central and offset columns, so we don't need the additional visualisation that the Morison elements would give us.

Number of Morison element types: 4

Drag | Fluid inertia | Drawing

Name	Pen Width	Pen Style	Pen 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 the displacement RAOs (and quantities dependent on them, such as mean drift loads and full QTFs). Morison drag will not affect results for load RAOs, added mass or wave radiation 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].

OrcaFlex dynamic analysis

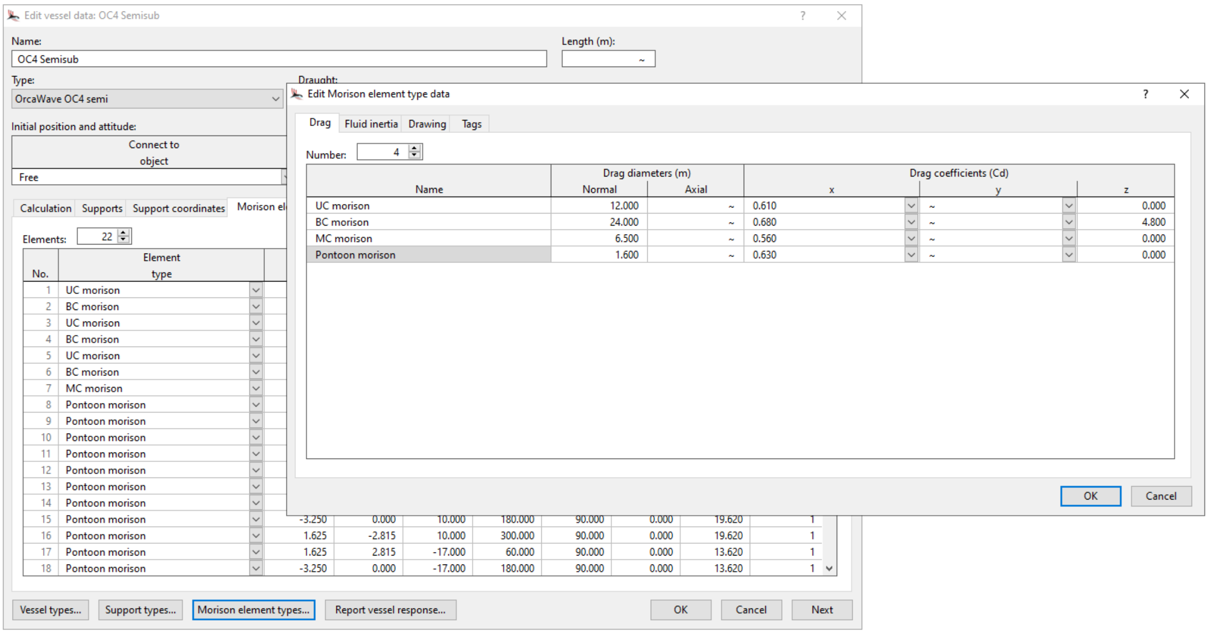
Setting up the OrcaFlex model

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

The data calculated during 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.



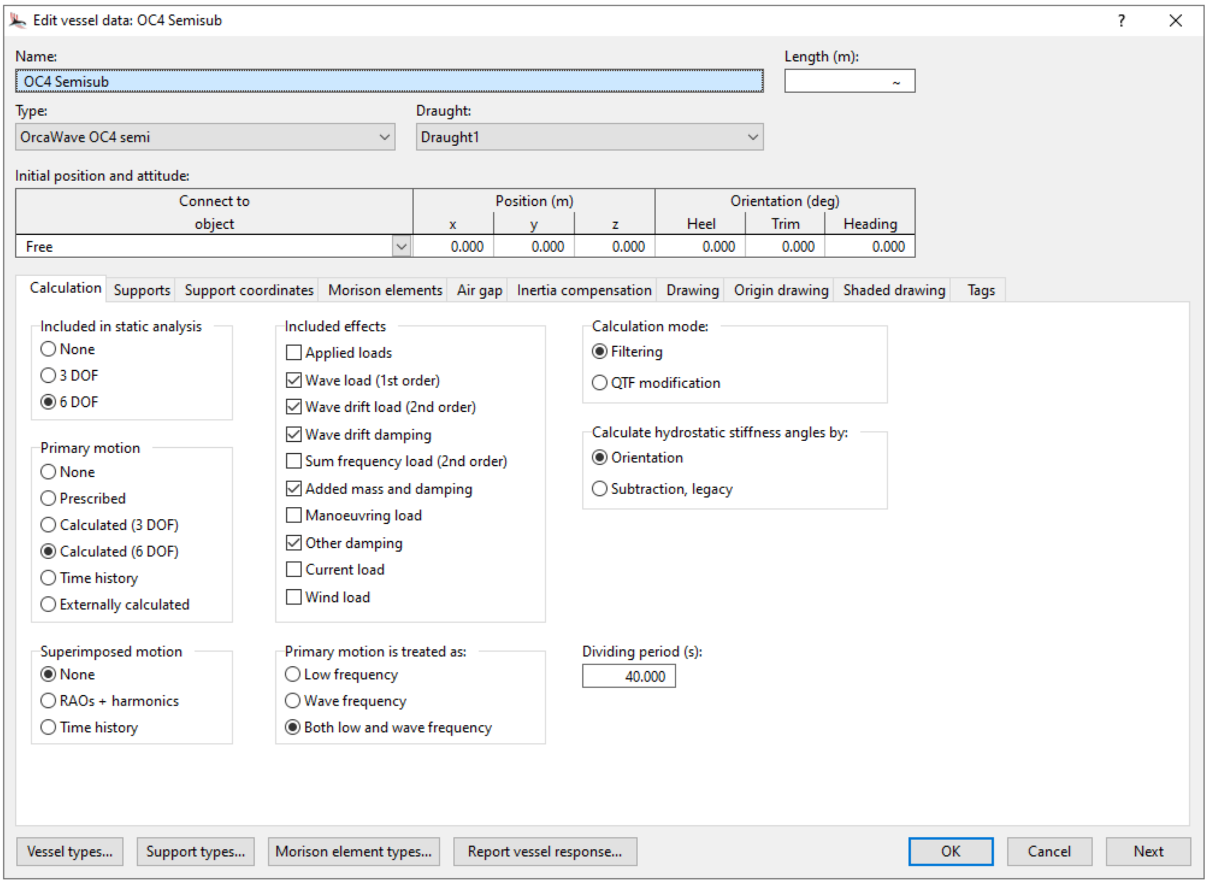
In this example, there are some additional pieces of data to set before we can run an OrcaFlex analysis.

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 and other OrcaFlex objects 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 included effects that will result in *both low and wave frequency* vessel motion, therefore we have also set the *dividing period* to filter the motion into its low and wave frequency components. This is necessary because some of the included effects depend on only part of the vessel primary motion during their calculation. For example, in this model the wave load (1st order), wave drift load (2nd order), wave drift damping included effects rely on only the vessel low frequency primary motion. Please see the vessel modelling overview page of the OrcaFlex help for further details.

Filtering the primary motion into wave and low frequency parts is not a strict process. In order to be successful, 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 shows that, in this case, the shortest of the above-mentioned natural periods is in yaw at ~64s. Furthermore, we have specified a JONSWAP wave spectrum with Hs =7m and Tp = 8, constructed from wave components of period up to ~17s. Information describing the wave components used to construct a wave train are available on the *waves* page of the *environment* data form, click *view wave components*.

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

Modelling the superstructure

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

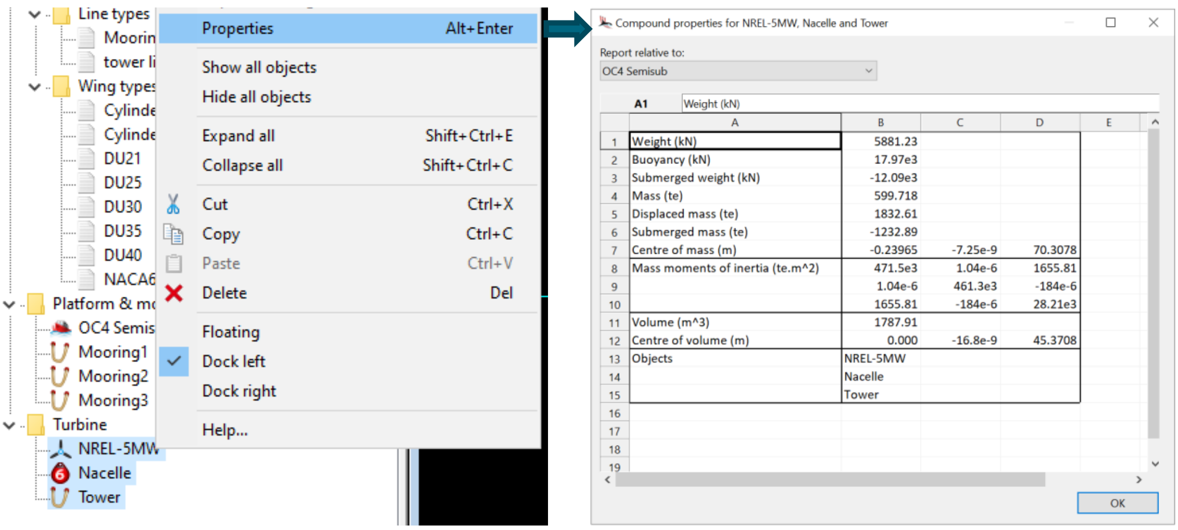
In the case of floating wind turbine systems, if we want to model aerodynamic loading on the rotor and/or flexibility of the tower & blades, then we need to model them explicitly. In the OrcaFlex model we have therefore included a turbine object, 6D buoy and line to represent the rotor, nacelle, and 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 already contains the mass and inertia of the turbine rotor, nacelle and tower. As we introduce these items as new OrcaFlex objects – each with their own mass and inertia properties – we need to make sure that we don't double-count their properties!

Manual manipulation of the vessel type properties is possible; however it is error prone. Conveniently OrcaFlex can do this calculation automatically, provided that you supply 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 compound 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 make the necessary corrections to the vessel mass, centre of mass, inertia and hydrostatics stiffness.



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.