F01 Lowering hydrodynamics

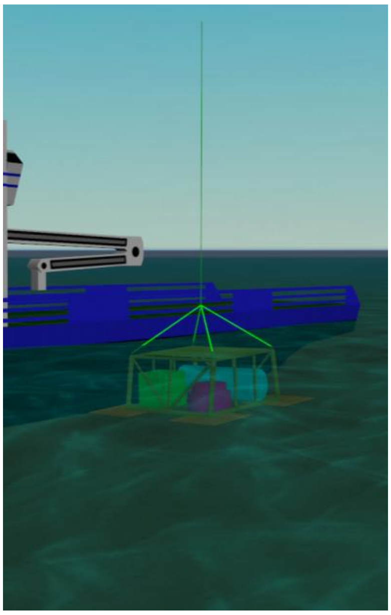
Introduction

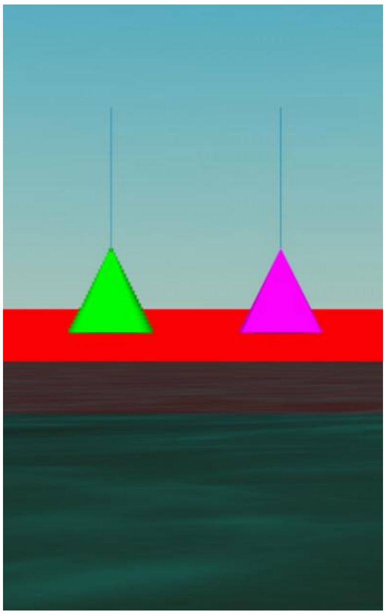
In these three example models, we consider a number of effects that often need to be accounted for when performing a lifting or lowering analysis through the sea surface in OrcaFlex.

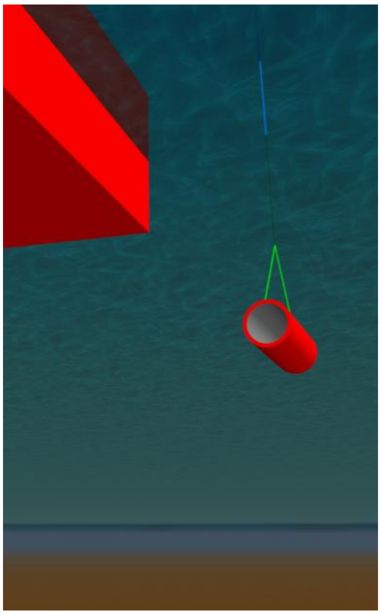
Firstly, a complex manifold structure is modelled using a number of objects connected together. In the dynamic simulation, the structure is lowered through the sea surface (*F01 Manifold block*). Hydrodynamic effects are applied, including slam forces.

In the next model (*F01 Lowered cone*), we look at modelling hydrodynamic slam forces in more detail, by considering a simple cone-shaped object lowered into still water.

Finally, we look at how to model the effects of water flooding into compartments within a structure and becoming 'trapped' as the structure is lowered into the water (*F01 Trapped water*). Again, we consider a simple object (a hollow cylinder in this case) to explain the modelling methodology. For a more complex example involving trapped water, see our separate example on suction anchor installation: F07 Suction anchor lowering.



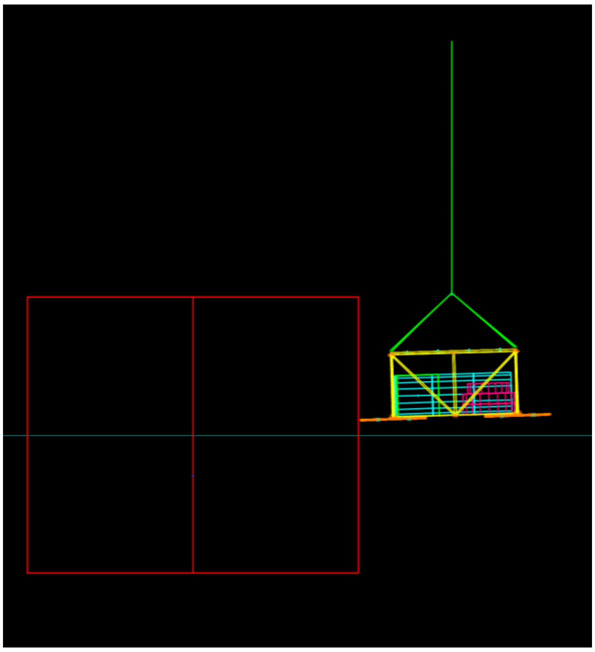


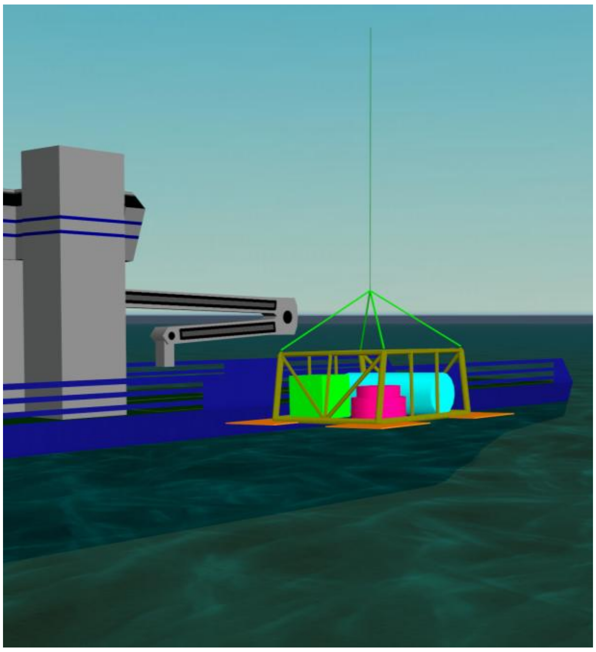


Manifold block

Building the model

On opening the simulation file, *F01 Manifold block.sim* you will see two views of the model, one in shaded graphics, and the other in wire frame.





The first thing to consider when building an OrcaFlex model of a lifting or lowering operation, is how the object's size affects the choice of OrcaFlex objects used to model it.

Crane lifting operations are often divided into two categories: light lifts and heavy lifts. *DNVGL-RP-N103* (*Modelling and analysis of marine operations, July 2017*) gives guidance on this, but typically, if the lifted object is very small compared to the vessel (< 1–2% of the displacement of the vessel) then the motion characteristics of the vessel are not affected by the lifted object. This is classed as a light lift.

If the lifted object is more than 1–2% of the vessel displacement, then this is classed as a heavy lift, and coupled dynamics of the vessel and the lifted object must be considered.

In OrcaFlex terms, this means that a light lift is modelled using a vessel whose motion is fully described by displacement RAOs. A heavy lift requires a calculated vessel, and therefore the *calculated (6DOF)* option is required, along with appropriate choices for the *included effects* and *primary motion is treated as* options. For further details about these settings, see the Modelling, data and results | Vessels | Vessel data | Calculation data of the OrcaFlex help.

In this model, the lifted object falls into the light lift category, and therefore the use of displacement RAOs for the vessel is appropriate. Open the vessel's data form and look at the *calculation* page to see how this method has been selected.

A second consideration regarding the lifted object's size is whether the object should be modelled using diffraction theory or drag/inertia theory. In this example, we are assuming that the lifted object is small compared to the wavelength, and therefore modelling the lifted object with Morison objects is appropriate. In OrcaFlex, the Morison objects are lines and buoys.

If the lowered object is large enough to diffract the waves, then it should be modelled with a diffraction object i.e. a vessel, with its motion fully calculated. This method will not be considered in this example; meaning we are using Morison objects to model the lowered object (payload), and a vessel whose motion is controlled by displacement RAOs.

Structure discretisation

If the payload is passing through the sea surface, then you need relatively accurate modelling of the distribution of buoyancy and hydrodynamics loads about the structure. The easiest way to achieve this is to use multiple objects connected together to model the complete payload as a discretised structure, rather than using a single 6D buoy (which may not be sufficient).

A single *lumped buoy* type 6D buoy handles changes in buoyancy and hydrodynamic loads in a simple way, and as a result may not be an accurate enough model for this type of analysis. A *spar buoy* type 6D buoy is better because it allows you to discretise it axially; however, there is no means to automatically discretise it in other directions. The *spar buoy* object is only really suitable for modelling cylindrical objects because the buoyancy is calculated from the cylindrical geometry. So for anything other than a cylindrical object the solution is to use several line and/or 6D buoy objects, connected together, to model the payload.

If the payload is deeply submerged however, and remains so throughout the simulation, then using a single buoy object might be sufficient.

When using multiple objects to model the payload, they need to be connected together to create a single rigid body. In the example model, it is convenient to use a reference buoy as a principal 'parent' object (*Main Buoy*). Multiple lines to model the tubular framework, and multiple 6D buoys to model the objects within the frame, are connected to the *Main Buoy* as 'children'. For further details about this 'parent-child' terminology, see the help page Theory | Object connections.

The mass and mass moments of inertia for the structure can either be applied to the main buoy – if you know these properties for the complete structure – or to the individual components. Note that if applying this data to the individual components, each individual mass moment of inertia is defined for the object itself *about its own, local centre of mass*. This means that additional inertia due to the offset of the object from the overall centre of mass (parallel axis theorem) will be automatically accounted for by its offset connection.

Object volumes should be split out among the components for maximum accuracy, as should drag and added mass properties. Note that OrcaFlex does not automatically model shielding effects between components, therefore the user must take into account the effect of shielding when assigning drag areas and coefficients. It is important to ensure that the total mass, volume, fluid inertia and drag are correct for the overall structure i.e. nothing is missed and nothing is double-counted. The data we have applied in this model are purely arbitrary and the user should assess each individual case on its own basis.

Data sources for these properties only cover basic geometries; if dealing with a particularly complex system then physical testing or CFD modelling are the best ways to get accurate values.

Make sure the *model browser* is in *view by groups* mode; this is set by right-mouse clicking in the *model browser* and checking that the *view by groups* option is ticked.

Look at the various objects in the *Manifold* group. As this is a complex model structure, the *Manifold* group is also split into sub-groups containing different component groups, to make items easier to find. The *Mud Mats* sub-group is split down further into groups containing the objects making up each separate mud mat. Open up the data form for any of the mud mat 6D buoys (e.g. *MudMat Port 1*) and look at the *properties* page.

Each mud mat has been assigned a *slam area*, based on the surface area of the underside of the mud mat, and *slam force data* specifying coefficients for *entry* and *exit*. Modelling of slam forces will be discussed in detail in the next example model (*F01 Lowered cone*).

Note that drag and added mass data have only been assigned to translations in the buoy's z direction. In this case, the mats are considered to be thin enough to have negligible drag or added mass effects on motion in the other directions. The rotational terms have all been set to zero, because some drag and added mass moments will arise naturally from the fact that the mud mats are discretised, and therefore the distributed translational drag and added mass forces will also resist rotations.

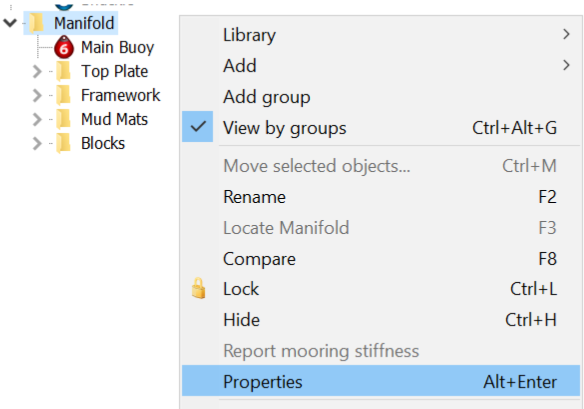
The line objects used to model the frame are all single segment lines, which means that they cannot bend. Both ends of each line are connected to the main buoy, so the lines move rigidly with the rest of the structure.

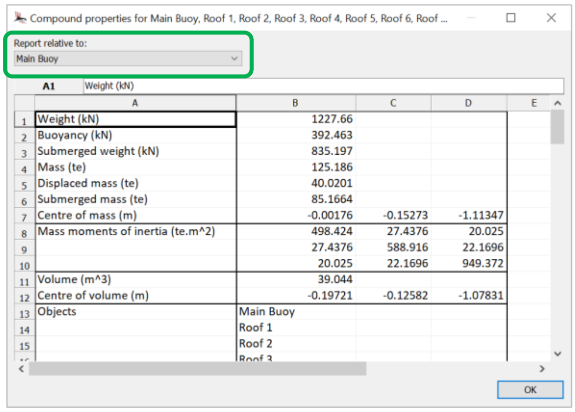
Compound properties reporting

As the manifold block comprises a number of objects, it is often useful to check the overall properties of the structure. This can be achieved by getting a *compound properties* report.

In the *model browser*, right mouse click on the *Manifold* group and select *properties*. The properties report shows the total properties for all the selected objects, under the assumption that they all move together as a rigid body. Here we are provided information about the total mass, volume, wet weight, etc. for the complete manifold structure.

The centre of mass and centre of volume are reported relative to a specific object; OrcaFlex by default will select the main (parent) object, if such an object exists. In this case it's the *Main Buoy* to which all other manifold objects are connected, but you can choose to report these values relative to any other selected object using the *report relative to* drop-down box at the top of the properties report.




Compound properties for Main Buoy, Roof 1, Roof 2, Roof 3, Roof 4, Roof 5, Roof 6, Roof ...
OK

Report relative to: Main Buoy

A1 Weight (kN)

	A	B	C	D	E
1	Weight (kN)	1227.66			
2	Buoyancy (kN)	392.463			
3	Submerged weight (kN)	835.197			
4	Mass (te)	125.186			
5	Displaced mass (te)	40.0201			
6	Submerged mass (te)	85.1664			
7	Centre of mass (m)	-0.00176	-0.15273	-1.11347	
8	Mass moments of inertia (te.m^2)	498.424	27.4376	20.025	
9		27.4376	588.916	22.1696	
10		20.025	22.1696	949.372	
11	Volume (m^3)	39.044			
12	Centre of volume (m)	-0.19721	-0.12582	-1.07831	
13	Objects	Main Buoy			
14		Roof 1			
15		Roof 2			
16		Roof 3			

Structure deployment

Line feeding is used at *end A* of the *Crane Wire* to lower the object into the water. The full length of wire, required for the simulation, must be included in the line's structural properties, therefore on the *structure* page of the *Crane Wire* data form, the length of the wire is defined as 20m.

On the *feeding* page, the *initial arc length* for *end A* is set to 8m, which means that only 12m of wire is 'active' in the model initially, with the remaining 8m being 'inactive' (but available to be paid out during the simulation). The crane *payout rate* is specified using a *variable data* source (*Winch Payout*) which ramps up the *payout rate* from zero to 0.125m/s during stage 0 of the dynamic simulation, then pays out the wire at a constant 0.125 m/s for the rest of the simulation.

A short *time step* is required in this model (0.001s) to enable the transient slam loads – which occur as the different objects cross the sea surface – to be accurately modelled. A sensitivity study should always be carried out on time step size to ensure that it is short enough to model the particular situation accurately. Running the same case with the *explicit time domain* integration scheme is often a good way to check that the chosen implicit integration scheme time step is short enough.

This simulation models the response of the manifold block to one specific crossing of the wave environment. Typically, many realisations of any given sea state would be required to provide confidence that the variations in the environmental conditions had been adequately modelled.

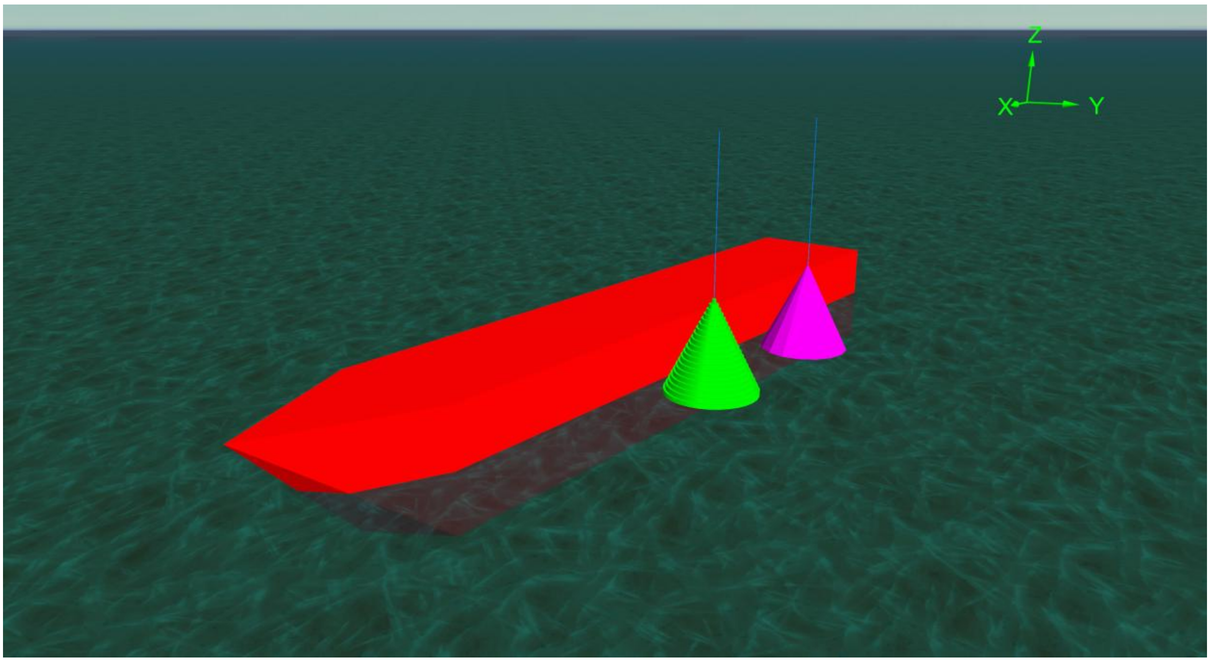
Results

Open the Workspace *F01 Manifold block results.wrk.* The results graphs show time histories of the *Crane Wire* top tension (upper right-hand graph), the payload's *Z* position (bottom left-hand graph), and the *slam force* occurring on one of the mud mats and one of the roof panels (middle-right and bottom-right graphs respectively).

Replay the simulation (*Ctrl + R*) to see the manifold's motion as it passes through the sea surface.

Lowered Cone

In this model, we use a simple cone-shaped payload to explain how water entry and exit slam forces are modelled on 6D buoys. For slam forces on lines, please refer to the example F06 Spool piece manoeuvring.



Building the model

Open the model *F01 Lowered cone.sim*. In this example, two cone-shaped buoys are lowered into still water. In this case, the mass and hydrodynamics of the crane wires are assumed to be negligible, and therefore a simple winch object is used to perform the lowering. To demonstrate the differences between them, one of the cones is modelled using a *spar buoy* type 6D buoy (coloured green), the other is a *lumped buoy* (pink).

The *spar buoy* cone consists of a stack of cylinders, which gradually change in outer diameter. This option means that the buoy has the physical geometry that you see displayed in the model. The lumped buoy however, while having the *appearance* of being a smooth cone, has no physical geometry associated with it. The cone shape simply comes from the drawing data specified on the *drawing* page of the *Lumped Cone* buoy.

The *Spar Cone*, with its defined geometry, provides much better modelling of surface piercing objects, although multiple lumped buoys can be connected together, as described in the previous example, to create more detailed objects with better discretised properties.

When a *lumped buoy* pierces the surface, it is a modelled as a simple vertical stick for the buoyancy calculation. The length of this stick is equal to the *height* specified on the properties page of the buoy's data form. The centre point of the stick is placed at the buoy's *centre of volume*.

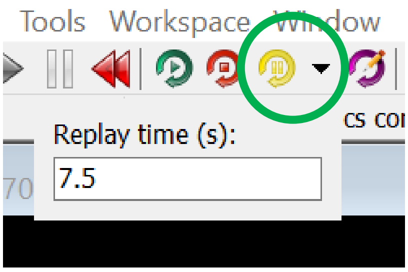
In this example, the *centre of volume* of the *Lumped Cone* buoy is positioned 2.567m above the buoy's origin. This means that the *height*, which is set to 10m (the overall height of the buoy), extends vertically above and below this point by 5m.

Open the workspace *F01 Lowered cone dry length.wrk*. The workspace shows the *dry length* results for the two cones – in other words, how much of the cone is out of the water. The top graph shows the *dry length* of the *Lumped Cone*, and the simulation is paused at 4.5s; this is the time that the *dry length* result shows that the cone first touches the sea surface. However, if you look at the position of the cone in the model, it is clearly not yet touching the sea surface. That's because the 'stick', which is protruding vertically above and below the buoy's centre of volume by 5m *has* now reached the sea surface.

For a lumped buoy, the change in buoyancy and hydrodynamic load with submergence is linear. The amount of the buoy that is submerged is approximated by the proportion of the *height* 'stick' that is submerged. This *proportion wet* is used to scale the buoyancy and hydrodynamic loads as the buoy crosses the sea surface.

This helps to show that a single *lumped buoy* provides a poor estimation of the variation with buoyancy as the cone crosses the sea surface. A better option for a surface piercing object is to use multiple lumped buoys connected together, or to use a *spar buoy* type 6D buoy.

Look at the *dry length* results for the *Spar Cone* in this model (bottom right-hand graph). Move the replay on to the point where the *dry length* starts to reduce. You can do this by using the dropdown arrow next to the *step replay* button, then set the time to 7.5s. Alternatively, you can press *Ctrl* on your keyboard and click the time history at the required point. This will move the simulation replay to the selected time, as evidenced by the vertical black line on the time history plot.



Replay time (s): 7.5

Notice that the *Spar Cone* only reports a reduction in the dry length when it actually *does* pass through the sea surface, because its change in buoyancy is determined by its geometry.

Hydrodynamic slam

Hydrodynamic slam forces have been applied to both cones in the model. For the *Spar Cone* this is done by assigning *entry* and *exit* slam coefficients to the lower-most cylinder. Of course, slam coefficients could be applied to each cylinder if deemed more appropriate.

Open the *Spar Cone* buoy data form and look at the *drag & slam* page. Scroll down the page to see the *slam force data* for cylinder 20.

OrcaFlex uses the direction of the relative velocity between the buoy and the sea surface to decide whether it is 'entering' or 'exiting' the water, and therefore which coefficient to use. The slam area used in the slam calculation is (in the case of a spar buoy) taken to be the instantaneous waterplane area, which is calculated from the buoy's geometry and the instantaneous position and orientation of each cylinder relative to the sea surface. The slam force is calculated for each cylinder of the buoy that has a slam coefficient assigned, and is applied to the instantaneous centre of the slam area of that cylinder.

For the *Lumped Cone*, which doesn't have defined geometry, we also need to specify the *slam area*, along with the *entry* and *exit* slam coefficients. Note that the area is a fixed value, and, unlike the spar buoy, does not change with buoy orientation. The buoy's height is used to determine the 'distance' over which the slam force is applied. So, if the buoy is 10m high and it has a slam area and coefficients applied to it, then the slam force will be applied for the full duration of the buoy's height crossing the water surface. This is probably not correct because the slam force only arises when surfaces are first coming into contact with the water.

In the case of a *lumped buoy*, if you don't want the slam force to be applied over the full height of the buoy, the simplest solution is to create a second 'slam' buoy to handle the slam force only; leaving the original buoy to handle everything else. In the model, this has been done by adding a buoy called *Slam Buoy*, which is hidden from view.

Open the data form for this buoy. Notice that it has negligible properties for everything except the *slam area*, *slam force data* and the *height*. Negligible properties can be set by simply pressing the *give buoy negligible properties* button on the bottom of the buoy's data form. The height is set to match the 'distance' over which we want the slam force to be applied; however, it is important that the height not be too small, as this could mean that the slam event is missed entirely (unless the *time step* used in the dynamic simulation is suitably small).

Also, slam force results are not spike-logged (see the User interface | Results | Producing results page of the OrcaFlex help for further details on spike logging), therefore a small logging interval must also be used.

Results

Open the workspace file *F01 Lowered cone results.wrk* to see the *slam force* results reported for the two cones. The *spar buoy* version shows a different peak slam force than the *lumped buoy*. The difference will be due to the lumped buoy contacting the water surface first (because of the simplistic handling of proportion wet, as described above). This further supports the guidance that a single lumped buoy is not recommended for modelling surface piercing objects, and that a spar buoy, or multiple lumped buoys should be used instead.

Trapped Water

In the model *F01 Trapped water.sim*, we consider how to model water that gets trapped within a structure when it is submerged, and hence contributes to the overall mass and inertia of the structure. It is convenient to think of the trapped water as simply being another component in the structure, which moves rigidly with the body.

For clarity, we will again consider simple objects for our payload – a single 6D buoy in this case – but the theory can be applied to much more complex structures.

The easiest way of adding inertia due to trapped water is to simply add extra mass to the object. Specifically you need to:

- Increase the object's *mass* by the mass of trapped water.
- *Mass moments of inertia* and *centre of mass* (CoM) values should also be revised to include the trapped water mass.
- You may also need to increase the object's *volume* to include the volume of trapped water (if it isn't already included), as it is essentially being treated as an internal part of the structure e.g. for a flooded buoyancy compartment. This affects both the hydrodynamic mass and the buoyancy of the object.

An alternative, which removes the need to revise the mass moments of inertia and CoM values, is to attach an additional 'point mass' to the structure. This is particularly useful if the volume of trapped water is relatively small in comparison to the overall object. So, rather than increasing the mass and volume of the object itself, you can instead include an additional 6D buoy with negligible properties (apart from the *mass* and *volume*) and connect it at the CoM of the trapped water. This effectively models the trapped water as a separate object that is rigidly connected to the main object. The mass moment of inertia and CoM effects will arise naturally from the offset connection. If necessary, multiple buoys can be used to represent distributed trapped water at multiple locations round the structure.

Trapped water for surface-piercing buoys

The above approach works well if the object is fully submerged and remains so during the simulation. However, if the object is lowered through the sea surface during the simulation, and therefore transitions from having no trapped water to having some, then this method is not appropriate. That's because the additional mass and inertia would be applied all the time, regardless of whether the object was submerged or not.

Furthermore, the above method will apply the additional body inertia in all three translational directions of motion, whereas it is possible to have different amounts of water trapped in different directions, e.g. for an open-ended structure.

So how do we add the effects of trapped water to an object that is being dynamically lowered through the sea surface, and that traps water in *some* directions of motion, but not all of them?

Modelling a hollow cylinder

If the object is a hollow cylinder, and can therefore be modelled using a *spar buoy*, then the flooding of the hollow bore is handled for you:

- For motion in the axial direction, the hydrodynamic mass of the buoy is calculated based on the annular volume of the buoy.

- However, for motion in the normal direction, the hydrodynamic mass is based on the overall volume of the cylinder. This assumes that the fluid inside the bore is effectively part of the structure. The help page Theory | 6D buoy theory | Spar buoy and towed fish added mass and damping provides some further details about this, see the sub-section *Reference fluid mass and inertia*.
- The hydrodynamic mass gets multiplied by the *added mass force coefficients (Ca)* to determine the added mass, and *inertia force coefficients (Cm)* to determine the fluid inertia, from external pressure effects on the cylinder.
- Note that this isn't the same as increasing the body inertia to reflect the mass of the water 'contents', this is also automatically added for you.

So, with a hollow spar buoy, the effects of the trapped water are correctly accounted for, including the fact that it is an open-ended structure and therefore the increase in inertia will be different in different directions.

OrcaFlex also correctly calculates when the trapped water is present (i.e. object submerged) and when it is not (object dry), as well as the transition from dry to wet (or wet to dry) as the object is lifted or lowered through the sea surface.

Modelling other geometries

If the object is *not* a hollow cylinder, and therefore the spar buoy is not an option for you, then one or more lumped buoys would need to be used to model the object. In this case OrcaFlex cannot automatically model the trapped water effect because the lumped buoy object has no geometry. This means that some care is needed when assigning properties to the object(s) to ensure that the trapped water is correctly accounted for.

This is demonstrated in the model *F01 Trapped water*.

Building the model

When you first open this model, you will see two objects – modelled on top of each other – being lowered from a vessel. One of them (coloured red) is a hollow *spar buoy*. The other (coloured pink) is a *lumped buoy*.

The *spar buoy* and the *lumped buoy* have been given identical properties; representing a steel tube, 10m long, with an inner and outer diameter of 2.5m and 3m respectively.

The *spar buoy* has been modelled as a single cylinder in this example, to provide as close a comparison as possible with an equivalent *lumped buoy*. Usually, the *spar buoy* would be modelled using a stack of cylinders to give a better, discretised model of the object.

The *lumped buoy* has been drawn as a cylindrical hollow tube, but this is for visualisation only (lumped buoys have no physical geometry).

Note that if your payload really was a hollow cylinder, then the *spar buoy* alone would suit your needs. The aim here is to demonstrate how to get a *lumped buoy* to match the behaviour of the *spar buoy*, i.e. by including all the effects that a hollow spar buoy is automatically including.

If you replay the simulation (*Ctrl + R*), you'll see that the buoys behave identically when they are in the air but not when they come into contact with the sea surface. This is the result of the *spar buoy* correctly modelling the added inertia effect of the water that floods into its bore, while the *lumped buoy* doesn't even have a bore to fill (remember it has no geometry!) therefore it cannot automatically include this effect.

What we can do, as a workaround, is increase the lumped buoy's *hydrodynamic mass* to reflect the increase in fluid inertia (added mass) due to the additional 'volume' of trapped water.

In the *model browser*, check that the *view by groups* option is selected (right mouse click in the *model browser*), and then hide the *Lumped Buoy (Original)* group by clicking on it and pressing *Ctrl+H*. Next, show the group *Lumped Buoy (HydroInertia)* using the same shortcut.

Open the data form for the *Lumped Buoy2* object and look at the *properties* page. This lumped buoy differs from the previous one only in the values used for the translational hydrodynamic mass.

Note, you can compare this buoy to *Lumped Buoy1* by multi-selecting both objects in the *model browser* (holding the *Ctrl* key and clicking on each object), before right-clicking and selecting *compare* (or using the keyboard shortcut, *F8*).

Here, *Lumped Buoy1* object has the *hydrodynamic mass* set to '~' in all three directions. This means that the hydrodynamic mass will represent the displaced mass of the fully submerged body (volume multiplied by water density). The *hydrodynamic mass* for *Lumped Buoy2* has been increased in the x- and y-direction to account for the mass of trapped water in the structure i.e. the hydrodynamic mass in these directions is set to the volume of *both* the structure and the trapped water, multiplied by water density). The *hydrodynamic mass* is then used to calculate the hydrodynamic inertia (i.e. added mass and Froude-Krylov forces).

Now, when you replay the simulation, you will see that the *Lumped Buoy2* matches the spar buoy's motion more closely, but it is still not the same. That's because we are still missing a bit of the inertia i.e. the *body* inertia from the trapped water.

If we were to increase the *mass* of the buoy to try to include this extra body inertia, we would increase it in all directions, all of the time (whether submerged or not), which would clearly not be correct.

The best option is to add a separate dummy buoy, with negligible properties for everything except for the *hydrodynamic mass* and *Ca*.

Hide the *Lumped Buoy (HydroInertia)* group and show the *Lumped Buoy (Body+HydroInertia)* group Open the *Trapped Water* buoy's data form to see the settings that have been given to this object.

In this case the *hydrodynamic mass* is set to be the trapped water mass, but only in the directions that the water is trapped (x and y in this case). *Ca* is set to 1 for the same directions and *Cm* must be set to zero to avoid additional (Froude-Krylov) fluid inertia being included. This now includes the additional body inertia that results from the extra mass of the water being added to the structure in such a way as to allow different effects in different directions, and to only apply the additional inertia when the object is partially or fully submerged.

Run the simulation replay again. The motion of this lumped buoy closely matches the motion of the *spar buoy*, as they are both now modelling the effect of the trapped water.

Results

Open the workspace *F01 Trapped water results.wrk*. This displays graphs of the payload's *Y* position during the simulation and the crane wire tension for *Hollow Spar Buoy* and *Lumped Buoy3* only. The results are clearly very similar, but will never be identical. The small differences between them come from how the change in proportion wet with submergence is calculated: linear for the *lumped buoy*, nonlinear for the *spar buoy*.

Further differences would appear if the wave and / or current direction were not perpendicular to the cylinders, due to slight differences in the drag formulation for the two different types of buoy.

The graph below shows the *Y* position for all four buoys plotted together, so that the differences in motion can be seen.

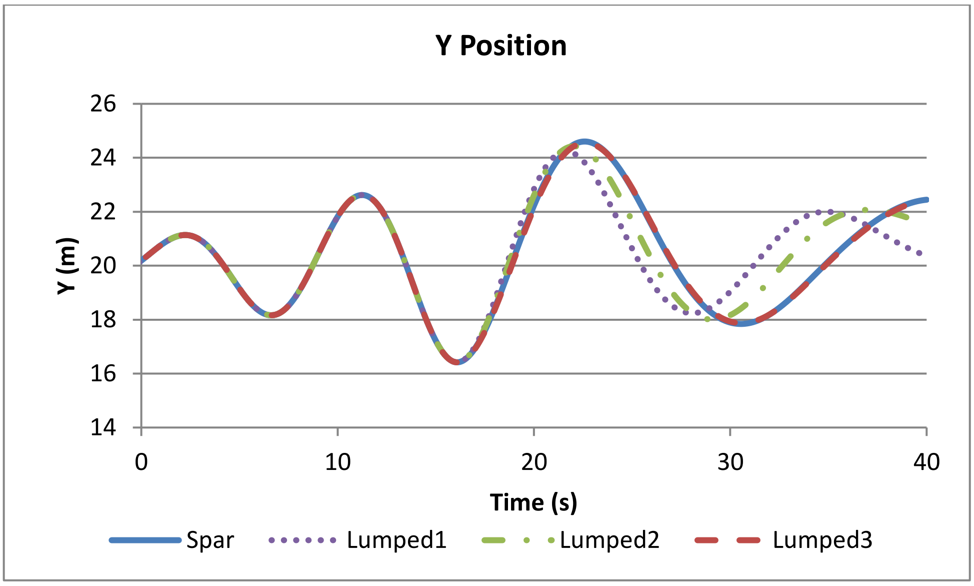


Figure 1: Payload Y results

In summary, if the object you are considering is a simple hollow cylinder then a hollow *spar buoy* should be used to model it, because all of the trapped water effects are automatically accounted for. If the flooding object is anything *other* than a hollow cylinder, then a more complex approach is needed, as demonstrated by the *Lumped Buoy3* method, to model the same effects. We model a hollow cylinder, in this way, simply to show how the same effects may be modelled.