C06 CALM buoy

Introduction

In this example, 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.

This document also describes the 'spar buoy short wave issue' and presents two options for avoiding problems when modelling scenarios where the wavelength is in the order of three times the buoy's diameter (or less).

Included are two models: the first (*C06 CALM buoy.sim*) demonstrates how the CALM buoy can be modelled as a single stack of cylinders, while the second (*C06 Discretised CALM buoy.sim*) demonstrates the use of multiple stacks of cylinders, to allow both radial and axial discretisation of the buoy's properties.

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 using a *constraint* object, which allows the top buoy to rotate about the axis of the base buoy. This is done by giving the constraint a single *Free* rotational degree of freedom.
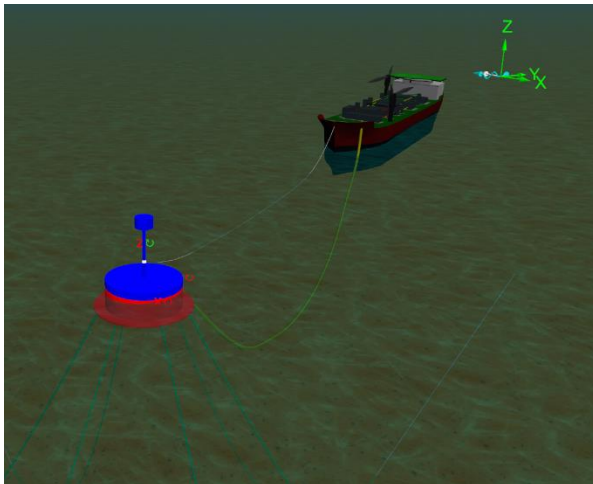
Open the data form for the constraint object *Rotation* and look at the options on the *degrees of freedom* page. Note that this constraint has only one degree of freedom, which is a rotation about its z-axis (*Rz*). The constraint is fixed to the base buoy and the top buoy is then connected to the constraint.

The constraint is currently hidden from the model view. To show it, select it in the *model browser*, right-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 white-coloured coordinate system representing the constraint. Note that the curly arrow next to the z-axis is green; this shows that rotation about this axis is free, while all other degrees of freedom (in red) are fixed.

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 Modelling, data and results | 6D buoys | Spar buoy and towed fish properties page of the OrcaFlex help explains this further. In this case,

we have used five cylinders to model the CALM Base, of which cylinder 4 represents the "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 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 any parts of the buoys that are above the sea surface will experience wind loading from aerodynamic drag. The *wind* page of the *environment* data form allows you to choose whether or not wind loads are included for vessels, lines, 6D buoys and 6D buoy wings.

The tanker is modelled as a *vessel* object which represents a free body subjected to wind, wave and current loading. Open the *Vessel* data form via the *model browser*. On the *calculation* 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 switched off i.e. to avoid applying that motion twice.

Note: 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, as we have here, the spectrum can include some components that infringe this requirement. The JONSWAP wave spectrum considered for this model – with a significant wave height (*Hs*) of 2m and period (*Tz*) of 6s – is an example of this. So, the wave components have been filtered as described in the '*Spar buoys short wave issue*' section below.

The Theory | Line theory | Interaction with the sea surface page of the help provides further details about modelling floating hoses.

Results

When the simulation file is first opened, a workspace is opened 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 value 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.

Spar buoys short wave issue

This section describes 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, this issue is only relevant for near-surface buoys because short waves do not penetrate far down in the water column.

In reality, 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 need to calculate the fluid load contributions (buoyancy, drag etc.) at a number of points *across* the diameter of the buoy. However, OrcaFlex spar buoys cannot be subdivided radially; they can only be subdivided in the buoy's *axial* direction i.e. by dividing it into a stack of cylinders.

OrcaFlex calculates the fluid kinematics (velocity, acceleration, surface elevation, surface slope etc.) based on the sea surface at just *one* point on each buoy cylinder and assumes that the fluid kinematics at that point apply across the cylinder. This is fine for wave components with a much longer wavelength than the buoy diameter. However, for waves shorter than about 3 times the buoy diameter, the fluid kinematics (and hence the loads the buoy experiences) will average out, since different parts of the buoy diameter are seeing different phases of the wave at any one instant. This can lead to unrealistic buoy motion.

The figure below illustrates this concept in the context of buoyancy force and moment calculation but similar problems arise for drag, added mass force, etc.. Here, three cases are considered, where the wavelength is less than 3 times the buoy diameter. The sketches show that 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 individual components that represent the sea state (OrcaFlex accounts for this). However, longer waves have shallower slopes so the short waves tend to dominate the surface slope.

For simplicity, the figure shows the situation where just a single short wave component is present, and it illustrates how the wavelength affects the buoyancy calculation. Generally, 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 buoy cylinder. 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 cylinder's centre of volume.

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

As the wavelength reduces, the discrepancy between the actual righting moment and the modelled righting moment increases. For example, in the third case (shortest wave), the actual righting moment due to buoyancy will be small because the wave crests and troughs are distributed evenly across the cylinder. However, the calculated buoyancy moment will be large since the shaded area is almost entirely on one side of the cylinder i.e. OrcaFlex will determine the centre of buoyancy to be offset by nearly half a diameter from the buoy centre.
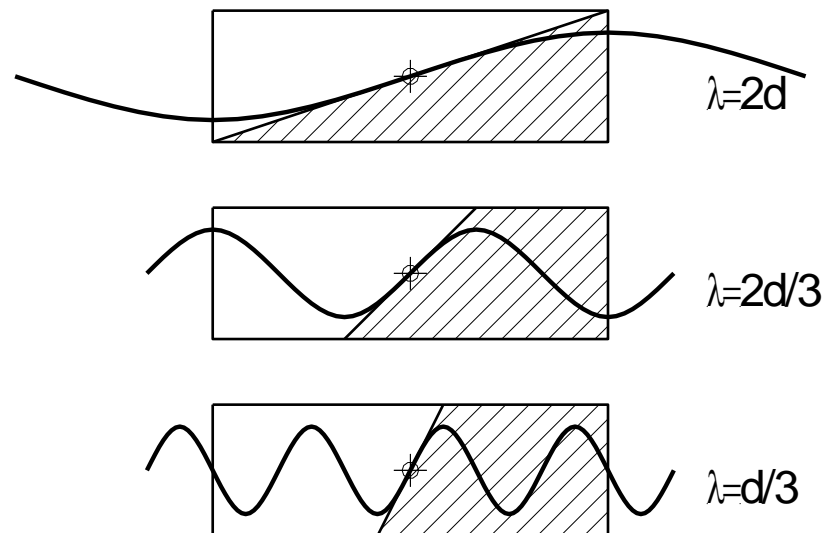
You can work around this problem by removing (or scaling down) the short wave components. There are two ways to do this in OrcaFlex:

- 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 frequency spectrum* button, then right-click on the plot and select *values*, before copying the table of spectral frequency and density values from the spreadsheet. Then change the wave type to *user defined spectrum* and paste the spectral frequency and density values into the *spectrum* table. 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, because the latter option will re-discretise the truncated spectrum; however, 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 (with the short wavelength components removed).

Discretised CALM buoy

In this example, the original wave environment is applied (JONSWAP spectrum, Hs = 2m, Tz = 6s). The wave spectrum includes components with wavelengths shorter than 3x diameter of the buoy.

As explained above, one option to deal with the 'spar buoy short wave issue' is to filter out the short wave components. However, there is an alternative method which allows you to leave the environmental conditions unchanged. This method involves *radially* discretising the buoy using cylinders of smaller diameter. The use of smaller diameter spar buoy cylinders means that fewer wave components will fall into the 'short wave' range of wavelengths.

Open the model *C06 Discretised CALM buoy.sim*.
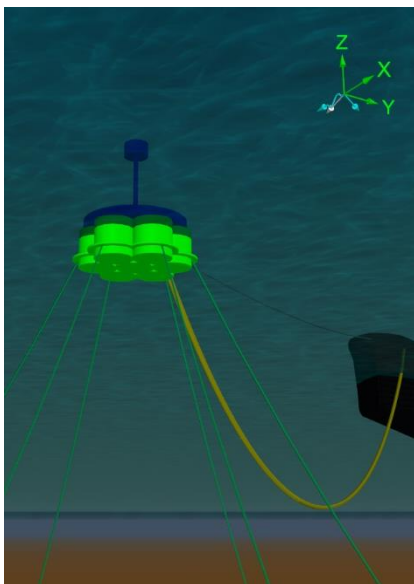
Here, the top section of the CALM buoy has been modelled as previously, but the lower section – which is exposed to fluid loads – has been split up into multiple buoys.

In the *model browser*, right click & make sure that the *view by groups* option is ticked and then examine how the CALM buoy group is structured. The blue *CALM Top* is a single spar buoy as before, with a constraint that connects 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 *Main* 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 zero *mass* and *mass moments of inertia*.

To ensure that the discretised buoy has equivalent properties to the single-stack buoy, modelled in the previous example, some care is needed when assigning properties to the constituent 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 main 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 here 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. This means that no adjustment of the added mass data is needed.

The same added mass coefficients, as those applied to the single buoy model, have therefore been applied to the cylinders comprising each of the seven buoys.

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. However, a difference in response will show when short wavelength waves are applied because the discretised buoy allows this behaviour to be captured more accurately.