C06 CALM Buoy

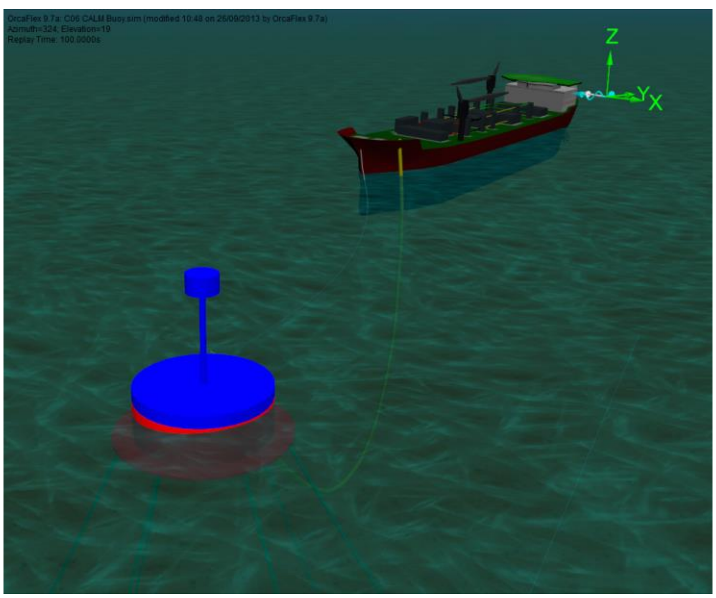
Introduction

In these examples, a CALM buoy is moored by six equally spaced mooring lines. A shuttle tanker is moored to the buoy by a hawser, with fluid transfer through a floating hose. These models are coupled analysis examples.

The examples also discuss the Spar Buoy Short Wave Issue and present two options for avoiding problems when modelling scenarios where the wavelength is in the order of three times the buoy's diameter or less. The first model shows the CALM buoy modelled as a single stack of cylinders, while the second models it as multiple stacks of cylinders, to allow both radial and axial discretisation of the buoy's properties.

1. CALM Buoy

1.1. Building the model



In the model 'C06 CALM Buoy.sim' the CALM buoy is modelled as two 6D spar buoys, named CALM Top and CALM Base.

The two buoys are connected together using a hinge arrangement, which allows the top buoy to rotate about the axis of the base buoy. This is done with two single segment lines, which tie the two buoys together while still allowing them one degree of freedom about the central axis. These lines are named 'Pivot1' and 'Pivot2' and are currently hidden in the model. To show them, select them in the model browser, right mouse click and select 'Show'. You will also need to switch to the wireframe view (Ctrl + G) and zoom in on the buoy to be able to see the short yellow lines in the centre of the buoys.

Run the replay and look at the motion of the top buoy relative to the base buoy (again this is easiest to see in the wireframe view); you should be able to see that the top buoy is rotating about the base buoy's axis.

Both buoys are modelled as a stack of co-axial cylinders. The OrcaFlex Help file section 'System Modelling – Data and Results | 6D Buoys | Spar Buoy and Towed Fish Properties' explains this further. In this case, we have used five cylinders to model the CALM Base, of which Cylinder 4 represents the projecting skirt, which will provide damping against wave-induced motions. Unit Damping forces and moments are applied to represent this. Note that the values used in this example are arbitrary; this data is usually established by model tests.

It is important to ensure that the physical and hydrodynamic properties of the buoy are as close as possible to the real CALM buoy properties. Look at 'System Modelling – Data and Results | 6D Buoys | Modelling a Surface-Piercing Buoy' in the OrcaFlex Help file for further discussion of data preparation for CALM buoys and the like. In the model, the properties are distributed out among the cylinders in the two stacks.

Note that the wind load on the buoy is represented by a global applied load on the top buoy because 6DofF buoys only experience wind load directly via wings.

The tanker is modelled as a free body subject to wind, wave and current loading. Look at the Vessel page. The primary motion has 6 DOF motions calculated. These include the current and wind loads, the 1st order wave loads, the added mass and damping effects, the wave drift loading and the wave drift damping, which are all specified in the Included Effects box. Because the 1st order wave motions are included in the calculated effects, load RAOs are used instead of displacement RAOs, and superimposed motion is therefore set to none to avoid applying that motion component twice.

Beware

This type of buoy analysis is only valid if the wavelength of the incident wave is greater than 3x diameter of the buoy. In irregular seas, the spectrum can include some components that infringe this requirement; the Hs 2m by Tz 6s JONSWAP spectrum storm applied in this model is an example of this, so the wave components have been filtered as described in Section 2 below.

Read the OrcaFlex Help section 'Theory | Line Theory | Interaction with the Sea Surface' for details on modelling floating hoses.

1.2. Results

When the simulation file is first opened, a workspace is opened up which shows a shaded view of the buoy and tanker. Look at the animation through Stage 1. Note how the hose and tanker drift due to the environmental loading. Note that the drift of the tanker is exaggerated because it is not included in the static calculation. We therefore see the current and wind drift included in the dynamics stage.

The instantaneous range graphs of the hose effective tension and curvature show how they change through the simulation. The graphs show results from the tanker to the buoy (an arc length of 0m is the tanker connection while an arc length of 120m is the buoy connection). You can see curvature waves travelling up and down the hose length.

2. Spar Buoys Short Wave Issue

This section documents an issue that can arise when modelling near-surface spar buoys.

A random sea is modelled in OrcaFlex using a large number of regular component waves, whose periods and amplitudes are chosen to match the specified spectrum. You can see the wave components chosen and their wavelengths by clicking the 'View Wave Components' button on the Waves page of the Environment data form.

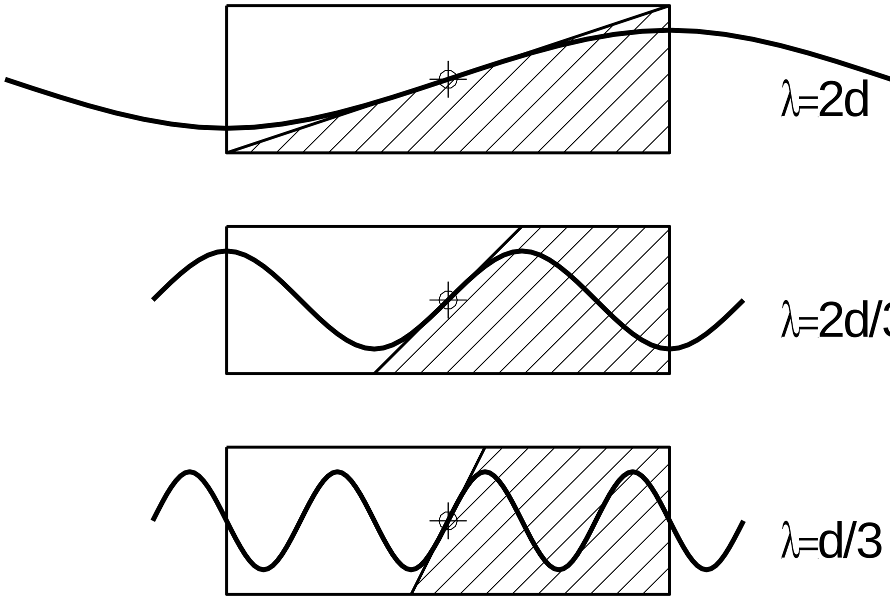
To cover the high frequency tail of the spectrum, the components include some short period waves. In some cases they can go down to a period whose corresponding wavelength is shorter than the diameter of a spar buoy in the model, and this raises a modelling issue. Note that the issue is only really relevant for near-surface buoys, since short waves do not penetrate far down in the water column.

A wave whose length is short compared with the buoy diameter will have effects that vary significantly across the diameter of the buoy. So to analyse a short wave's effects accurately OrcaFlex would have to calculate the fluid load contributions (buoyancy, drag etc.) at a number of points across the diameter of the buoy. But in OrcaFlex spar buoys cannot be subdivided in that radial direction - they can only be it subdivided in the buoy's axial direction, by dividing the buoy up into a stack of cylinders.

OrcaFlex calculates the fluid kinematics (velocity, acceleration, surface elevation, surface slope etc.) based on the sea surface and fluid kinematics at just one point on each cylinder of the buoy, and assumes that the values at that point apply right across the cylinder's diameter. This is fine for wave components a lot longer than the buoy diameter. But for waves shorter than about 3 times the buoy diameter the fluid kinematics, and hence the loads, average out since different parts of the buoy diameter are seeing different phases of the wave at any one instant.

The result of this is that the effects of the wave components shorter than about 3 diameters are exaggerated in OrcaFlex, since it cannot allow for the fact that the effect of such components are averaged across the buoy diameter.

The figure below illustrates the point for the calculation of the buoyancy force and moment (similar problems arise for drag, added mass force etc.), for three cases where the wavelength is less than 3 times diameter.



OrcaFlex determines the water surface slope at the centre of the buoy and then assumes this slope is constant across the buoy. Of course in a random sea the surface slope is a combination of the slopes of the various individual components that represent the random sea (and OrcaFlex allows for this), but longer waves have smaller slopes so the short waves tend to dominate the surface slope. So for simplicity the figure only shows the situation where there is just a single short wave component present, and it illustrates how its wavelength affects the buoyancy calculation.

OrcaFlex calculates the buoyancy force and the centre of buoyancy (i.e. the point where it acts) by calculating the wetted volume and centre of wetted volume of each cylinder of the buoy. And each cylinder's wetted volume and wetted centroid is calculated by assuming that the surface through that cylinder is the tangent plane to the wave surface directly above or below the volume centre of that cylinder.

The shaded section of the buoy therefore indicates what OrcaFlex will assume for the immersed volume and hence the magnitude of the buoyancy force and the centre of buoyancy, and so the size of the buoyancy moment applied.

As the wavelength reduces, so the discrepancy increases between the actual and the modelled righting moment. For example in the third case (shortest wave), the actual righting moment due to buoyancy will be small, since the wave crests and troughs are distributed fairly evenly across the buoy, but the calculated buoyancy moment will be large since the shaded area is almost all on one side of the buoy, so OrcaFlex will calculate that the centre of buoyancy is offset by nearly half a diameter from the buoy centre.

You can work around this problem by removing (or scaling down) the short wave components. There are two ways to do this in OrcaFlex, as follows.

- Copy the wave components chosen by OrcaFlex, by clicking the 'View Wave Components' button and then copying the frequency, period, amplitude and phase lag columns. Then change the wave type to 'User Specified Components' and paste the wave components back into OrcaFlex. Finally, delete (or scale down) those components that are shorter than about 3 diameters.

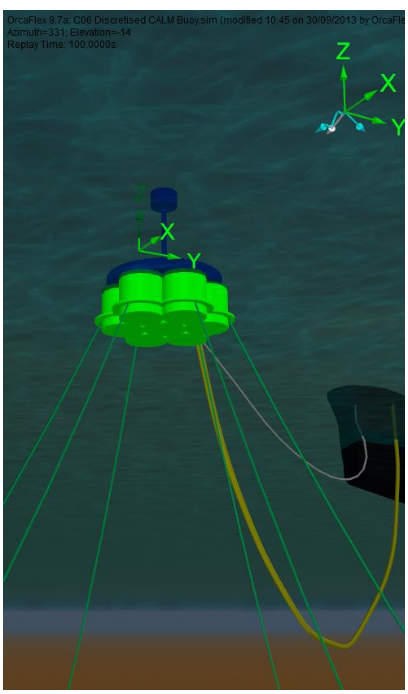
- Alternatively you can copy the spectral density values, by clicking the 'View Spectrum' button, then right clicking and selecting Values, and then copying the table of spectral frequencies and density values. Then change the wave type to 'User Specified Spectrum' and paste the spectral frequency and density values back into OrcaFlex. Finally, delete (or scale down) the last few entries to truncate (or reduce) the spectrum for wavelengths less than about 3 diameters.

Note that these two methods will not give exactly the same results, since in the latter OrcaFlex will re-discretise the truncated spectrum, but they should give statistically equivalent results.

In the ‘C06 CALM Buoy.sim’ model, the wave components have been edited to remove the short wavelength components. In this case, the buoy is 11m diameter, therefore wavelengths of <33m (i.e. 3xD) have been removed. Open the Environment data form, and look at the Waves page to see that the wave type has been set to ‘User Specified Components’. This page also shows the table of included components, which has had the short wavelength components removed.

3. Discretised CALM Buoy

In this example, the original wave environment (Jonswap spectrum Hs = 2m, Tz = 6s) contained wave components with wavelengths shorter than 3x diameter of the buoy. As explained above, one option to deal with the ‘Short Wave Issue’ is to filter out the short wave components. However there is an alternative method that allows you to leave the environmental conditions unchanged; this method involves radially discretising the buoy in order to better model the situation. The use of smaller diameter spar buoy cylinders means that fewer wave components will fall into the ‘short wave issue’ range of wavelengths.



3.1. Building the model

Open the model ‘C06 Discretised CALM Buoy.sim’.

In this model, the top section of the CALM buoy has been modelled as previously, but the lower section, which is exposed to fluid loads, has been split up into multiple buoys. In the Model Browser, right mouse click and make sure that the ‘View by Groups’ option is ticked, and examine how the CALM Buoy group is structured.

The blue CALM Top is a single spar buoy as before, with two pivot lines to connect it to the base while allowing it to spin on its axis. The CALM Base group in the Model Browser contains seven 6D Buoy objects, one for the centre stack of cylinders and one for each of six radial stacks.

The centre stack is called the ‘Master’ buoy. This is the buoy to which all the other buoys are connected to create a single rigid body, and the entire CALM buoy’s mass and mass moments of inertia data are assigned to it. The radial buoys are assigned negligible mass and zero mass moments of inertia.

To ensure that the discretised buoy has equivalent properties to the single-stack buoy of the previous example, some care is needed when assigning properties to the multiple buoys.

The volume of each of the multiple buoys was calculated by dividing the volume of the single buoy by the number of buoys in the group (i.e. seven in this case). From this, the diameters of the multiple buoy sections were calculated. Other properties were assigned as follows: -

Drag Forces

The inner stack is completely shielded from fluid flow in the normal direction, therefore the normal drag areas are set to zero for all sections of the master buoy.

The radial buoys are not shielded and will therefore experience drag forces from flow in the normal direction. In reality, different buoys would contribute differently to the total drag force, depending on where it was positioned relative to the oncoming flow. However to avoid any dependence on the flow direction it is assumed in this case that all radial buoys contribute equally to the drag force.

To ensure equivalency with the single buoy model, the normal drag areas assigned to the sections of the single buoy are divided by six (the number of buoys in the radial ring) and assigned accordingly.

The axial drag force will be experienced by all seven of the buoys in the discretised arrangement, therefore the axial drag areas assigned to the lower sections of the single buoy are divided by seven in this model and assigned to each of the multiple buoys.

As a check that the drag properties have been assigned correctly, calculating the sum of all the drag areas x drag coefficients, in both the normal and axial directions, should result in the same values for both the single buoy and multiple buoy models.

Added Mass

The added mass contribution to Morison's equation is proportional to the displaced volume; therefore by dividing the volume of the single buoy amongst the multiple buoys, we are also dividing up the added mass contribution. No adjustment of the added mass data is therefore needed and the same added mass coefficients have been applied to the sections of each of the seven buoys, as were applied to the single buoy model.

Radius of Ring

Finally, we need to calculate the radius on which the ring of buoys needs to be positioned, and this is done by calculating the second moment of area for the bottom face of the single buoy, and calculating the radial positions of the multiple buoy arrangement that results in the *same* second moment of area.

The resulting single and multiple-buoy models will behave identically in rock and heave tests in still water, as they have equivalent properties applied. They will also respond to longer period waves in the same way, but a difference in response will show when short wavelength waves are applied (as discussed in Section 2), with the multiple buoy option modelling the behaviour more accurately.