# L01 Default vessel

Introduction

In this example we use OrcaWave, the diffraction and radiation solver included with OrcaFlex since version 11.0, to re-create the hydrodynamic data set used by the OrcaFlex default vessel. This is the vessel type data that you see when you first add a new vessel to an OrcaFlex model. It was generated for us in a 3rd party diffraction tool, many years ago, but we have recreated it here to demonstrate the use of OrcaWave and the import & subsequent use of the data in OrcaFlex.

Note: OrcaWave has been extensively validated against WAMIT. For full details, please refer to the validation study which is available for download from the Orcina [website](#).
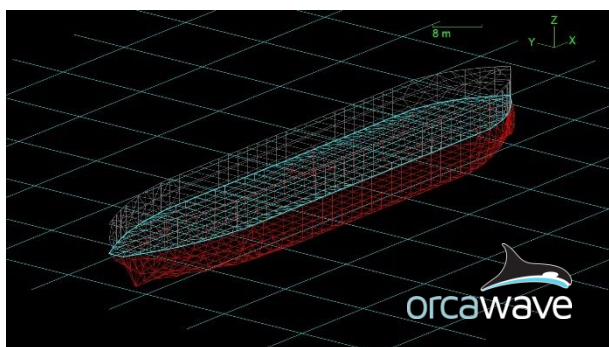
OrcaWave diffraction analysis

Calculation & output settings

OrcaWave data files have the file extension *.owd* and the results files *.owr*. In this example we will use several OrcaWave cases to compare the results generated by using different settings.

Open the file *L01 Default vessel.owr.* The OrcaWave user interface is very simple compared to OrcaFlex and consists of several pages into which the data to be used in the diffraction calculation are input.

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. 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.

In this case we have the mesh available from the original diffraction analysis and we use this as the starting point. To reduce the number of panels modelled in the diffraction analysis the mesh makes use of half-symmetry along the xz-plane. The mesh is truncated at the free surface:
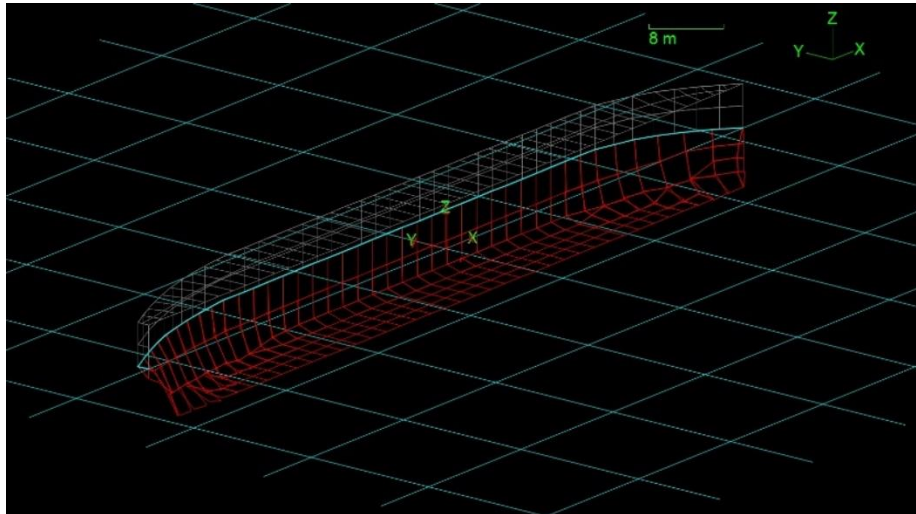
The mesh in its original format contains 216 panels. The speed of the calculation and the accuracy of the results are dependent on the number of panels contained in the mesh (similar to the number of segments used to model an OrcaFlex line). Therefore, mesh sensitivity studies are usually performed to establish the optimum mesh density.

In this case we only intend to replicate the original diffraction analysis results. It should be noted that our original vessel mesh has coarse resolution by modern standards, but this example is not a meshing study, and we benefit from the fast calculation time that a coarse mesh provides. We therefore only make a few minor improvements to the mesh as we work through the analysis.

Defining a body

The *bodies* page is where we import the mesh file. OrcaWave can perform multibody analysis, so there could be more than one body specified here but, in this example, we are considering only a single body.

The *length for OrcaFlex import* is set to 103m, the length of the default vessel. This property is not used by OrcaWave, but it can be set here for convenience so that the *vessel type length* is automatically set upon import to OrcaFlex.

The *body mesh file* specifies the name of the file that contains the vessel mesh. As we are making use of half-symmetry in the mesh file, the *symmetry* data item needs to be set accordingly (*xz plane*).

The *control surface mesh file* specifies the name of the file that contains a control surface mesh. This will be used in the quadratic load calculation but we will discuss this in more detail later in this example.

Body inertia

Jumping to the *inertia* page, the vessel's *centre of mass*, *mass* and *moment of inertia tensor* are specified. The values considered here have been copied directly from the default OrcaFlex vessel. We are specifying the inertia by a *matrix (for a general body)*. In OrcaFlex, the inertia matrix is defined about the **centre of mass,** therefore the corresponding *inertia origin* has been selected in OrcaWave.

**Calculation & output settings**

On the *calculation & output* page, we choose the type of solve that we want to carry out. As we are re-creating the data used in the OrcaFlex default vessel, it's worth listing the diffraction results that it contains, and that we therefore want OrcaWave to generate:

- Displacement RAOs
- Load RAOs
- Wave drift QTFs (Newman's approximation)
- Hydrostatic stiffness matrix
- Added mass and damping matrices.

In addition to calculating this data, OrcaWave is capable of calculating full QTFs, sea state RAOs (disturbance data) and multibody data, but these types of data are not covered in this example. Other damping data is also generated and will be discussed later in this example.

The default OrcaFlex vessel also contains data for wind and current loading; note that this information is not generated in a diffraction tool. Further details about this can be found on the [Modelling, data and results | Vessels | Vessel types | Current and wind loads](#) page of the OrcaFlex help.

The *diffraction solve type* determines which sets of data OrcaWave calculates:
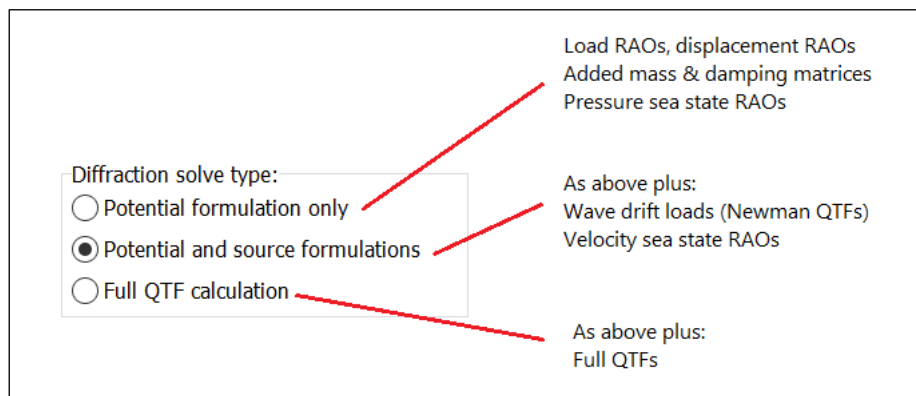
We require Newman QTFs to be calculated as well as the first order effects, therefore the calculation type selected in this example is *potential and source formulations*.

OrcaWave then offers some further calculation choices:

Firstly, we have a choice of *load RAO calculation method*, either *Haskind* or *diffraction*. The two methods are mathematically equivalent and both methods can be implemented with no additional computation cost. With this considered, we will use the default option of *both*. This means that two sets of load RAOs will be available for import into OrcaFlex. The *preferred load RAO calculation method* choice determines the default choice to be imported to OrcaFlex, but you can change your mind at the time of import. Note that the preferred choice also dictates which load RAO set is used in the calculation of displacement RAOs.

Checking for agreement in the load RAOs generated by the *Haskind* and the *diffraction* methods is often a useful quality check on the results.

There is a further choice of method used for the quadratic load calculation (QTFs) i.e. *pressure integration* or *control surface integration*. Here, both options are ticked but this time there is an additional computation cost and therefore the calculation time will be increased. The *control surface integration* method requires an additional mesh, but it is often more accurate for vessels with sharp corners / edges; hence, we have selected it as the preferred method here. This will also be the default choice when we come to import the data to OrcaFlex.

The final setting to mention on the *calculation & output* page is the choice of *linear solver method*. The direct solver is often faster for smaller meshes, but the iterative solver is often faster for larger meshes. A secondary factor that affects performance is the number of headings. The direct solver can solve for multiple headings without performing much extra work beyond what is needed for a single heading. However, for iterative solvers the total work is proportional to the number of headings. With this example the direct solver runs fractionally faster than the iterative solver, but neither took longer than 1 minute to run on an 8-processor laptop.

It is possible that memory consumption, instead of calculation time, will be a limiting factor in the production of OrcaWave output. Diffraction calculations require the solution of matrices whose dimensions are directly related to the number of panels in the calculation mesh. As a result, a refined mesh can demand a large quantity of your computer memory during calculation. You should ensure that the OrcaWave thread count – which can be set from the *tools* menu – is low enough that the analysis will fit your available memory. To help inform your choice, OrcaWave presents the estimated memory consumption *per thread* on the *validation* page.

Full details of all the calculation choices, and of the remaining data items on this page, can be found in the [OrcaWave help](#).

Setting up the environment

On the *environment* page we define the water depth and the wave periods & headings that we want to include. The original default vessel data was calculated using 400m water depth, therefore we have opted to consider the same here.

For interest, we also ran the analysis with 100m water depth (the default OrcaFlex water depth). The influence this parameter has on the results is discussed later in this document, in the '*Comparison of results – 1st order*' section.

The 24 wave periods and 9 wave headings listed on the *environment* page are the periods and headings that were considered in the original analysis.

Constraints

The *constraints* page provides the means to apply external stiffness and damping matrices. The *external stiffness matrix* would, for example, be used to apply the mooring stiffness matrix if you were generating displacement RAOs for the vessel in its moored condition.

The *external damping matrix* can be used to apply additional sources of damping to the body. In this case you will see that we have applied additional roll damping. This is discussed in the '*Comparison of results – 1st order*' section.

Mesh validation

To demonstrate the mesh validation tools we are going to first study the original mesh. To do this, reset the model (F12), and then on the *calculation & output* page untick the *divide non-planar panels* box. Also, on the *bodies* page untick the *add interior surface panels…* box.

Then click on the *mesh view* tab. You will see an OrcaFlex style view of the mesh or meshes. The view can be zoomed, panned and rotated in the same way as with an OrcaFlex view. In the list of *view options* down the right-hand side, make sure that the *body mesh* and *waterlines* boxes are ticked, but the *dry body panels* and *control surface mesh* are not ticked. You will now see the vessel's mesh with the waterline highlighted in blue:
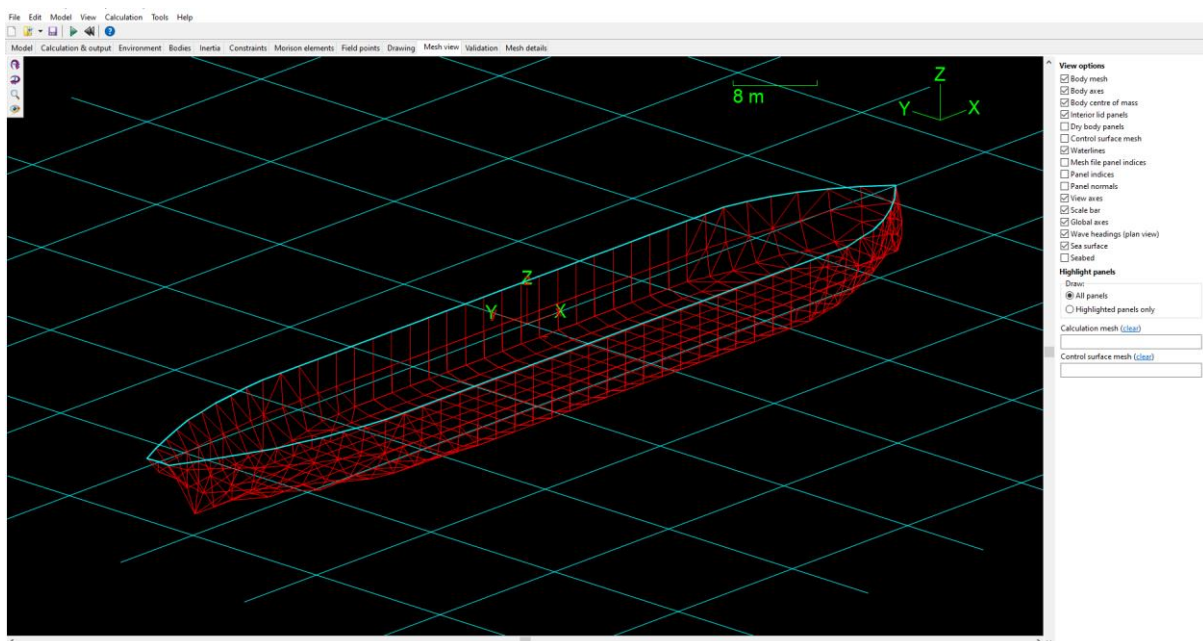
Next, click on the *validation* tab. OrcaWave performs a validation of the mesh or meshes, and in this case two warnings are reported.

Specifically, these warnings refer to the following issues:

    a)   Several panels in the mesh are non-planar.
    b)   Irregular frequency effects are expected from the *Body1* mesh.

These are common warnings, so it is worth explaining each one.

Firstly, warning (a) is a result of the mesh being quite coarse for the hull curvature being modelled. In OrcaWave, all panels must be planar i.e. each panel must have all its vertices lying on a single plane. Triangular panels, with only 3 vertices, are naturally planar, however quadrilateral panels may not be. If the vertices that make up a panel in the mesh file are non-planar then OrcaWave will project them onto a common plane. In other words, OrcaWave will move vertices slightly to make the panels planar.

Warning (a) is telling us that this has happened, and a list of the affected panels is given on the *validation* page. To see which panels the numbers listed refer to, click the *show in mesh view option*. The affected panels are then highlighted:
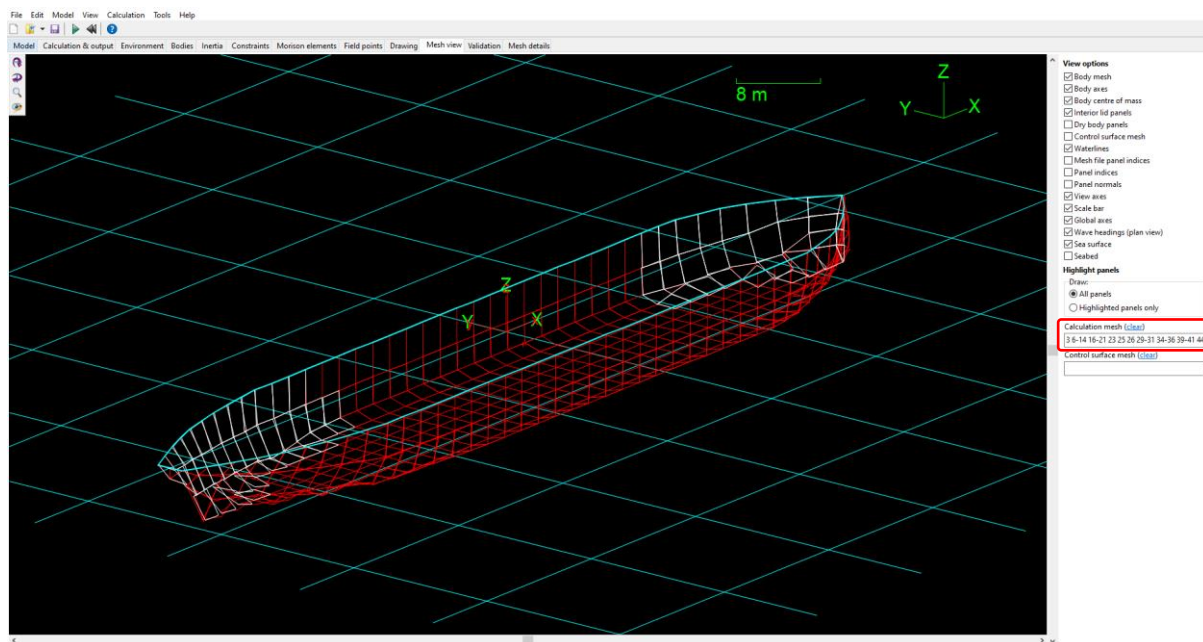
If you zoom in on these panels, you will see the effect that making them planar has had:
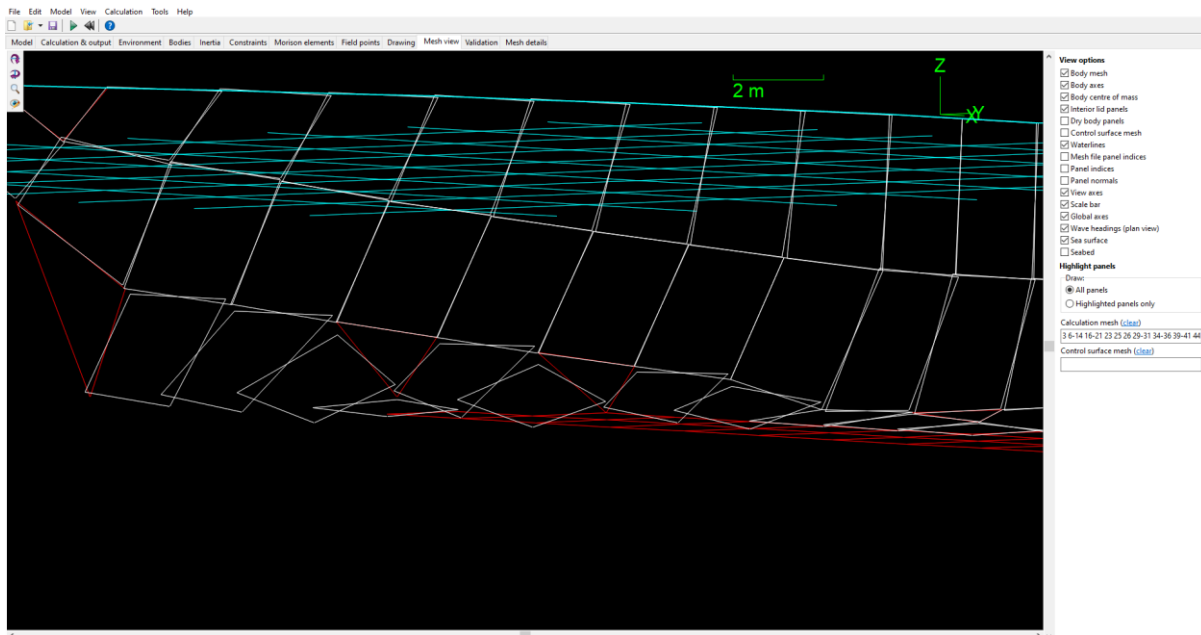
It is possible that the vertices / panels being moved in this way will have a negligible effect on the results. However, the easiest way to improve the mesh is to triangulate the non-planer panels i.e., split each non-planar panel into two triangular panels. This obviously increases the number of panels in the mesh, and therefore the calculation time. So, it might be worthwhile running sensitivity checks to see what effect non-planar panels have (versus more panels) with regard to the accuracy of the results and the calculation run time.

In this example the run time is very quick, so we have triangulated the non-planar panels to create a modified mesh. This can either be done in the original meshing tool (e.g. Rhino) *or* you can get OrcaWave to do this for you by ticking the *divide non-planar panels* box on the *calculation & output* page. Tick this box and look at the mesh view again to see the effect on the panels (note you will have to click on *clear* in the *highlight panels* section to remove the previously highlighted panels).

Warning (b) tells us that there is a risk of irregular frequency effects occurring. Details of how these effects arise are given on the [Theory | Irregular frequencies](#) page of the OrcaWave help. The key thing to note here is that they can cause erroneous results if not accounted for correctly. The recommended method for removing irregular frequency effects is enabled in OrcaWave by supplying mesh panels that cover the interior free surface. These panels can be included in your mesh file, or you can ask OrcaWave to add these panels to your mesh automatically, by ticking the *add interior surface panels…* box on the *bodies* page.

Asking OrcaWave to mesh the free surface *might* lead to mesh quality issues e.g. panels with high aspect ratio if the body waterline has very short segments. So, adding the free surface mesh to your body mesh file gives you more control over the quality of this mesh. However, in this case, OrcaWave meshes the free surface well, using the *triangulation method* available on the *bodies* page.

Tick the relevant box (*add interior surface panels…*) and then go back to the *mesh view* page. Check that the *interior lid panels* box is ticked, in the list of *view options*, and you should see the interior surface panels drawn in blue. On the *validation* page OrcaWave now reports no errors.

If the *dry body panels* box is also ticked on the mesh view page, you will see that we have also added some panels above the water line. These have been added for visualisation purposes only;

when imported into OrcaFlex the mesh file can be used to add graphics to the vessel, so showing the extents of the hull above the surface is useful. Note however that the panels above the free surface will not be used in the OrcaWave calculation, and OrcaWave automatically detects that they are above the free surface, so inclusion of these panels in the mesh file will not slow down the OrcaWave run.
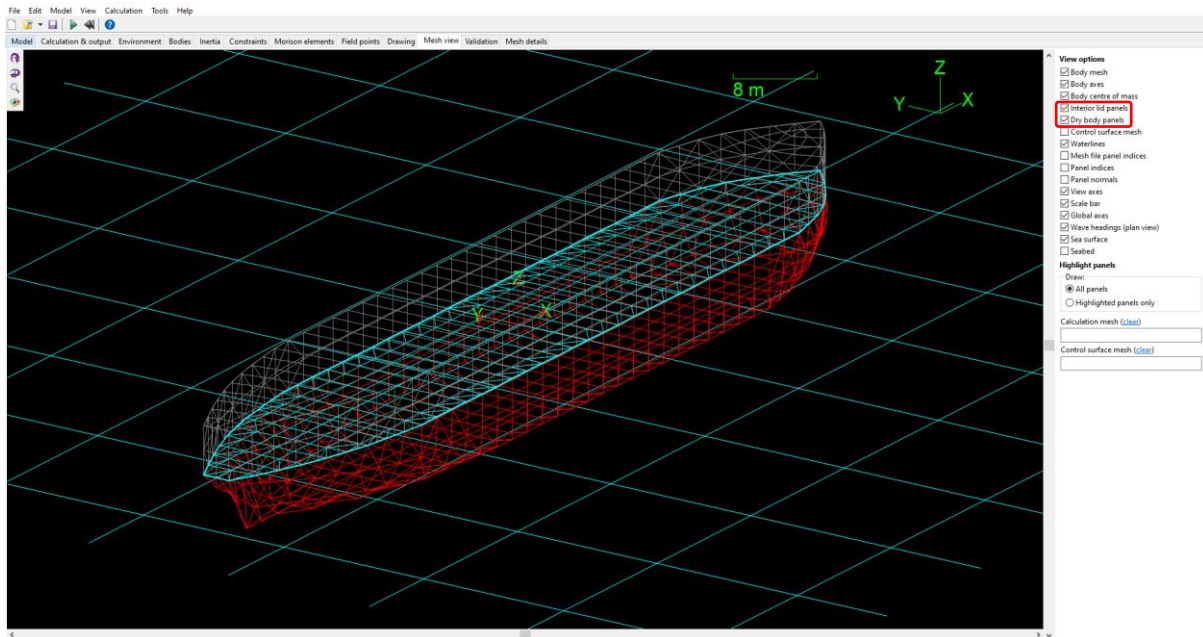

The changes made to remove non-planar panels and irregular frequency effects have increased the mesh from 216 to 940 panels. However, the run time is in the order of ~1 minute so the penalty for having this improved mesh is not too onerous.

Note that a more detailed mesh validation check is possible, by ticking the *perform validation of panel arrangement* box on the *calculation & output* page. This performs some further checks (e.g. overlaps and gaps) but the checks take longer to perform. This option is often used when first importing a mesh, and turned off for later work once you are happy with the mesh quality.

Control surface mesh

Finally, we need to add a further mesh to represent the control surface. This is needed in this case because we have opted to calculate the quadratic load using the *control surface integration* method as well as the default *pressure integration* method. The latter does not need an additional mesh, but here we are going to compare results from the two methods. The control surface mesh has again been created in Rhino. This mesh needs to surround the body, have the same symmetry as the body mesh, and (for a partially submerged body) must include the free surface between the control surface and the body waterline.

The control surface mesh has already been added to this model, so on the *mesh view* page, ticking the *control surface mesh* box will show the control surface in yellow:
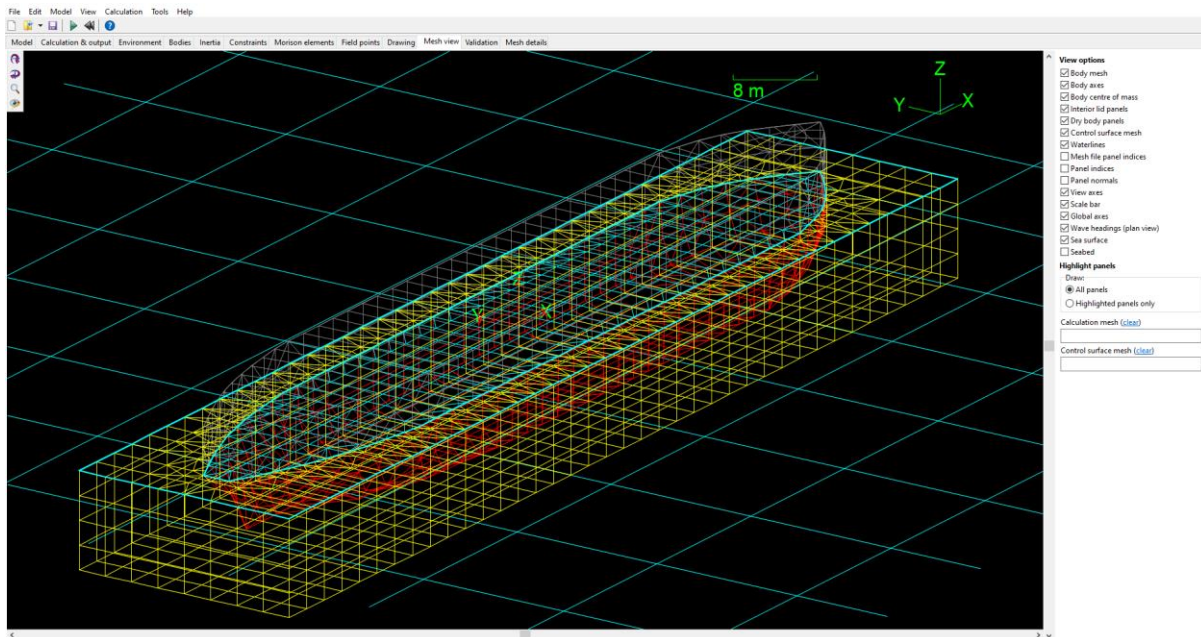
You can examine this mesh by ticking / unticking the relevant boxes and manipulating the view.

Note that one further check, which is always worth making, is to check the direction of the *panel normals*. Ticking this box in the *view options* list displays the direction of the *interior* surface of each panel. Generally, the panel normals should point *into* the hull so if any panel normals are pointing in the wrong direction, then you must return to the meshing tool to correct this.

Summary

This is the conclusion of the set up for our analysis. To summarise, we have specified:

- the required outputs,
- the applied environment values of water depth, wave heading and wave period,
- the analysed body via its inertia and mesh description, and
- additional meshes of enclosed free surface and control surface for use in the calculation.

We have also reviewed the OrcaWave validation of these inputs, meaning we can now generate and view the OrcaWave results.

Viewing the results

Re-open the *L01 Default vessel.owr* file, which contains the results of the OrcaWave analysis. The results are presented across two pages: *graphs* and *tables*.

The graphs should be recognisable to anyone familiar with the OrcaFlex *Check RAOs* plots produced from the *vessel type* data form in OrcaFlex. The tables provide the full set of results, spread across a number of pages, in tabular form. These results can be exported in spreadsheet format, however as we will be using them in OrcaFlex, there is no need to do this because OrcaFlex recognises the *.owr* file.
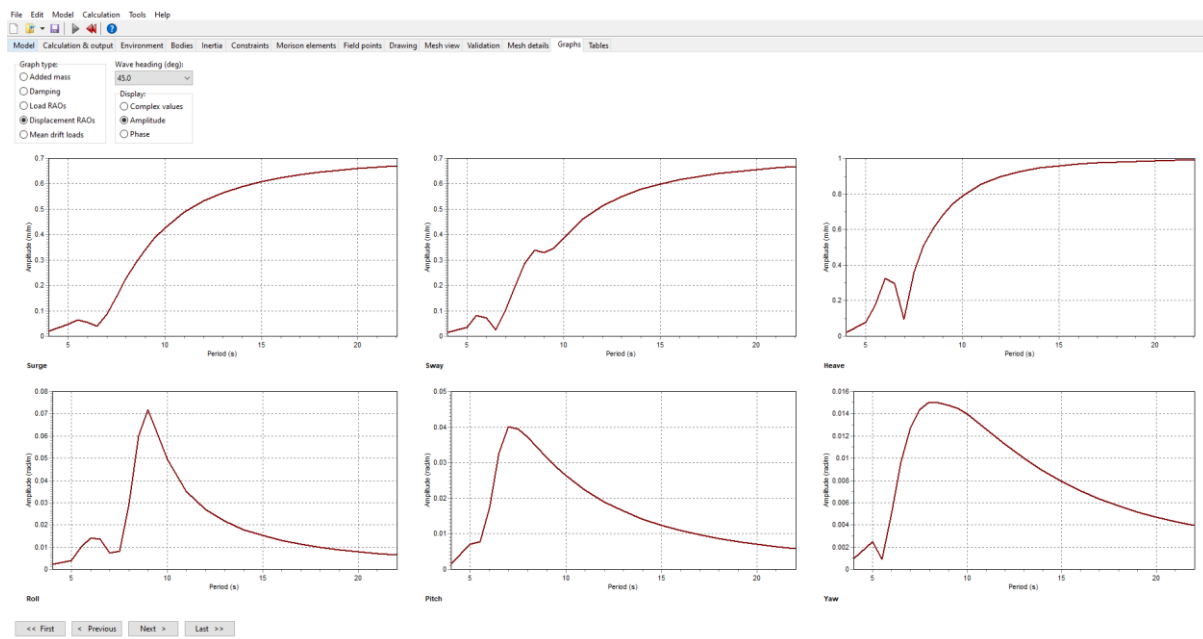
OrcaFlex dynamic analysis

Import to OrcaFlex

There are two ways to import the vessel diffraction data to OrcaFlex. If you are starting a brand-new model, you can simply open the OrcaWave *.owr* file in OrcaFlex, either by dragging and dropping it into an OrcaFlex window, or via the *file | open* menu command. This method will create a new model with a vessel in it and with the vessel type data populated with the OrcaWave diffraction results.

If the water depth used in the OrcaWave analysis was anything other than infinity, then that will have been imported also, and the water depth in the OrcaFlex model will have been set to this value. There are a number of other parameters that are also conveniently set when using this method. Please see the [Modelling, data and results | Vessels | Importing hydrodynamic data | OrcaWave](#) page of the OrcaFlex help for further details.

The second method of importing vessel data is via the *import...* button on the *vessel type* data form. This is the option you would use to import hydrodynamic data generated by any other diffraction tool. We will demonstrate this method here.

In OrcaFlex, open the model *L01 Default vessel.sim*. In this model we are comparing the original OrcaFlex default vessel with the 'new' vessel data generated by OrcaWave. We have therefore added two vessels to the model.

The *Original vessel*, which is currently hidden (press *Ctrl+H* on the object in the *model browser* to show it) is drawn with a green pen, and the *OrcaWave vessel*, is drawing with a red pen. Note that the OrcaWave vessel has made use of the panel mesh file that was used in the OrcaWave analysis! Hence, we have a much better representation of the vessel's geometry.

To see the import process, first reset the model (press *F12*). Then open the *OrcaWave default vessel* data form from the model browser. This is in the list of *vessel types*:
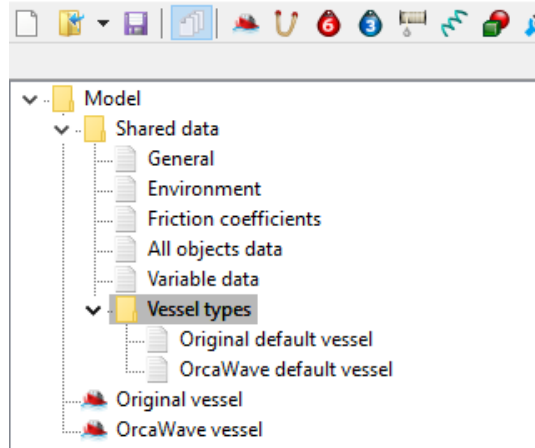
The *vessel type* data form contains the data that has been imported from OrcaWave already, however you can repeat the process by clicking the *Import…* button at the bottom of the data form and selecting the OrcaWave results file *L01 Default vessel.owr*.

The *import vessel data* form then appears. Note that the *centre of mass* is reported here. OrcaFlex uses this information to deduce how the origins used by the diffraction tool relate to the origins used by OrcaFlex. Therefore, it is important that the *centre of mass* is set *before* the diffraction data is imported. This data is set on the *vessel type* data form, on the *structure* page. In this case, it has already been correctly set. The *clear existing data* check box allows you to delete all existing data from the vessel's data form before importing the new data. Ticking this box ensures that you don't accidentally use any default vessel data in your analysis.

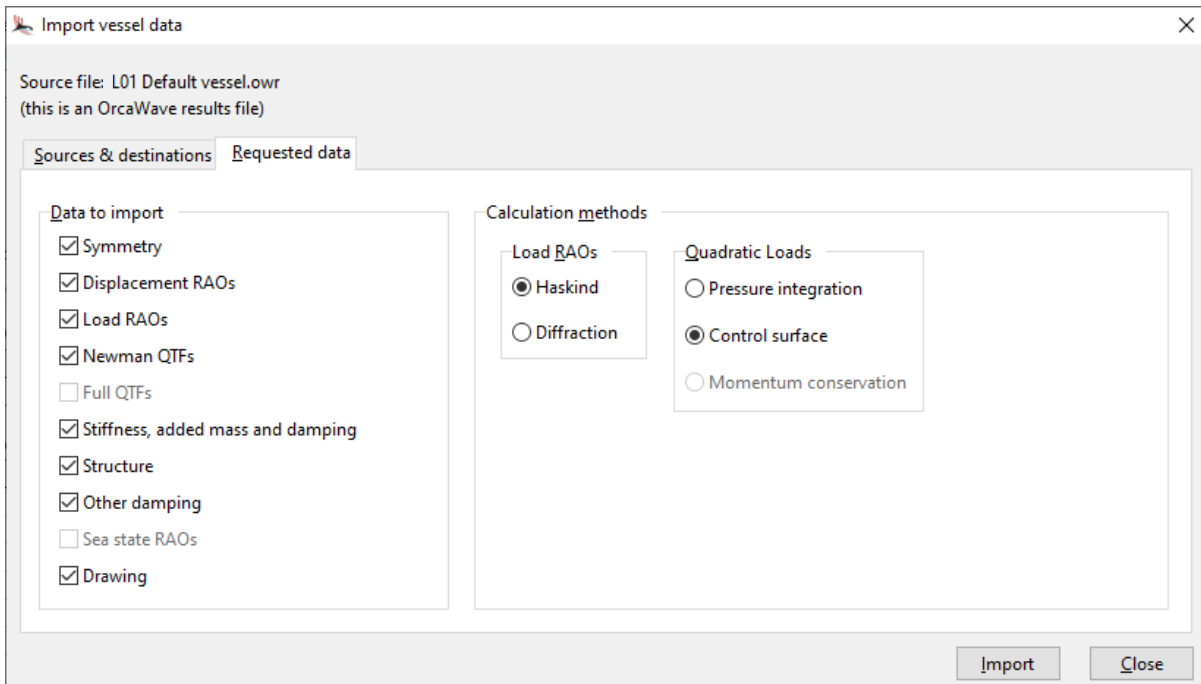| Source	Destination		OrcaFlex centre of mass		
	Vessel type	Draught	x (m)	y (m)	z (m)
Body1	OrcaWave default vessel	Draught1	2.530	0.000	-1.974

☑ Clear existing data

Import   Close

The *requested data* page gives you control over which data sets contained in the diffraction output file are imported into OrcaFlex. In this case we are choosing to import everything that is available (we did not calculate Full QTFs or Sea state RAOs, meaning these are greyed out). The calculation methods for *load RAOs* and *quadratic loads* are as per the 'preferred' settings we selected in the OrcaWave analysis, but these could be changed here if necessary.

To import the data, press the *import* button and check any warning messages that appear (in this case there are none).

## Comparison of results – 1st order

We ran several OrcaWave cases to check out the influence of the various parameter settings.

To compare the 1st order results from OrcaWave with the data in the default OrcaFlex vessel we used the *report vessel response* option (see the [Modelling, data and results | Vessels | Vessel response reports](#) page of the OrcaFlex help for details). This allows us to report the displacement RAOs for specified points on the vessel, and for different wave directions. By checking these results, we will be comparing both the displacement RAO calculation and, because the displacement RAOs are derived from the load RAOs, it will check the load RAO calculation also.

Firstly, we checked the influence of the water depth in the diffraction calculation. OrcaFlex has a default water depth of 100m, so we looked at the diffraction results with a water depth of 100m in OrcaWave, versus setting it to 400m. Below we have plotted the surge RAOs, for a 0-degree direction, at the vessel origin (for brevity we have chosen to only show the plots that display results of interest).
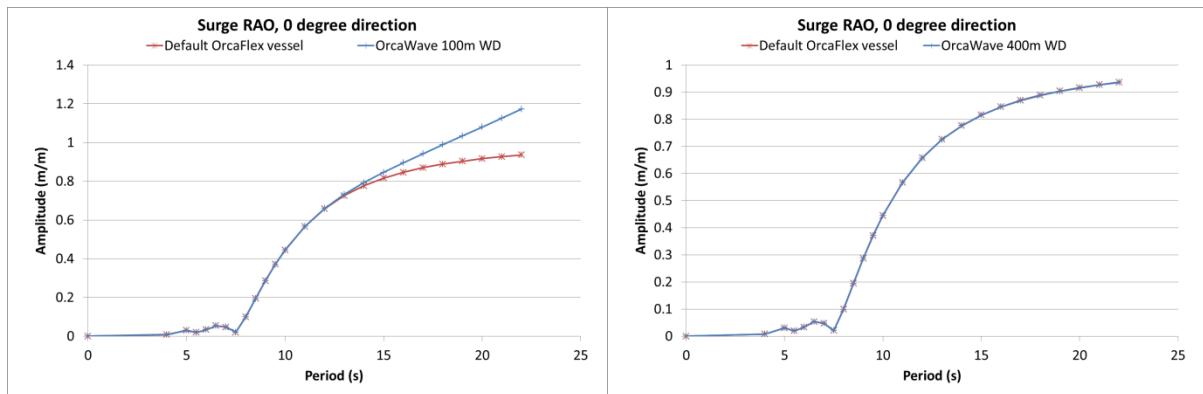
It is clear from the above left-hand plot that setting the water depth in OrcaWave to 100m has a significant influence on the surge results at longer wave periods when compared to the original default vessel data. Setting the water depth to 400m in the OrcaWave calculation produces excellent agreement, as shown in the right-hand plot. This demonstrates the importance of using the appropriate water depth in the diffraction calculation, particularly if you are considering a relatively shallow water application.

Next, we compare the plots for sway and roll, for the 45-degree direction, at the vessel origin. In the first two plots the OrcaWave calculation included no external damping so that we can show what a body motion resonance often looks like:
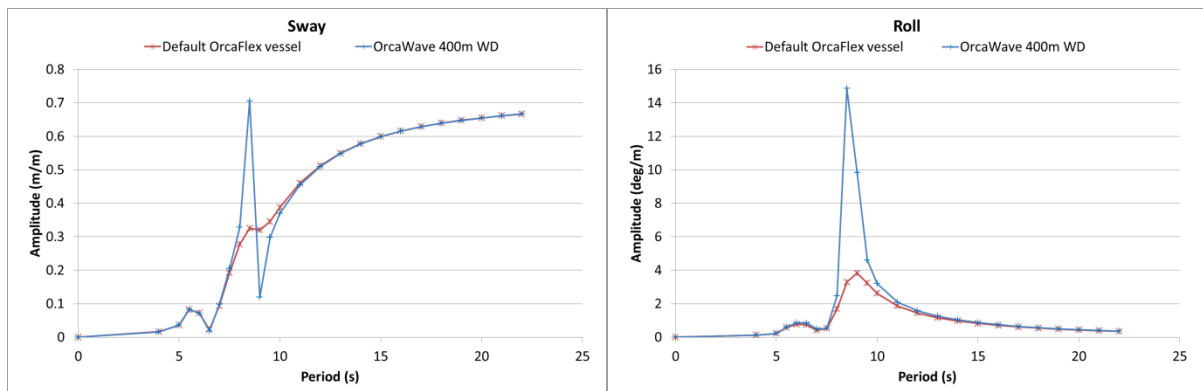

Here, we clearly have significant disagreement between the OrcaWave data and the existing default vessel data, at a period of around 8.5s. Upon closer examination of the data, the amplitude graphs have smooth variation in the added mass & damping, and in the load RAOs, through the 8.5s region. The spikes only occur in the displacement RAOs. This is classic behaviour for a body motion resonance, in this case a roll resonance. Potential theory typically overestimates this motion because it does not consider viscous damping. It is common practice to apply an external damping matrix to the body in the diffraction analysis to account for this.

In this case, we can see that the original vessel data accounts for some linear roll damping (applied as *other damping*) so the OrcaWave analysis was repeated with an *external damping matrix* applied. You can see this on the *constraints* page of the OrcaWave file (the same value appears in OrcaFlex on the *other damping* page of the *vessel type* data form). Note that OrcaWave is also able to calculate the roll damping as a percentage of critical, if the critical damping coefficient is known. Further details about this option can be found on the Constraints page of the OrcaWave help.

So far, all of the OrcaWave results shown here have been calculated using the default *load RAO calculation method* i.e. the *Haskind* method. In the plots below we also include the results from the *diffraction* method.

Applying the external damping has clearly had the desired effect, and both sets of OrcaWave displacement RAOs show good agreement with the original results, although it is noted that the *diffraction* method appears to give slightly better agreement than the *Haskind* method, probably suggesting that *diffraction* was the method that was used in the original analysis.

At this point we would usually do a mesh sensitivity check to see if more panels created better agreement between the two load RAO calculation methods, however because the original vessel analysis was done with a particular mesh density, we are limited to using that in this comparison. The subject of mesh convergence is covered in example L02 OC4 semi sub.
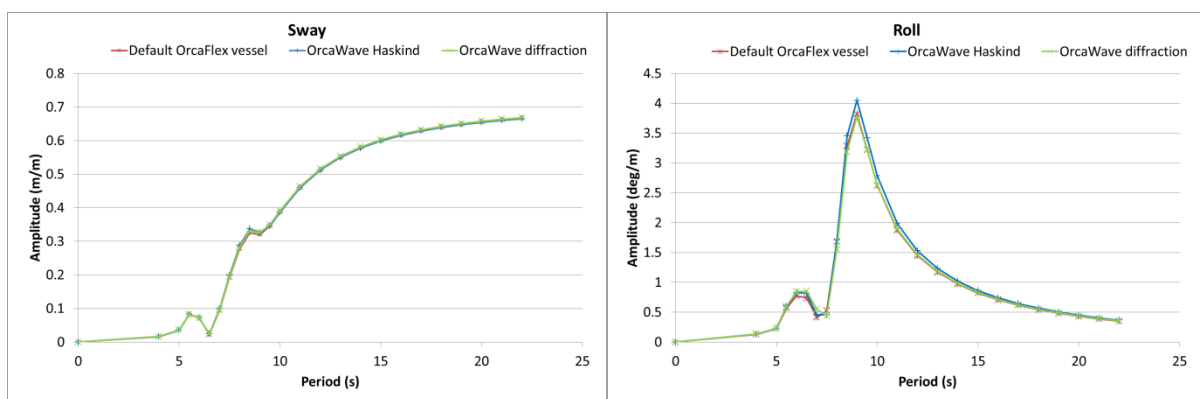
The above graphs show the amplitude of the generated RAOs, but we also need to check the phase. This can be achieved by plotting the data; however you could instead run an OrcaFlex simulation in a regular wave so that you can visually compare the response.

If you have reset the OrcaFlex model, please re-open the simulation (*L01 Default vessel.sim*) and make sure the *Original vessel* is shown in the model view. Next, open the workspace file *L01 Default vessel phase check.wrk*. Run the replay to see how the two vessels respond to the default wave loading: *H* = 7m, *T* = 8s, Dean stream wave type. When viewing the simulation replay, you should be able to see that the pitching motion of the two vessels is slightly out of phase.

We investigated this issue by also running a diffraction analysis in WAMIT, which showed that the WAMIT results agreed with the OrcaWave results. It is possible that either the RAO origin or the RAO phase origin used by OrcaFlex for the original vessel data is not specified correctly. In any case, we are satisfied that the results generated by OrcaWave are correct.

Comparison of results – 2nd order

We also generated wave drift loads in the form of Newman QTFs in the OrcaWave analysis. This was done using both the *pressure integration* and the *control surface* methods for comparison. The *control surface* method requires an additional mesh, as described previously, and is expected to be the more accurate method for bodies of this shape.

We also compared the results with the original vessel QTFs, however it is noted that the data are reported about different origins (the original vessel QTF data is reported about the centre of gravity, the OrcaWave results are reported about the vessel origin). Force QTF data can therefore be directly compared, but moments cannot. It is worth noting that the results can be reported relative to an origin of your choice, but this can only be achieved via the API; hence, allowing direct

comparison of the different sets of results. This is beyond the scope of this example but further details about this can be found in the API help.

The plots below show the surge and heave results for the 45-degree wave direction, comparing the two OrcaWave methods with the original vessel results:
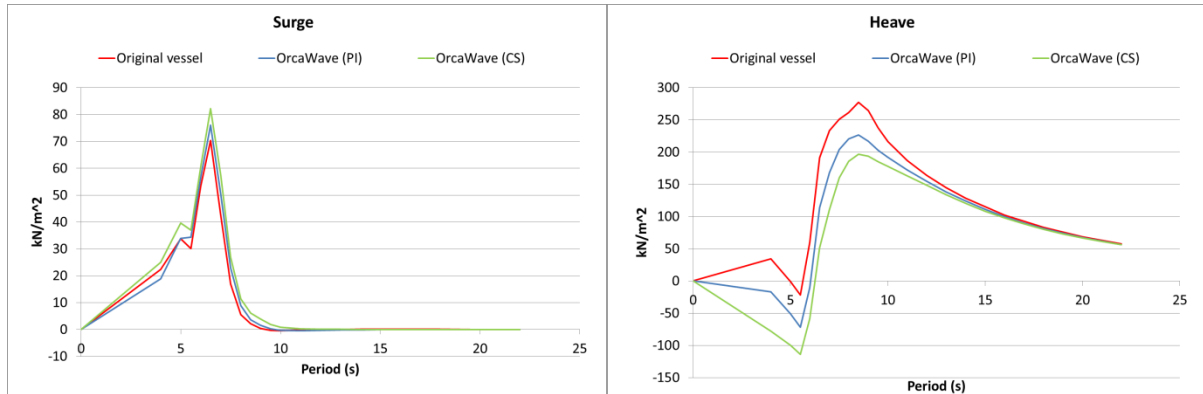

It is known that quadratic loads are often the slowest to converge when performing a mesh convergence study and, in this case, it is likely that the mesh should be refined further to get better agreement between the methods. In this case we are restricted to using the original mesh which, while appropriate for RAO generation, is possibly too coarse for the quadratic load calculation. A detailed discussion on the effects of mesh refinement is offered in the example L02 OC4 semi sub.

Setting the remaining data

For completeness, we also set the *current load* and *wind load* data for the *OrcaWave default vessel* type, by copying and pasting the datasets from the *Original default vessel* type.

OrcaFlex also requires the RAO and QTF data to span the range of frequencies involved in the simulation. The data imported from OrcaWave includes wave periods between 4 and 22 seconds. If the wave train modelled in OrcaFlex includes components outside of this range then OrcaFlex will make some assumptions about how the RAO and QTF data is applied to these components and will issue a warning, e.g.:
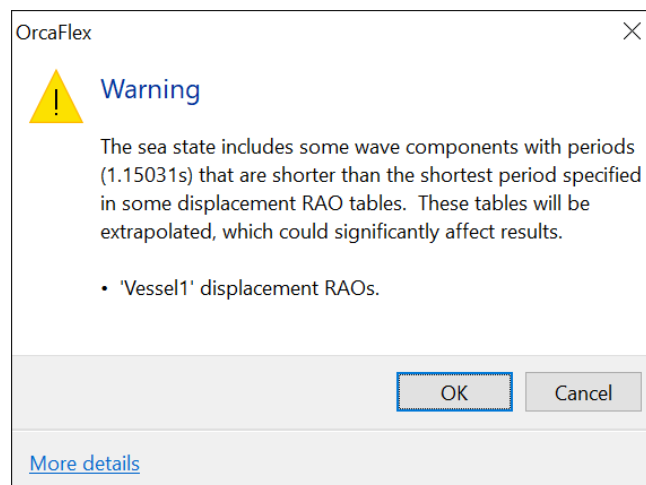
To avoid this warning, you can define data for zero and infinity periods in your RAO and QTF tables, following guidance offered on the Modelling, data and results | Vessels | Vessel types | RAOs page of the OrcaFlex help. We have taken this approach for this example model.

Finally, both the wire frame and the shaded image in OrcaFlex can also utilise the panel mesh. The mesh can be imported as panels at the same time as the diffraction data is imported. This panel data can be found on the *drawing* page of the *vessel type* data form. Switching to the shaded graphics mode (*Ctrl+G*) shows the hull form in the shaded view.