
Hybrid Buoy-Vessel Modelling

1 Introduction

Generally, the floater for a particular system will fall within either the diffraction or drag/inertia regime. It can then be modelled in OrcaFlex either as a vessel (for the diffraction regime) or 6D spar buoy (for the drag/inertia regime).

However, it is occasionally necessary to consider a hybrid model, using both a vessel and a buoy rigidly connected together. For example, it may be desirable to allow a non-linear variation in buoyancy force with floater pitch/roll.

This note describes how this can be done for a circularly symmetric object whose axis is vertical, e.g. a CALM buoy or SPAR, by attaching a 6D spar buoy to a calculated vessel in OrcaFlex.

Section 2 gives a brief summary of the typical approach in this type of model, while Section 3 gives further detail and background information.

2 Modelling Summary

2.1 Object Connections

Create a vessel object and a spar buoy object and connect these together. Either the vessel can be connected to the buoy, or the buoy to the vessel. The objects should be connected so that their origins are coincident with zero relative rotation.

2.2 Mass and Buoyancy

On the spar buoy data form, enter the mass, mass moments of inertia and centre of mass location. Also fill in the Geometry page appropriately.

On the Structure page of the vessel type data form, set the Mass and Moments of Inertia to be negligible (say 1E-6, since OrcaFlex won't allow zero values) and set the Centre of Gravity to zero.

On the Stiffness, Added Mass, Damping page of the vessel type data form, set the Hydrostatic Stiffness matrix to be all zeros, since the buoyancy is being modelled by the spar buoy. Set the Displaced Volume to zero.

2.3 Vessel and 6D Buoy Hydrodynamic Loads

On the Added Mass & Damping page of the buoy data form, set the added mass & damping to be specified by "RAOs and matrices for Buoy" and set all the other data on that page to zeros. Set the data on the buoy Drag & Slam page to zeros. This is required because both these effects will be modelled using the vessel object.

On the vessel data form set the vessel length to '~' (meaning same as vessel type length). And on the Calculation page set the Primary Motion to "Calculated (6DOF)" and the Superimposed Motion to "None". The vessel may be excluded from statics (by setting the Included in Static Analysis option on the Calculation page to "None") or have its static position calculated (by setting the Included in Static Analysis option on the Calculation page of the vessel data form to "6DOF").

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Set the Included Effects on the Calculation page of the vessel data form to include "Wave Load (1st order)", "Added Mass and Damping", "Current Load", "Wind Load" and possibly also "Wave Drift Load (2nd order)", "Wave Drift Damping" and "Other Damping".

2.4 Vessel Type Properties

On the vessel type data form, set the vessel type length to the object diameter, and on the Conventions page set the Symmetry to "circular".

Corresponding vessel type data need to be set for each Included Effect selected. Data for "Wave Load (1st order)", "Added Mass and Damping" and "Wave Drift Load (2nd order)" are usually imported from a diffraction package output while data for "Current Load", "Wind Load" and "Other Damping" must be entered manually.

2.5 Filtering Vessel Response

Since the floater motion includes both first and second order (wave and low frequency) contributions, the 'Primary Motion is treated as' setting on the Calculation page of the vessel data form needs to be set to "Both and wave frequency". An appropriate Dividing Period should also be set on this page; typically to a dividing period whose corresponding frequency is about half way between the expected significant wave and low frequency response frequencies.

2.6 Floater Drawing

You might also want to hide the vessel in the 3D view, since the spar buoy will probably draw the object in a more convenient way. This can be done by right-clicking the vessel in the model browser and choosing Hide. Alternatively you could set the Number of Edges on the Drawing page of the vessel type data to zero.

3 Background Information

3.1 Object Connections

Historically, vessels were not permitted to be "slave" objects in OrcaFlex, however, it is now possible to have either the vessel or the buoy as the slave in the connection relationship. In terms of the floater's response, it doesn't particularly matter which object is the master, as the objects are rigidly connected together.

Connecting the objects together at their origin ensures that their local axes are coincident. Although not essential, this makes it easier to set consistent data for both objects - which is important as they both represent the same physical object.

3.2 Mass and Buoyancy

3.2.1 6D Buoy

Both the buoyancy and the mass properties of the floater will be applied through the 6D buoy.

The buoyancy is defined through the 6D buoy because OrcaFlex determines the buoyancy of a spar buoy directly from the submerged cylindrical volume. Specifically, the instantaneous wetted volume and centre of volume are calculated directly for each cylinder in the buoy stack based on its defined geometry (outer diameter and length).

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Thus, the buoyancy force can be calculated accurately for an object with circular symmetry, varying in a non-linear way as the buoy pitches / rolls. Vessels only permit a linear hydrostatic stiffness matrix to be defined, which is less accurate for larger rotations.

It would be equally reasonable to set the mass, mass moment of inertia and centre of mass data on the vessel. However, since the buoyancy calculation must be carried out by the 6D buoy, it makes some sense to also set the mass (and hence weight) properties on this object too.

It should be noted that the mass moments of inertia are those about the local 6D buoy axes, passing through the specified centre of mass location.

The co-ordinates of the centre of mass are given relative to the buoy origin. The position of the origin for a 6D spar buoy, relative to its geometry, is effectively defined through the Stack Base Centre Position data item on the Geometry page of the buoy data form. This defines the position of the base of the stack of cylinders relative to the buoy origin. The default setting of zero has the buoy origin at the base of the stack, on the buoy centreline.

3.2.2 Vessel

The mass, moments of inertia and centre of gravity must be set to negligible values in the vessel type data as these are already defined on the 6D buoy.

The vessel's hydrostatic stiffness describes the vessel's buoyancy force – if the vessel tries to heave downwards (or pitch or roll) then the hydrostatic stiffness resists this motion. Since the buoyancy effects have already been included through the 6D buoy, we would be double-accounting if they were also applied to the vessel.

3.3 Vessel and 6D Buoy Hydrodynamic Loads

3.3.1 6D Buoy

Selecting “RAOs and matrices for Buoy” ensures that the buoyancy calculation is determined using the 6D buoy's instantaneous position relative to the mean water level; and not with respect to the instantaneous sea surface. The floater buoyancy contributions arising from wave crests and troughs should already be accounted for through the vessel's Load RAOs (first order wave loads) and so including them in the 6D buoy's buoyancy calculations would mean double-accounting.

6D buoys calculate their drag (and linear damping) loads based on the total buoy and fluid velocities, including contributions from both current and wave water particle velocities. This means that there is no separation of the hydrodynamic loads into low frequency (second order) and wave frequency (first order) effects – unlike the vessel object. Since many of the hydrodynamic fluid loads (as opposed to buoyancy) will already be present within much of the vessel type data (e.g. RAOs, QTFs etc.), it is generally better to model all of the hydrodynamic fluid loads, including drag / damping, through the vessel.

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3.3.2 Vessel

The vessel should be treated as a free body in dynamics, with its equation of motion fully calculated (in all degrees of freedom), thus the Primary Motion must be set to “Calculated (6DOF)”. Since the vessel motion is then fully described, no Superimposed Motion is required.

The vessel can also be treated as a free body in statics. This is achieved by setting Included in Static Analysis to “6DOF”. The vessel can be removed from statics (and so will remain at its defined Initial Position for the static calculation) by selecting “None” for Included in Static Analysis.

The Included Effects determine what load contributions will be included in the vessel calculation. Since we assume that the floater is large enough to lie within the diffraction regime, then most of environmental loads will be more accurately applied through the vessel.

It is likely that the model will need to consider wave frequency loads, therefore including ‘Wave Load (1st Order)’ is essential. Also, it is likely that hydrodynamic and aerodynamic drag will be important second order effects and these can be captured through the ‘Current Load’ and ‘Wind Load’ Included Effects.

It should be noted that Current Load and Wind Load act only in the horizontal plane. If the floater has significant axial and/or pitch(roll) drag then this would be included through the ‘Other Damping’ Included Effect. Other Damping permits both linear and quadratic damping to be applied but it should be noted that this damping is not proportional to the relative fluid velocity but, rather, to the vessel’s wave frequency motion relative to earth.

Finally, second order (low frequency) wave drift effects may also be applied through the ‘Wave Drift Load (2nd Order)’ Included Effect. It is possible to include the influence of the vessel’s low frequency motion on the wave encounter frequency by checking ‘Wave Drift Damping’ as an Included Effect. If Wave Drift Damping is not checked then the wave drift loads will be calculated assuming that the vessel remains stationary with respect to the incoming waves.

3.4 Vessel Type Properties

We do not wish to perform any Froude Scaling of the vessel type data and so we must set the vessel Length to match the vessel type length. The vessel type Length is simply set equal to the floater diameter for completeness (and for future reference).

The Symmetry should be “Circular” as we assume here that the floater is axisymmetric – this is consistent with the fact that we use a 6D spar buoy to model the floater’s buoyancy. Setting circular symmetry means that both Load RAO and QTF data need only be supplied for one single wave direction.

Much of the vessel type data can be set by a single import from a diffraction package output text file. These would include Load RAOs [used in Wave Load (1st Order) calculations], QTFs (used in Wave Drift calculations) and Added Mass and Damping data (of which, the frequency-dependent data are to be preferred).

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Output from AQWA and WAMIT can be automatically imported by OrcaFlex; data from other packages require the user to “mark-up” up text output file with header text strings prior to input. Both the diffraction package units and conventions can be specified in the marked-up text file, allowing OrcaFlex to convert into the prevailing units / conventions at the time of import.

Current and Wind Load arise from hydrodynamic drag (i.e. they represent quadratic damping) and so cannot be determined by a diffraction package, which would consider a potential flow solution only. OrcaFlex uses the OCIMF (Oil Companies International Marine Forum) method to describe these second order drag loads. The necessary drag areas and associated load coefficients must be manually entered into OrcaFlex on the Current and Wind Load pages of the vessel type data.

Other Damping is also not something that would be determined by a typical diffraction package. However, the additional damping it represents might be included in the diffraction analysis as a manually input constant damping term, in which case the data values may be in the diffraction package output text file. If so, but only for AQWA files, OrcaFlex can (optionally) include it in the automatic import of vessel type data. Otherwise it needs to be entered manually by the user, on the Other Damping page of the vessel type data.

3.5 Filtering the Vessel Motion

Most of the vessel Included Effects require only a part of the vessel’s total motion as input. For example, Current and Wind Load are assumed to be relative to the vessel’s low frequency motion only; damping of the wave frequency motion is assumed to arise from Added Mass and Damping and possibly also Other Damping. Thus, only the low frequency part of the vessel motion should be input to the Current and Wind Load calculations.

A filter is used to permit the vessel motion to be split up into these wave and low frequency parts. Since OrcaFlex has to use a time domain filter, the cut-off achieved cannot be very sharp. This means that the Dividing period specified for the filter should be as far removed from both the first order and second order response periods as possible. Generally we recommend using a dividing period whose corresponding frequency is the arithmetic mean of the most significant first order and second order response frequencies. But a good separation is not always achievable, and in these circumstances it is always advisable to perform a sensitivity check on the choice of dividing period.

3.6 Floater Drawing

The vessel drawing does not affect the calculations, but it may be confusing to show both vessel and buoy in the 3D view.

Since the 6D spar buoy is drawn using a stack of cylinders of the same dimensions as those specified in the Geometry page of the buoy data form, it will probably produce a reasonable image of the floater in the 3D view.

However the vessel or vessel type drawing page data could be used to give more control over the 3D wire frame view of the floater, by specifying your own drawing vertices and

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edges. Or the floater could be represented in the 3D view using connected Drawing type shapes or, in the shaded view, through an imported .x 3D drawing image. In each of these cases, the 6D spar buoy drawing would need to be suppressed by setting the Pen Style to be blank (on the Drawing page of the buoy data form).

We hope that the information in this article is useful, but do contact us if you have any comments or questions.

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