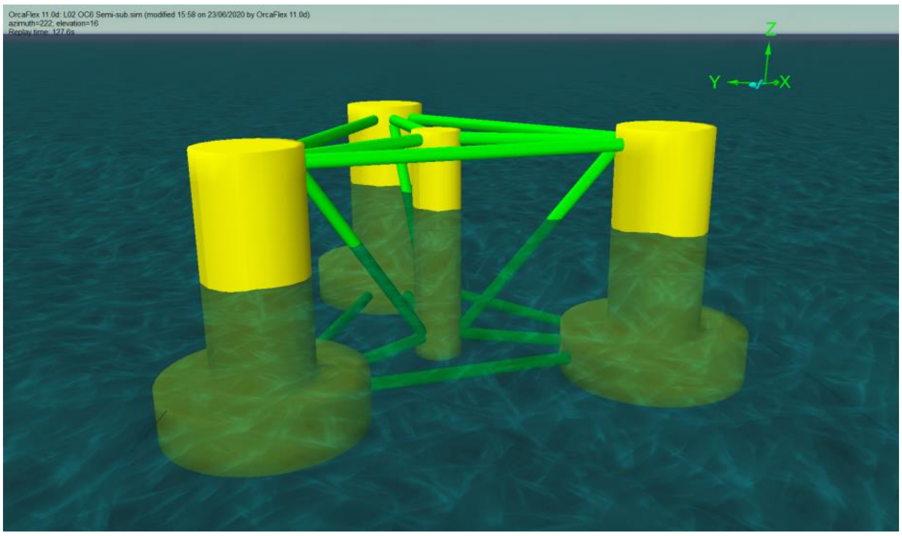
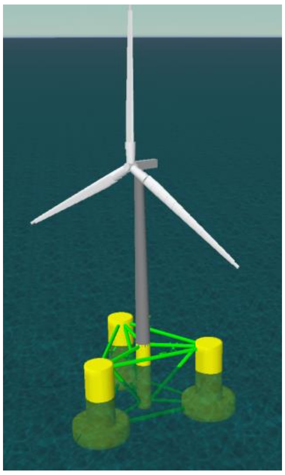
L02 OC4 Semi-sub

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 also 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 and tower used in this example are taken from our K01 floating wind turbine 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 for your own analysis purposes, you must 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 the full list, please see: https://www.orcina.com/webhelp/OrcaWave/Redirector.htm?Data,Meshfileformats.htm).

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

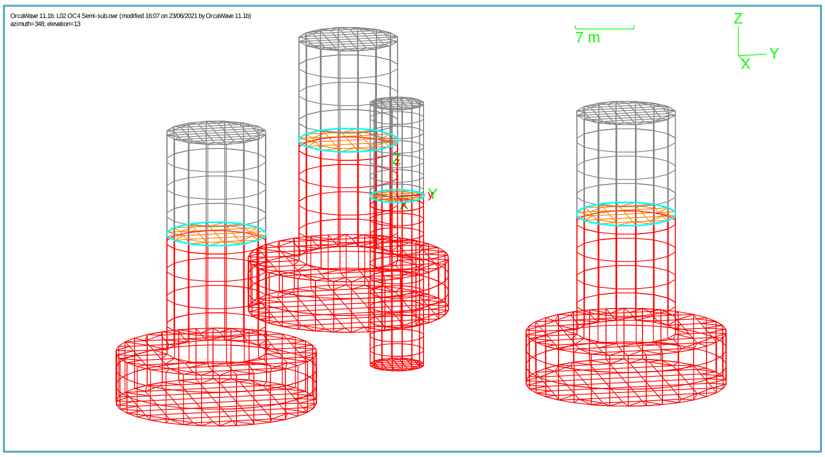


Figure 1: Panel mesh

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

In this example we use OrcaWave to generate 1st order wave load data (load RAOs) plus stiffness, added mass and damping data. Displacement RAOs will also be output (with no external stiffness or damping included), however because our OrcaFlex analysis will use a vessel in 'fully calculated' mode, we will not be using these.

Setting up the analysis

The platform consists of a main central column attached to three larger offset columns via a series of smaller diameter cross members, which are also referred to as 'pontoons'. For this example, the platform is assumed to be a rigid body. It is also assumed that the cross members are small enough to contribute only Morison drag to the platform's loading, meaning they are not included in the diffraction analysis (and are therefore not present in the mesh file shown in the Figure 1 above). Instead, these members will be added to the platform as *Morison elements* in the OrcaFlex model. 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). The mass and inertia properties for each of these components are listed in the table below, along with the combined properties which will be applied in OrcaWave.

		Centre of mass (rel. 0,0,0)			Inertia about object's CoM		
	Mass (te)	**X (m)**	**Y (m)**	**Z (m)**	**Ixx (te.m²)**	**Iyy (te.m²)**	**Izz (te.m²)**
Platform	13473	0	0	-13.46	6.827E+06	6.827E+06	1.22E+07
Tower	249.718	0	0	43.318	1.206E+05	1.206E+05	1818.39
Nacelle	240	1.9	0	89.35	350.02	5409.97	2607.89
Rotor (incl. hub)	110	-5.45202	0	90.0395	19550	19550	39060
Total	14072.72	-0.01021	0	-9.89018	11.33E+06	0	13.18E+03
					0	11.32E+06	0
					13.18E+03	0	12.23E+06

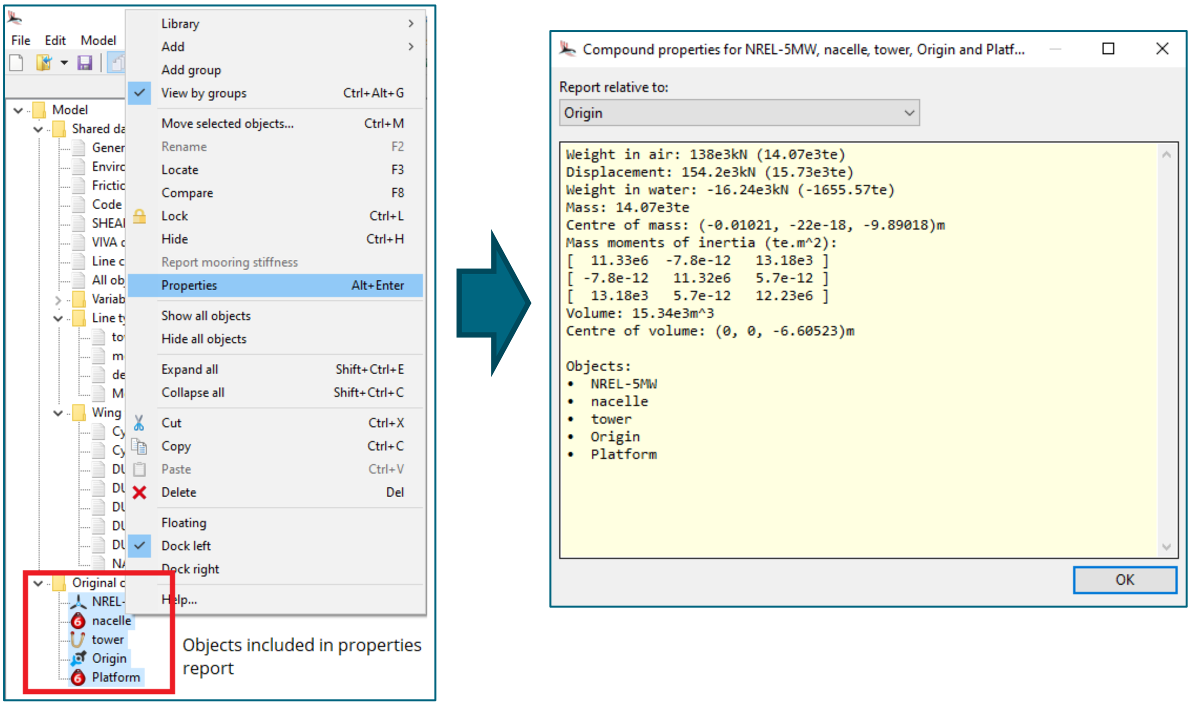
Table 1: Component properties

Note that the inertia matrix (highlighted in the table in the red box) for the complete system is specified about the combined centre of mass. OrcaWave requires this data to be specified about the body origin, so a matrix transformation is needed. This process is also covered in example *L01 Default vessel*. The inertia matrix reported about the body origin is shown below:

x	y	z
12.71E+06	0	11.76E+03
0	12.7E+06	0
11.76E+03	0	12.23E+06

Table 2: Inertia properties for OrcaWave input

Also, note that if you don't know the combined centre of mass position or the total inertia matrix, you can make use of OrcaFlex to calculate it for you. To do this, create an object for each of the component parts (a simple lumped mass 6D buoy will do), assign them their individual mass, CoM and inertia properties, and place them in the appropriate relative positions/rotations. Then multi-select (in the model browser) the objects that you want to include, right mouse click, and select *properties*. The properties report will give you the compound properties for the selected objects, regardless of whether they are actually connected to each other. In the screen shot below we also include an arbitrary constraint object *Origin* (which has no mass to contribute) and positioned it at the point that we want the centre of mass reported relative to i.e. the platform origin at (0, 0, 0). At the top of the properties report the *Origin* was then chosen as the *report relative to:* option. Note that the reported inertia matrix is about the combined centre of mass.



The water depth considered is 200m, and the platform's draft is 20m.

The OrcaWave analysis considers 31 wave periods, ranging from 3.75s through to 24s, and 9 wave headings between 0 and 180 degrees, spaced at 22.5 degree intervals.

Open the OrcaWave results file *L02 OC4 Semi-sub.owr* to see where these data are applied. 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*; the interior surface panels can be seen in orange if you rotate the view and ensure that the *interior lid panels* view option is ticked in the *view options* panel. In this instance the *triangulation method* creates the most suitable mesh on the interior surface.

The results of the OrcaWave analysis can be viewed on the *graphs* and *tables* pages.

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 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 4 different mesh densities (ranging from ~900 up to ~5000 panels), so that the results could be compared.

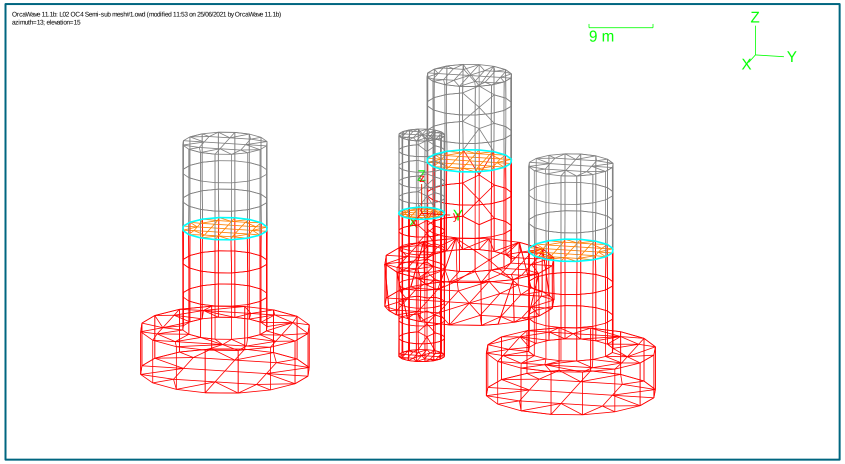


Figure 2: Mesh #1, 864 panels

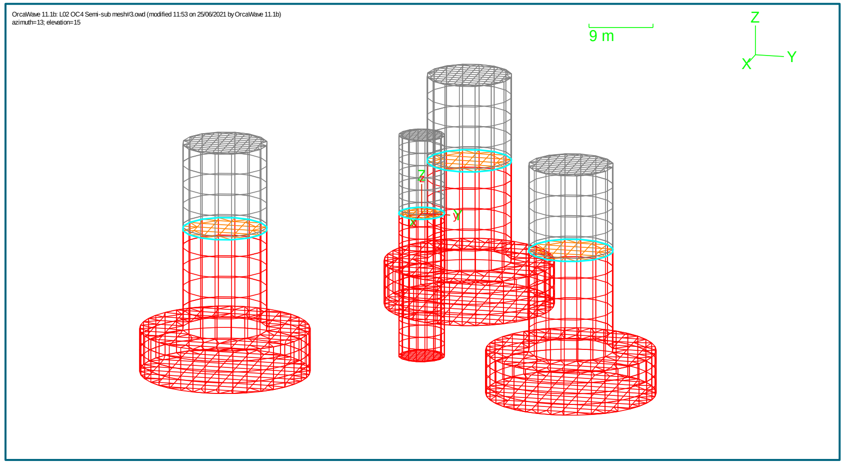


Figure 3: Mesh #2, 1710 panels

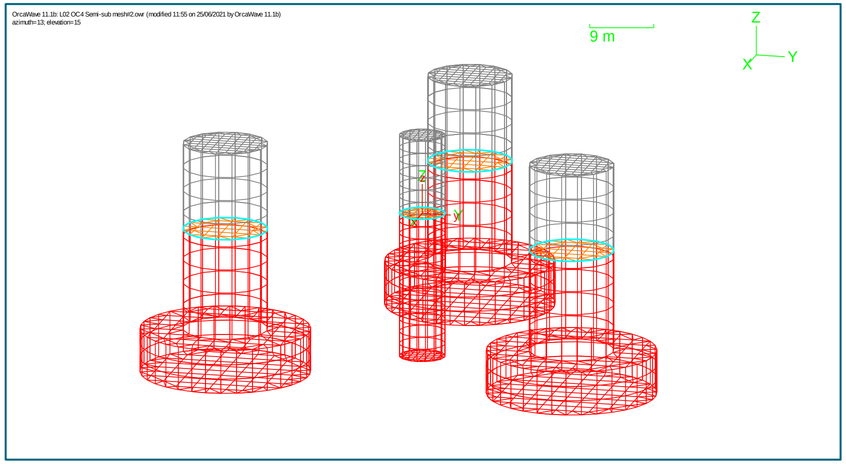


Figure 4: Mesh #3, 2086 panels

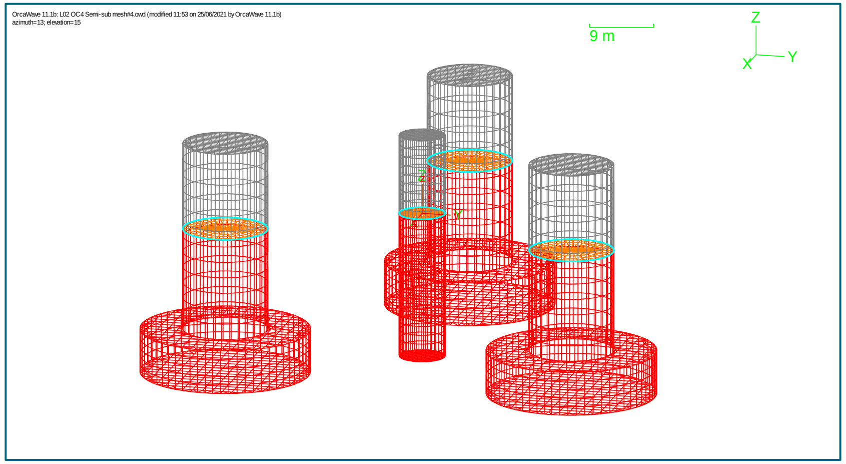


Figure 5: Mesh #4, 5140 panels

It was found that the mesh shown in Figure 3 (Mesh #2, 1710 panels) gave comparable results to the finest mesh (Mesh #4, 5140 panels), in Figure 5. Only the coarsest mesh (Figure 2) produced results that were not in complete agreement with the finer-mesh results.

A selection of the load RAO comparison results is shown in Figure 6 below. Meshes #2, #3 & #4 produce very similar results, however mesh #1 is clearly not good enough. Mesh #2 was therefore selected as the optimum for this example, and we have used this to generate the *L02 OC4 Semi-sub.owr* file.

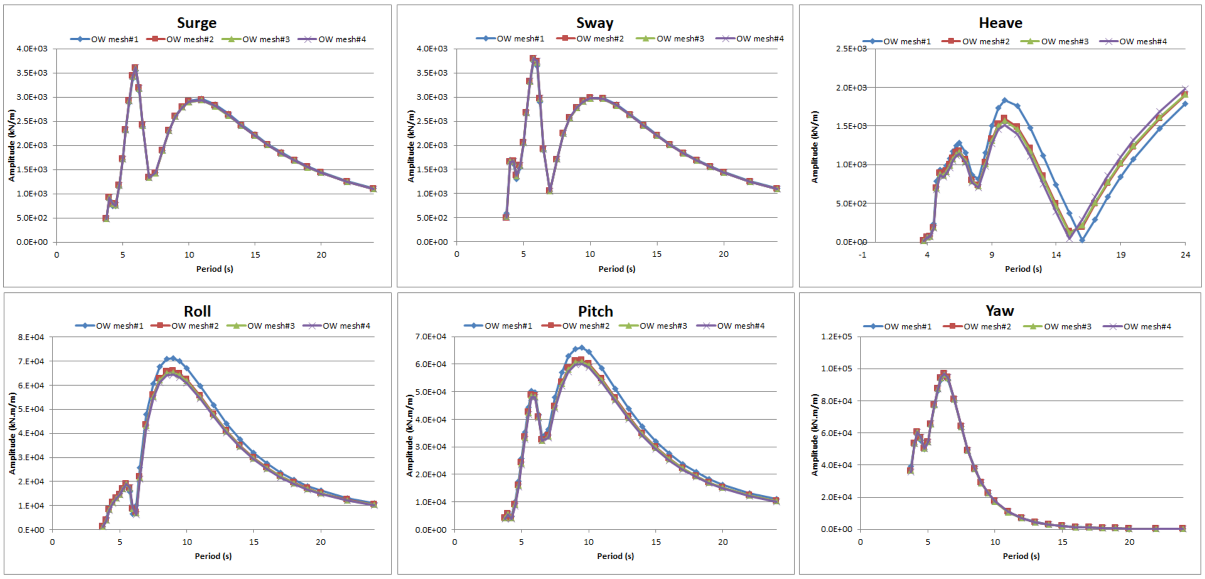


Figure 6: Load RAO amplitude plots for different mesh densities, 45° direction

OrcaFlex dynamic analysis

Setting up the OrcaFlex model

Open the OrcaFlex model *L02 OC4 Semi sub.sim*. Make sure the model browser is in *view by groups* mode (right mouse click in the model browser to access this option, or use the shortcut *Ctrl+Alt+G*). The model contains two groups '*Included superstructure*' and '*Explicit superstructure*'. The explicit superstructure group is currently hidden.

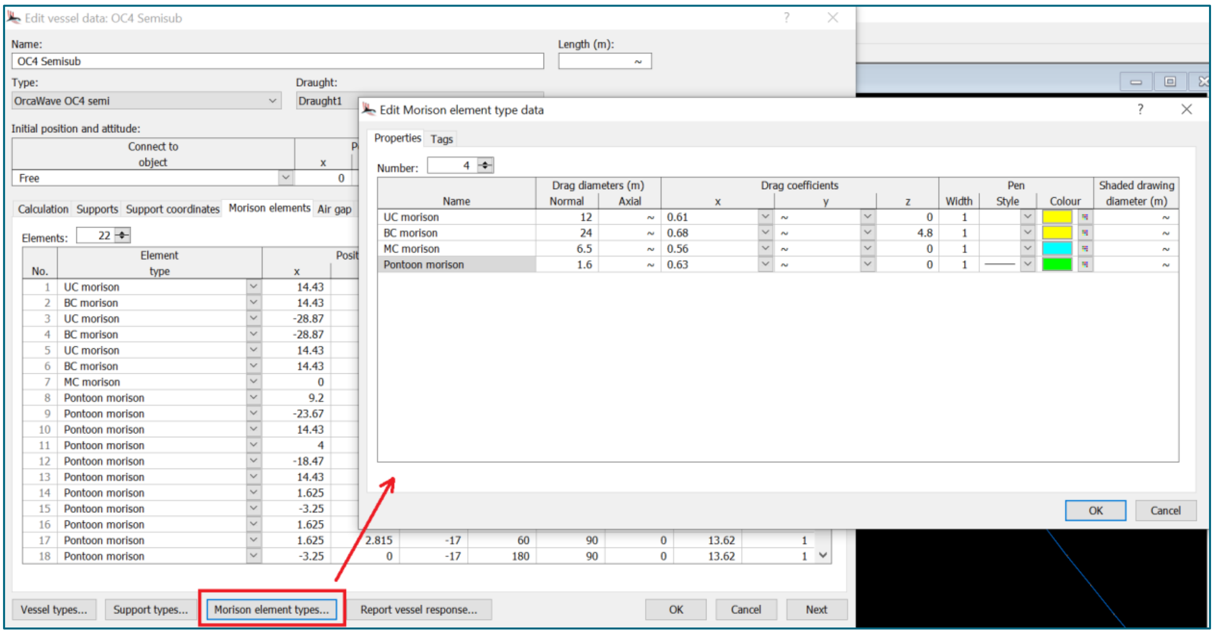
The OrcaWave-generated data has been imported into OrcaFlex as a vessel type named *OrcaWave OC4 semi*. In this example, there are a number of additional pieces of data to assign before we can run an OrcaFlex analysis.

Firstly, because the diffraction analysis mesh file did not include the small diameter cross members, the volume of these items is not included in the displaced volume calculated by OrcaWave. This will affect the equilibrium draft of the platform. The OC4 documentation states that the draft of 20m is achieved when the platform and its moorings are in still water.

The displaced volume of the platform in its equilibrium position is specified in the OC4 documentation as 13917m^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 given in the OC4 documentation, and connected each mooring line between the platform and the seabed.

The cross members have been added as Morison elements. This is done on the *Morison elements* page of the *OC4 Semisub* data form:

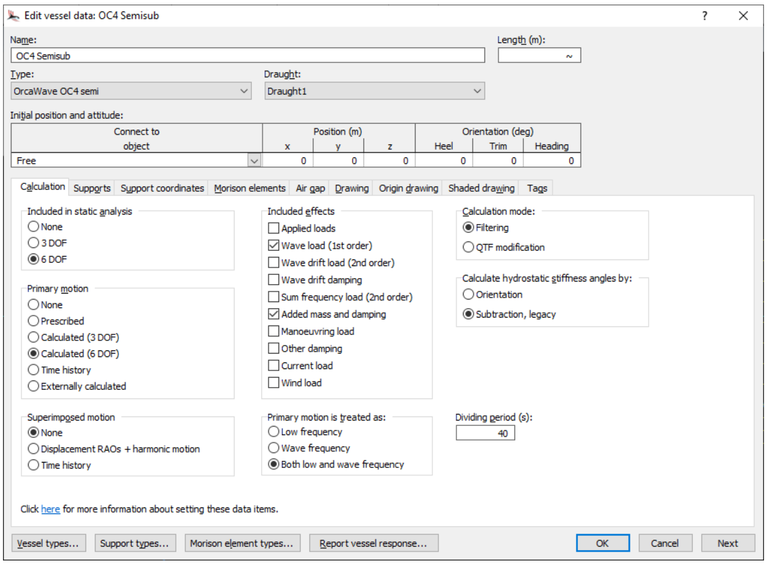


The pontoon elements represent the cross members. The central main column and the three offset columns also have Morison elements applied to them, as they are deemed to be of a size that will have the drag loading more accurately modelled by Morison's equation. See the help file for further details.

The properties and methodology applied here are part of the output from the later OC6 study, which focussed on platform hydrodynamics.

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.

To enable this, the *included in static analysis* option and the *primary motion* option are both set to *'6DOF'*. The *superimposed motion* option is set to *'None'*.



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

In this example the vessel is subject only to wave frequency excitation therefore the *primary motion is treated as:* option can be set to *wave frequency.* See help for further details on these options.

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 systems, if we want to include the rotation of the rotor and flexing of the tower and blades in our OrcaFlex model, then we need to model them explicitly.

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. If we were to then add the turbine and tower as separate objects in the OrcaFlex model, each with their own mass and inertia properties, we would double-count the mass and inertia of these objects.

So if 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 update the vessel type's hydrostatic stiffness matrix.

In this case, the mass and inertia for the platform minus the superstructure are already known (see Table 1). However if you do not have this information you can calculate it by subtracting the superstructure properties from the total properties.

The details of how to do this are explained in the separate document *'Explicit modelling of floater superstructures.pdf'*. The calculation sheet we used, to demonstrate the necessary adjustments for this particular floater and superstructure arrangement, is also provided with this example (see *'L02 Superstructure subtraction.xlsx*).

In the OrcaFlex model, a second vessel type has been created: *OrcaWave OC4 semi explicit superstructure.* This vessel type is a copy of the *OrcaWave OC4 semi* vessel type but with the tower, rotor and nacelle contributions to the mass and inertia removed. To do this, the following data was copied from the calculation sheet, referred to above, into the new vessel type:

- Mass
- Moment of inertia tensor
- Centre of gravity
- Hydrostatic stiffness matrix

A second group of objects has been created in the model browser called *explicit superstructure*. This group contains a vessel that uses the modified vessel type, a duplicate set of moorings, plus the tower, rotor and nacelle. The tower, rotor and nacelle objects have been copied directly from our K01 Floating wind turbine example model. Click on the *explicit superstructure* group in the model browser, right mouse click and select *show*. This set of objects has been deliberately superimposed on the *included superstructure* set, so that we can easily compare the platform motions (the responses of the two platforms will be very similar if the superstructure subtraction has been done correctly).

Note that in order to do this comparison the rotor has been modelled as 'parked' i.e. it is not rotating and therefore this rotation does not affect the platform motion. To do this, no wind is applied and the following changes have been made to the turbine object:

- The *generator control mode* has been set to *specified rotation*, with an *angular velocity* of zero.
- The blade pitch controller has been removed, and the *blades DOFs* set to *fixed*.
- The BEM calculation has been disabled by setting the *included induction* to *none*.

Of course, the whole point of explicitly modelling the tower, nacelle and turbine is to ensure the coupled behaviour between these objects and the floater *can* be included in the analysis; so normally the above changes to the turbine object would not be required. The reason we have made these changes in this case, is to ensure a like-for-like comparison can be made between the response of the platforms i.e. to check that the process of removing the influence of the superstructure components from the *OrcaWave OC4 semi explicit superstructure* vessel type has been done correctly.

Results

Run the replay to see the two platforms moving; the motion is identical which indicates that the relevant superstructure properties have been correctly removed from the platform vessel type used in the explicit superstructure arrangement.

A couple of workspace files have been created to show some results of interest. Open *L02 OC4 Semi-sub platform motion.wrk* to compare the *X* position and *Rotation 2* results for the two platforms. A second workspace, *L02 OC4 Semi-sub mooring tension.wrk,* compares the tension at the top end of one of the mooring lines.

Here we can see that the two platforms move in a very similar way.