

A02 Midwater arch systems

Introduction

In these examples, three types of riser system are shown: a lazy S (both simple and detailed), a steep S and a pliant S. An S configuration is similar to a catenary but has support provided at about midwater by an arch structure.

On opening each simulation file, the default Workspace will present views in wireframe and shaded graphics of the system.

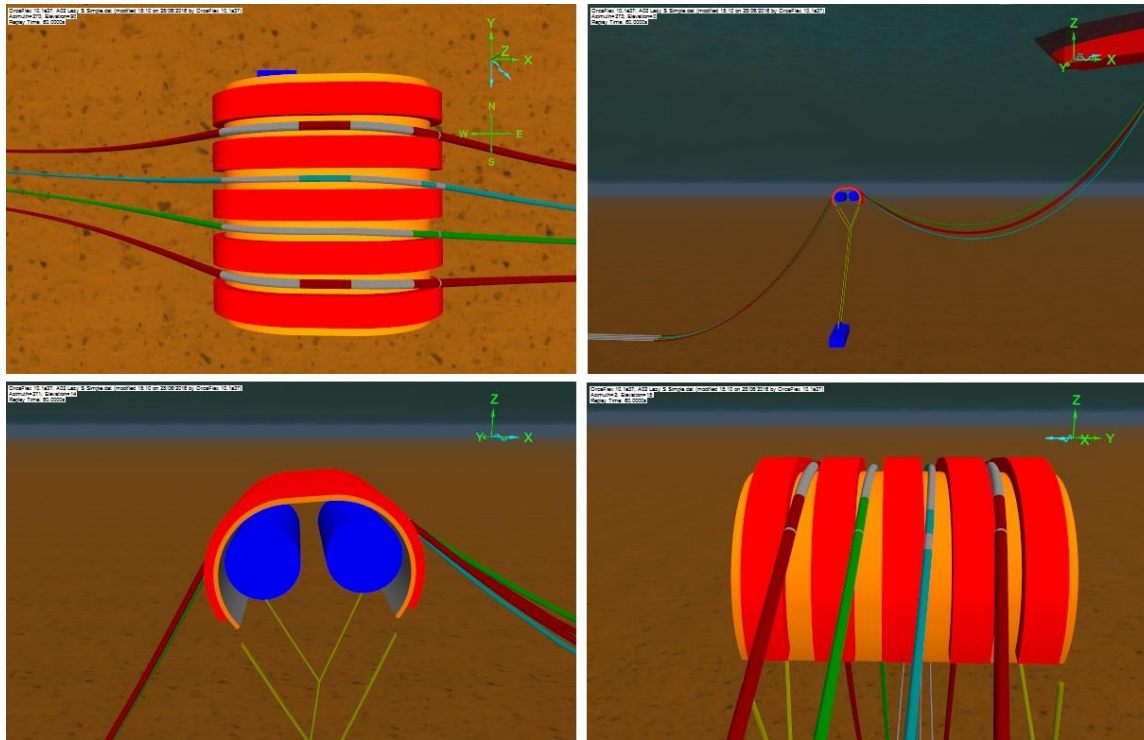
The examples also show:

- Modelling of midwater arches.
- Contact between lines and with shapes, including friction.
- Modelling bridles and tethers.
- Using supports to model arch gutters.
- Setting the model north pointer.

Lazy S simple

A lazy S configuration is similar to a catenary but has additional support provided at about midwater by an arch structure. 'Lazy' means that the riser centreline is near parallel with the seabed on contact while 'S' describes the line shape as a result of the arch.

When you open the simulation file (*A02 Lazy S simple.sim*) you will see four shaded views. These show the midwater arch in plan, side and elevation views as well as a side elevation of the whole system.

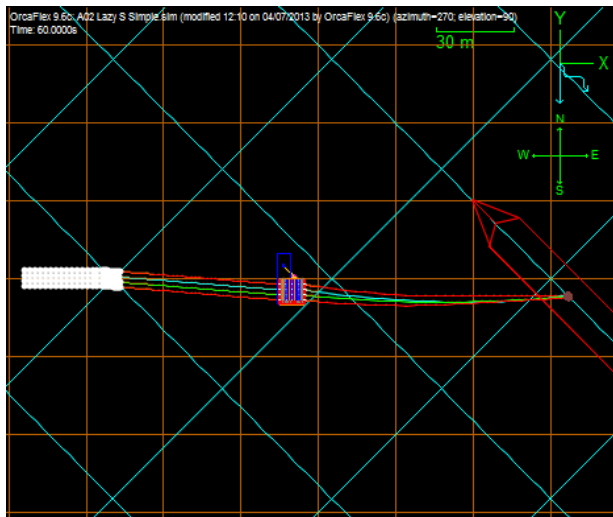


This example has three risers and an umbilical extending from a vessel to the seabed. All four lines pass over the same midwater arch.

There is a range of arch designs used in the industry. This example represents a structure with two buoyancy floats with four gutters passing over the top. The example shows the basic principles so the analyst can apply them to alternative arch structures as well.

Make sure the model browser is in *view by groups*, set by right-clicking in the model browser.

Building the model



The arch plan view shows a compass. The settings for this can be found on the [drawing](#) page of the [general data form](#). Because there are a significant number of similar objects in this model they are identified relative to these compass directions.

The plan view also shows the weather directions; current is out of the riser plane and waves are 45° off current. The vessel is head to waves with an offset collinear to waves. This offset is applied by moving the vessel initial position.

Each of the flexibles is connected to the arch using [mid line connections](#). This method means that each riser can be modelled using a single

line, running from the vessel hang-off down to the seabed. Each line is clamped to the arch, in this case by a clamp that is 1m long and mounted to the top of the arch structure.

Open the data form for the line [10" Riser N](#), and look at the [mid-line connections](#) page. You will see that the line has two mid-line connections, one at each end of the clamp, which effectively fixes a 1m long section of line in place. The line has been split into multiple sections so that we can ensure that nodes are positioned exactly at the places where we want to apply connections (arc lengths 135m and 136m), as well as being able to apply shorter segmentation in the sections that need it. The connections could be made directly to the [Arch 6D buoy](#), however in this instance we have chosen to connect both connections to a [constraint](#) object called [10" Riser N Clamp](#). We have done this because the constraint's connection load results will be the total of the loads acting on the clamp, and therefore we get the results we want out directly, rather than having to sum the loads from the two connection points.

A more detailed alternative is to use another 6D buoy to model the clamp instead of a constraint, which would enable you to include the physical and hydrodynamic properties for the clamp. You would then connect the mid-line points to the clamp buoy, and again use the connection loads to report the total clamp loads.

In either case, the use of mid-line connections allows moments to be transferred to the arch from the flexibles.

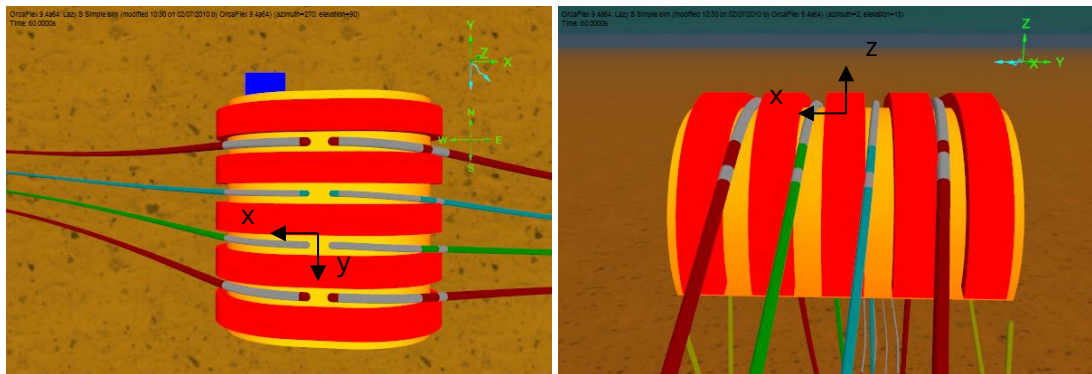
Neighbouring risers have been given different upper catenary lengths to reduce the risk of contact when loading is out of the riser plane.

The arch itself is built up of several objects.

- [Arch](#). A 6D lumped buoy that provides the physical and hydrodynamic properties.
- [Vertical Support](#). A group of shapes that provide vertical restraint to the flexibles.
- [Horizontal Support](#). A group of shapes that provide horizontal restraint to the flexibles.
- [Arch Drawings](#). A group of shapes that provide the image of the arch structure.

Arch is a 6D (6 degrees of freedom) lumped buoy that contains the physical and hydrodynamic properties of the whole arch structure. With this option, OrcaFlex requires you to determine these overall properties.

Open the *Arch* 6D buoy data form and look at the properties page. The arch is in the *Arch Structure* group. The buoy origin is at the top of the arch (clamp height) and on the centreline. This is a convenient location when attaching flexibles because their location is typically given relative to this point. The *centre of mass* and *centre of volume* have therefore been specified relative to this location too.



The buoy rotational hydrodynamic terms have not been set. For a large, well restrained, structure such as an arch the rotational terms do not have a significant effect on the system response. Therefore in this example they have not been included.

Note that the actual mass and volume of the arch have been given. It is important to apply the correct values because dynamic analysis uses them for physical and hydrodynamic inertia as well as net buoyancy.

If the structure will trap water as it moves then this trapped water should be included in the total mass and volume of the structure so that the physical and hydrodynamic inertia are correct.

Also, note that arches typically have complex shapes. The reference shapes for hydrodynamic values are simple and so the analyst needs to make assumptions during selection. The overall hydrodynamic properties are therefore uncertain. It is recommended that sensitivity studies are carried out on the hydrodynamic terms used. This should include the rotational terms if it is suspected they are significant for a particular system.

The *Arch* and most of the *Support* shapes are hidden in the views. What you are seeing is a group of shapes in the *Arch Drawings* group that give the appearance of the actual structure. These *drawing* type shapes have no stiffness and are for visualisation only. This is a useful feature when presenting to clients who may not be analysts themselves. It allows them to see the model in a way they are familiar with.

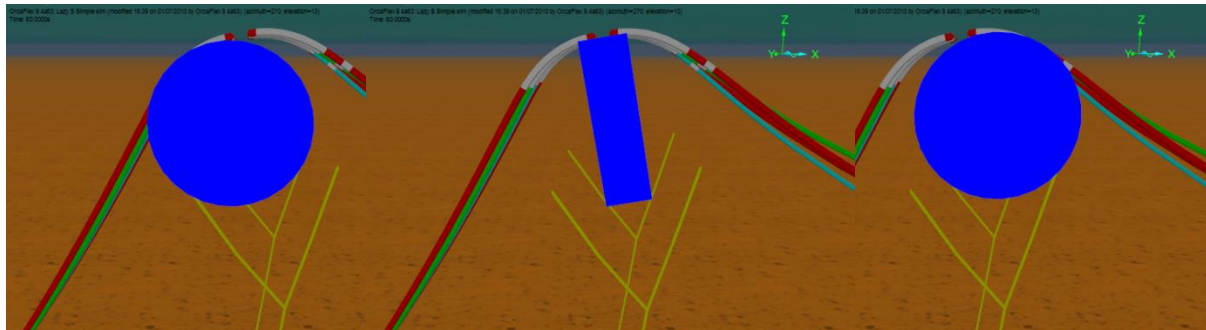
To see any hidden object right click on it in the model browser then select *show* from the dropdown menu. The same process but selecting *hide* will make it invisible again. Note however that *hide/show* only affects the views. The object is still present in the mathematical model and will still affect the system.

The views below show the hidden support structure as it is built up.

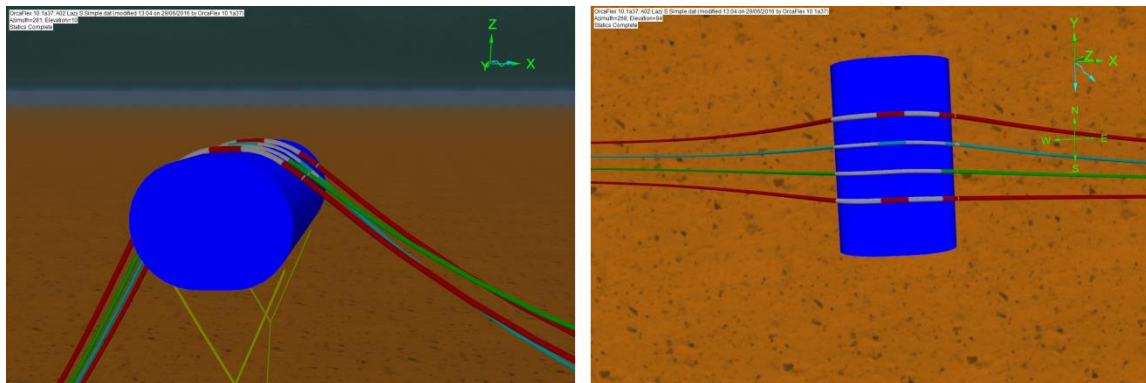
The arch gutters that the flexibles pass through are modelled in this example by shapes. Shapes interact with the nodes of lines and so line segmentation is refined in the region of shape contact.

The model browser group *Vertical Support* contains shapes representing the bottom of the gutter. These are *elastic solid* shapes with stiffness so they will produce a reaction force.

Gutter W (the left hand view) provides the curved lower catenary support. *Gutter E* (the right hand view) provides the curved upper catenary support. *Clamp* provides the flat part in between.



Because every gutter bottom in this system has the same radius, this group of three shapes has been extended beneath all the gutters instead of a group being required for each one.



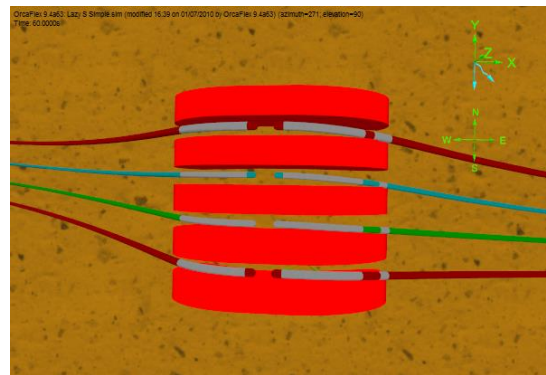
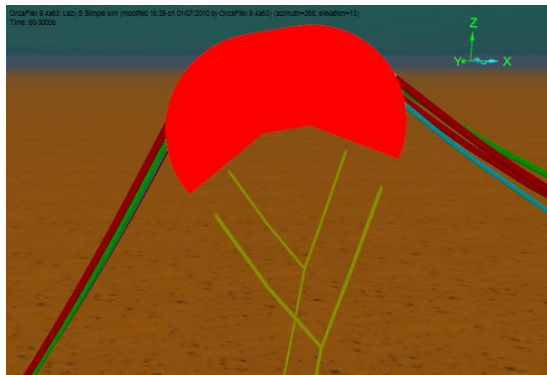
Friction is applied between the flexibles and these shapes. Friction between lines and shapes is not set on the *line types* data form but instead on the *friction coefficients* data form that can be accessed via the model browser. Note that shape-line friction is only active in dynamics.

A very simple arch model might contain just these vertical supports. The risers are able to roll on and off the arch, but the only lateral restraints while on the arch would be friction and the bend stiffness of the riser. Riser curvature at the clamp location would therefore be highly conservative.

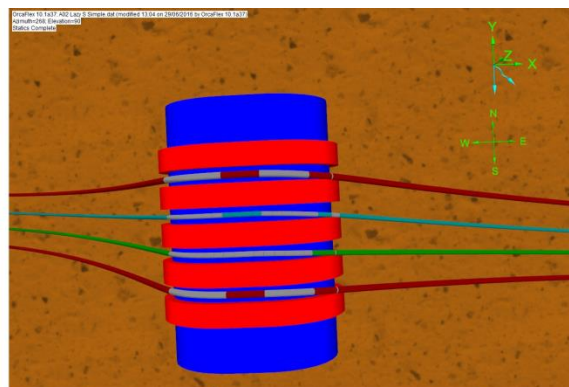
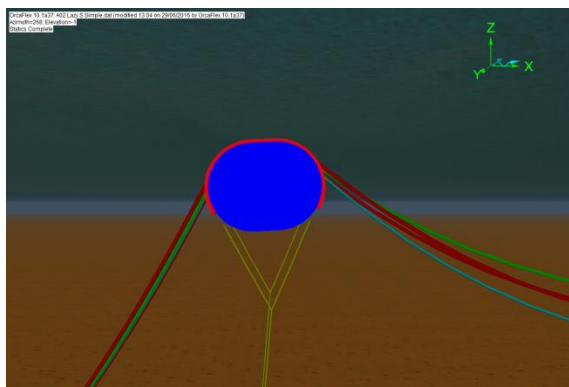
Also all lateral moments would be transferred at the clamp connection only rather than distributed along the gutter wall and so produce errors in the yaw response of the arch. Therefore it is recommended that the gutter walls are represented in some form.

The model browser group *Horizontal Support* contains shapes to represent the walls. The walls in this example are very simple but should be sufficient for a design iteration stage. Each wall has its own model browser group and contains shapes for the upper catenary, lower catenary and clamp regions.

Note the curved walls are made from *curved plate* shapes with a sweep of about 130°. Having a greater radius than the vertical supports, if they swept a full 360° to make a cylinder then they might interact with the tethers. This could provide additional, unrealistic restraint to the arch.



The support structures combine to produce the following:



The shapes in the support group generate effective boundaries for the movement of the lines. They are not intended to represent specific pieces of kit. For example, the bottoms of the gutters might be made of pipework or plate steel. These would be quite thin structures and yet the shapes here have significant thickness.

Although the actual structure may have thin walls it is not advisable to model them as such. If a shape is say 2mm thick then a node entering slightly more than 1mm will be pushed to the other side of the shape. It is better to make the shape as thick as you can without interfering with other lines or buoys. The nodes would then have to enter further into the shape to end up on the wrong side.

The result is a more robust system for loading applied in a range of directions.

The arch is restrained by bridles and tethers. These are contained in the *Tethers and Bridles* group. The bridles are built as lines attached to the arch at their top connections (end A). The tethers, also lines, are anchored onto the seabed at their bottom connections (end B).

The tethers and bridles can be connected directly to each other; in this case the top end (end A) of each tether is *free* and the bottom ends of the two bridle lines are connected to it.

Drawing-type shapes represent the gravity base and the tether posts for visualisation only.

The bridles and tethers in this example have been assumed chain. Actual chain data should be used but if this is yet to be decided, then generic chain properties can be produced using the line type wizard routine. If you reset the simulation file, you can then see the wizard in action.

Select '2" chain' on the line types data form then click on [wizard...](#) at the top right of the form. You are now in the line type wizard routine. Step through it to see how the 2" Chain' properties were built.

Note that, unlike the risers, the chain properties have [compression is limited](#) on the [limits](#) page of the line types form turned on. This is because chains go slack rather than resisting compression.

Results

If your model is in [reset](#) mode then reload the simulation file. Load the [A02 Lazy S results.wrk](#) workspace via the workspace dropdown menu. This will present four time histories.

The top left shows the arch surge (X) motion. This has settled into a cyclic response. However the arch yaw ([rotation 3](#)) shows a more complex response with a double oscillation per wave instead of the single oscillation seen in the arch surge.

This is not unusual because the arch is responding to transverse loads from the flexible upper and lower catenaries. These have different configurations in the water column so will have different load magnitudes and phases.

This complex response is seen in the arch pitch ([rotation 2](#)) at the top right and the tether tension at anchor at bottom right. These both show a slight rise in response at the time the arch sees its second yaw oscillation.

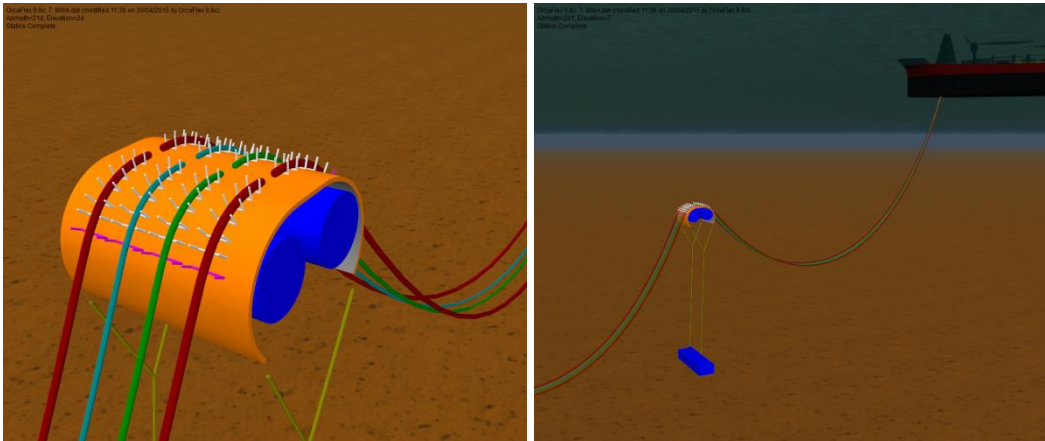
Now load a second workspace called [A02 Lazy S results#2.wrk](#). In this workspace we present the clamp loads for each flexible in the [Static State](#) in a table format. These are the pull-out loads on each clamp. We use the [connection Lx-force](#) result, which gives the connection force along the axis of the flexible. When showing [static state results](#), you can add multiple results to the same table (as we have done here), by holding down the [Ctrl](#) key while selecting results from the [results menu](#).

Also plotted is a [time history](#) of the 10" Riser S clamp [connection Lx-force](#), which allows us to see the maximum pull-out force, which could be used in the design of the clamping system.

Lazy S detailed

The more detailed version of the Lazy S system (A02 Lazy S detailed.sim) has the following additional complexity.

- Arch properties from a composite structure.
- Refined gutter wall modelling.



Discussion of the overall system construction is contained in the Lazy S simple section earlier in this document. Only the changes to the system will be discussed here.

Open the simple model in a separate copy of OrcaFlex on the same machine (the OrcaFlex licence will allow this). Having both open together will allow comparison of the two modelling methods.

Make sure your model browser is in *view by groups* mode, as before.

Building the model

The physical and hydrodynamic properties of the arch can be produced by a single lumped buoy with the overall properties calculated and specified by the user. Alternatively, components of the arch can be produced by other objects attached to a common buoy. The user specifies the properties for these components and OrcaFlex calculates the overall properties.

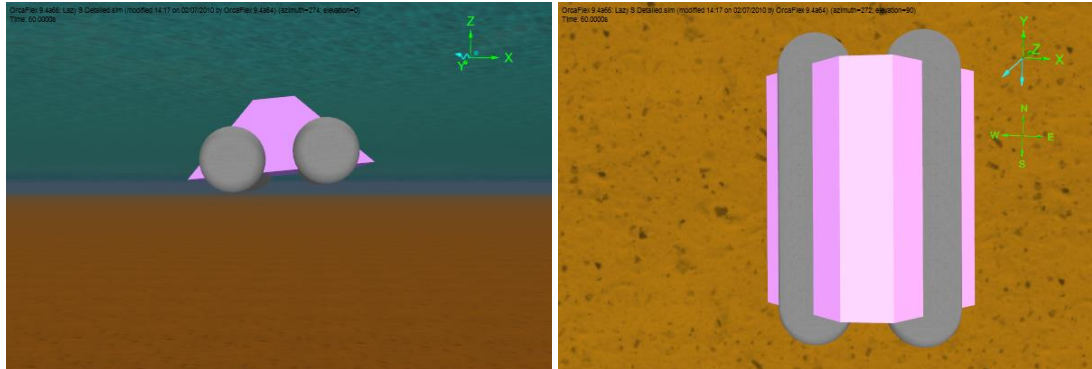
Adding components to the arch increases the size, complexity and runtime of the model, so care should be taken not to add unnecessary detail.

This more detailed approach can be helpful for investigation of specific problems, for example having hydrodynamic loads calculated for each major object means if one end of the arch experiences very different flow from the other, then the resulting moments on the arch will be captured.

Also, it can be convenient to have a buoyancy tank modelled as a line if you want to consider some cases with the tank flooded. This saves having to replace the overall buoy properties for the empty condition with those for flooded. All you have to do is change the line contents density.

In this example, only the two buoyancy tanks have been separated out. Each has been modelled as a series of single segment lines attached at both ends to the 6D buoy *Arch*. Being single segment lines, and connected to the 6D buoy in this way, the stiffness properties are not important. The lines are in the *Tanks* group of *Arch Structure*.

The advantage of using a series of single segment lines is that loads are calculated for each line and applied at its end connections, distributing the loads along the tank length. This will capture any resulting moments from change of flow across the length.



On the line types data form, you can see the properties of the tanks in *Buoyancy Tank* type. It is important to be careful setting the line Cd values. Lines use the surface area in the axial drag formula, not the end area. The line axial Cd therefore needs to be calculated so it gives the correct resultant drag.

In this example, the two tanks are also side-by-side so one will shield the other when flow is along the arch local x-axis. However OrcaFlex does not automatically calculate shielding so both tanks will experience undisturbed drag when in reality the downstream tank will see reduced flow. The options for obtaining the correct horizontal normal drag are therefore:

- Divide the horizontal drag between the two tanks by halving the horizontal flow Cd, therefore applying non-isotropic normal Cd. Resulting pitch moments will not be exactly right because both tanks see drag but the differences will be typically small and the arch is unlikely to be sensitive to them.
- Turn wake effects on so the downstream tank sees reduced flow. However wake reduction will not include the effects of neighbouring structures such as supports and gutters and again there are more calculations so runs are slower.

The first of these has been applied in this model.

In the vertical direction (line local x), both tanks see full flow so normal Cd is 0.7 (the full amount). In the horizontal direction (line local y), the normal Cd has been halved to 0.35 so each tank will produce half the drag.

Open the *Buoyancy Tank East 1* line data form via the model browser. Note that torsion has been turned on and the ends connections are built in (stiffness of *infinity*). This is not necessary for a line with both ends connected to a rigid object, because there can be no rotation along its length. However it does remove the warning message that is produced when non-isotropic properties are applied and torsion is turned off.

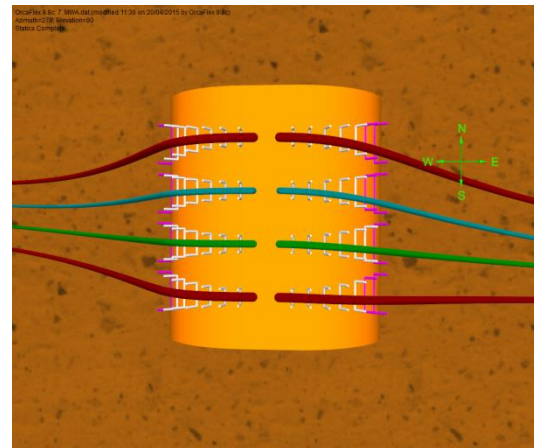
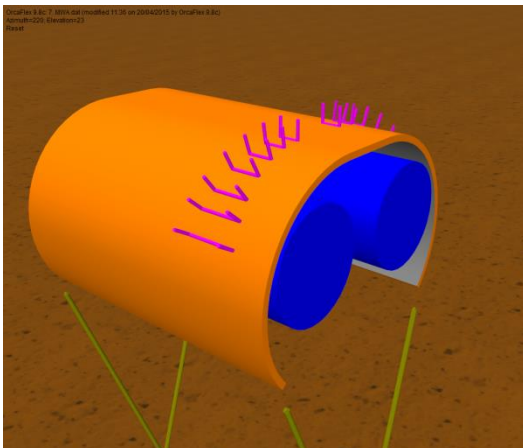
The remainder of the arch properties are then calculated and applied to the 6D buoy so the resultant physical and hydrodynamic properties match those used in the simple model.

Compare the data for the *Arch* buoy in the two models. Taking away the tank contributions has changed the volume, mass, moments of inertia, centre of mass and volume and the drag areas. In this simplistic example, the mass has reduced by approximately a factor of ten, therefore we have reduced the mass moments of inertia by the same factor.

Note the line objects have been hidden from view and *drawing* shapes have been used for visualisation in this example. For more information on hiding and showing objects, see the *Lazy S Simple* model discussion earlier in this document.

There are several options available for modelling the gutter walls. In this example, we show a method that uses the *supports* feature.

The *Gutters* sub-group (within the *Arch Structure* group) contains eight 6D buoys. Each buoy carries a series of U-shaped supports, which represent the struts of the gutter. Each set of supports has a *supported line* allocated to it, to indicate which riser or umbilical is supported by which gutter.



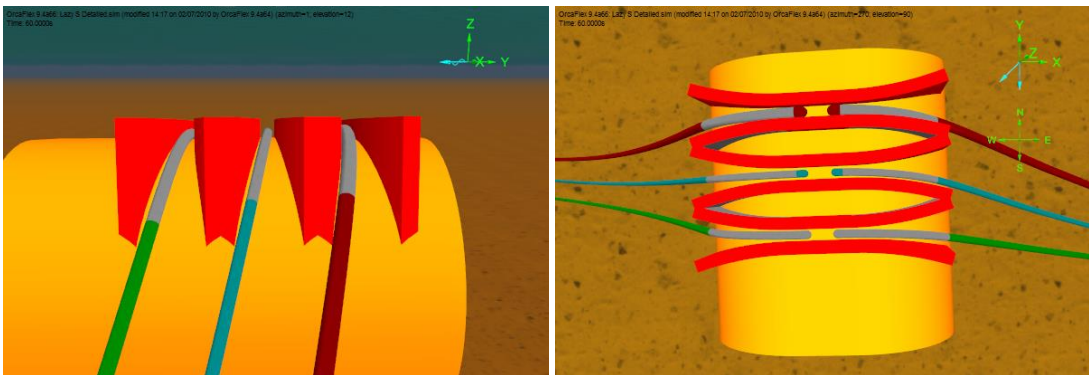
Look at the *supports* and *support coordinates* pages of any of the *Arch Supports* 6D buoys. This is where the positions of the supports are specified. Click on the *Support Types...* button at the bottom of the data form to open the *support types* form. You will see that seven different widths of support have been created here in order to model the radius of the arch gutter. Full details of the supports feature can be found in the OrcaFlex help file section *Modelling: data and results | Supports*.

The *Arch Support* buoys all have negligible properties in this example, so they have no effect on the arch response other than that generated by the contact of the riser and umbilicals. You could, if you wish, assign actual properties to these objects (i.e. give them the gutter's mass, volume etc.) and then remember to remove their contribution from the *Arch* properties.

This wall modelling method allows detailed control of the gutter wall and base shape, and greatly simplifies the static solution because OrcaFlex knows that each supported line must lie within the set of supports to which it is assigned. To demonstrate this, reset the model (press **F12**) and then re-run the static calculation by pressing **F9**. You will see the eight riser and umbilical lines jump very quickly into place within the gutter boundaries.

Available results for the supports include clearance and lift out results, as well as reaction force results for individual supports or for entire sets of supports. Open the workspace file [A02 Lazy S supports.wrk](#) to see the support force and lift out results for the *lower 10" N riser*.

If you prefer to model the gutter walls as smooth surfaces, then you can do so using elastic solid shapes (see image below). In this instance each wall is constructed from two curved plates and a rectangular block. Elastic solids are also required to form the curved arch surface i.e. to provide vertical support for the risers and umbilicals (see the [A02 Lazy S simple](#) model for details of how to do this).



If the gutter walls have a constant radius in plan view then this is a convenient way of modelling them. It is also the method to use if your need to include friction effects between the risers and the gutter walls. This method gives improved curvature and moment modelling without a penalty on file size and runtime, when compared to the simple model.

Results

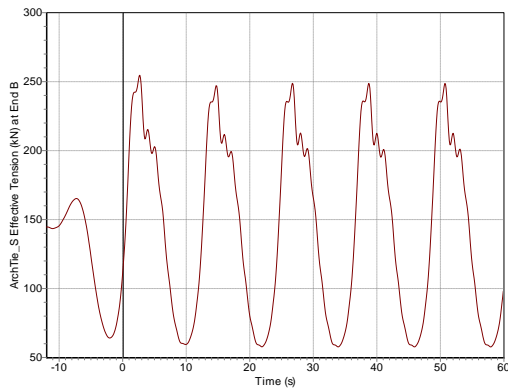
Load the [A02 Lazy S results.wrk](#) workspace via the workspace dropdown menu. Make sure this is also loaded for the [Lazy S simple](#) model so the results can be compared.

Some of the plots below have matching axes. To do this in OrcaFlex, double click on each graph to access and modify the plot parameters. The parameters can be copied and pasted from one view to another to get the same scale showing in two plots.

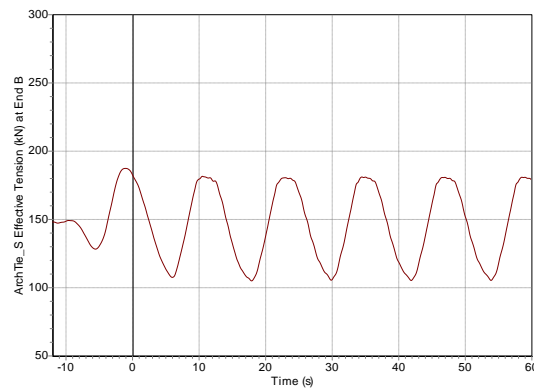
In the screen shots below, all 'simple' model plots are on the left and 'detailed' model plots are on the right.

The plots below show variation of tension at the bottom of a tether with time. The plot axes have the same scales. Tension variation is reduced in the more detailed model. The minimum tension is now $\sim 10te$ instead of $\sim 6te$.

OrcaFlex 9.8c: A02 Lazy S Simple.sim (modified 14:10 on 26/01/2015 by OrcaFlex 9.8b)
Time History: ArchTie_S Effective Tension at End B

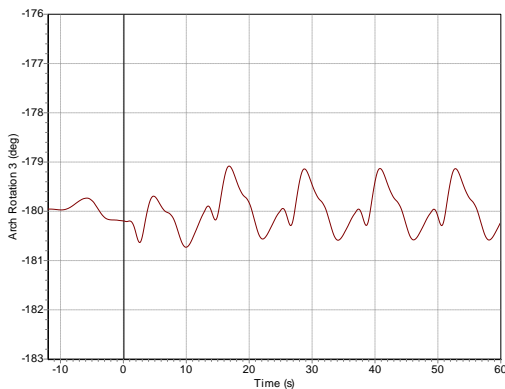


OrcaFlex 9.8c: A02 Lazy S Detailed.sim (modified 14:25 on 20/04/2015 by OrcaFlex 9.8c)
Time History: ArchTie_S Effective Tension at End B

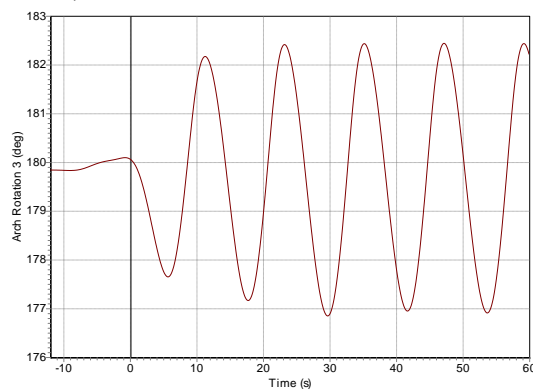


The plots of arch yaw (*rotation 3*) time history have the same range but the simple model has a negative range, the detailed model a positive range. The simple model has a yaw variation of between 179° and 181° (-181 and -179). The detailed model has a yaw variation between 177° and 183° . This is an increase from $\pm 1^\circ$ to $\pm 3^\circ$. The increased yaw is due to the more accurate modelling of the moments on the arch from the riser contact with the wall.

OrcaFlex 9.8c: A02 Lazy S Simple.sim (modified 14:10 on 26/01/2015 by OrcaFlex 9.8b)
Time History: Arch Rotation 3

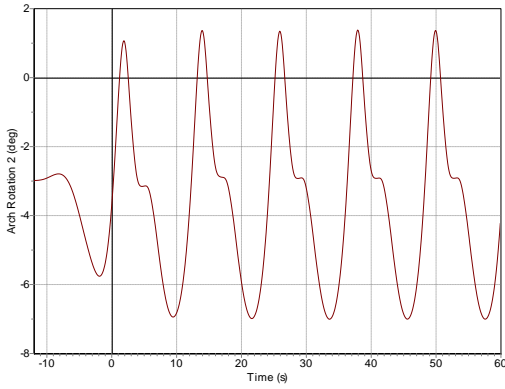


OrcaFlex 9.8c: A02 Lazy S Detailed.sim (modified 14:25 on 20/04/2015 by OrcaFlex 9.8c)
Time History: Arch Rotation 3

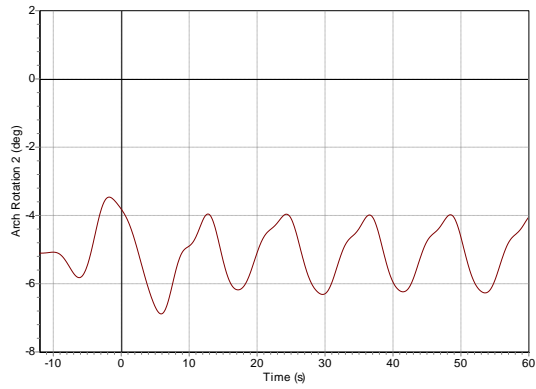


Arch systems have complex motions so a single change can vary more than one response. An example of this is shown in the plots below. The detailed model reduces the arch pitch variation (*rotation 2*) and shifts the mean arch surge (X).

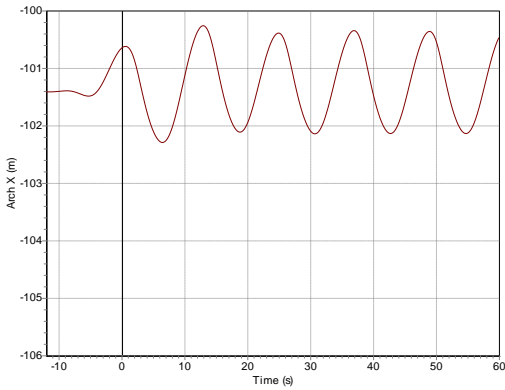
OrcaFlex 9.8c: A02 Lazy S Simple.sim (modified 14:10 on 26/01/2015 by OrcaFlex 9.8b)
Time History: Arch Rotation 2



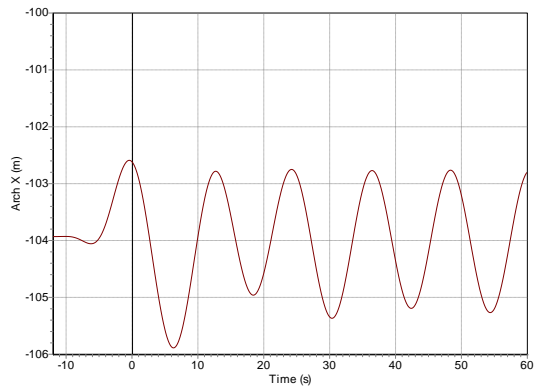
OrcaFlex 9.8c: A02 Lazy S Detailed.sim (modified 14:25 on 20/04/2015 by OrcaFlex 9.8c)
Time History: Arch Rotation 2



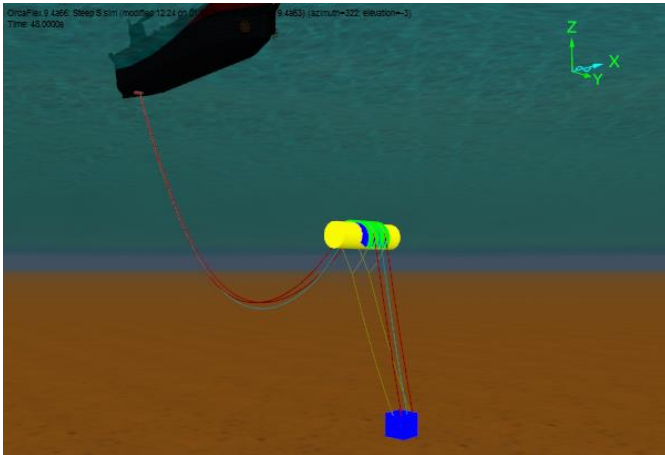
OrcaFlex 9.8c: A02 Lazy S Simple.sim (modified 14:10 on 26/01/2015 by OrcaFlex 9.8b)
Time History: Arch X



OrcaFlex 9.8c: A02 Lazy S Detailed.sim (modified 14:25 on 20/04/2015 by OrcaFlex 9.8c)
Time History: Arch X



Steep S riser



The Steep S system (*A02 Steep S.sim*) has a similar arrangement to that seen in the *Lazy S simple* example earlier.

However, instead of the lower catenary descending and lying on the seabed it terminates at a near vertical connection.

'Steep' means that the riser centreline is near vertical at the lowest end while 'S' describes the line shape as a result of the arch.

This example has two risers and an umbilical descending from an FPSO to the seabed. The central umbilical has a longer upper catenary to keep it out of the plane of the risers and reduce the risk of contact.

When you open the simulation file, you will see two views of the system and two plots. The upper view is a wireframe plan of the system. Note the North pointer in this case has been chosen to be in the riser plane and not aligned with a global axis. The lower view is a shaded elevation of the system.

Make sure your model browser is in *view by groups* mode, as before.

Building the model

Details of arch construction have been discussed in the earlier lazy S systems, therefore only the seabed termination will be considered here. The lower catenary is vertical rather than horizontal when it reaches the arch gravity base. The *Gravity Base* is included in the model as a *drawing-type shape* and is for visualisation only.

End B of each flexible lower catenary is anchored 5m above the seabed, on top of the arch gravity base. Double click on any of the three 'lower' lines in the model browser to see the settings.

The line end B declination in this example is 170° , indicating the line is heading down into an end connection that is 10° ($180^\circ - 170^\circ$) from vertical. The azimuth is 10° because anchored connection orientations are relative to the global axes directions. The riser system is on a heading 10° anti-clockwise from the global X direction.

The connection stiffness is infinity so it is built in. For more information on end connection settings see the *A01 Catenary and wave systems | Simple catenary* example.

The lower catenary lengths have to be optimised carefully. If the flexibles are too slack then they could enter compression as the arch moves. If too taut then they could become the tethers for the arch system. Typically, they are tauter than seen in the lazy systems.

A taut line will want to descend vertically during the static search. It will resist the shape restraint more than in the lazy system. This means more care is usually needed to get an acceptable static convergence. It is easier for the static search to find a solution where the line is on the 'wrong' side of the shape, 'wrong' being the one you don't want.

Temporary restraints (such as links or winches) can assist the convergence, as can using the supports method described in the [Lazy S detailed](#) notes. Alternatively, a spline could be used to approximately define the required line shape. This is selected in the [statics](#) table on the line data form. Its settings are specified on the [spline starting shape](#) page of the same form.

The spline does not need to be very precise because the static analysis will refine the line position. It just needs to be enough to direct the line to the required side of the shape at the start of the static analysis.

Reset the file by selecting [reset](#) in the [calculation](#) dropdown window. Switch the lower left hand view to wireframe mode (click in the view window and press [Ctrl + G](#)). The splines will appear as grey lines. The control points will appear as crosses.

Control points can be dragged by holding down the left mouse button. The control points will move in the plane of the view and the spline will adjust accordingly. Remember to check the result in plan as well as elevation view.

If the lines leap around during the static convergence then the search may need a bit more damping. Look at the [full statics convergence](#) page of the [line data form](#). [Min damping](#) has been increased from 1.0 to 1.5 while [max damping](#) has been increased from 10 to 15. This will reduce overshoot but can make the convergence slightly slower.

For more assistance with static convergence issues, check out the [statics convergence guide](#) in the [resources](#) section of our website.

Results

If the model was [reset](#) then reload the simulation file. Two instantaneous range graphs are presented to the right of the views. The upper plot is for [10" Upper East](#) riser and the lower is for [10" Lower East](#) riser. They show the variation of effective tension along the length at any instant in time.

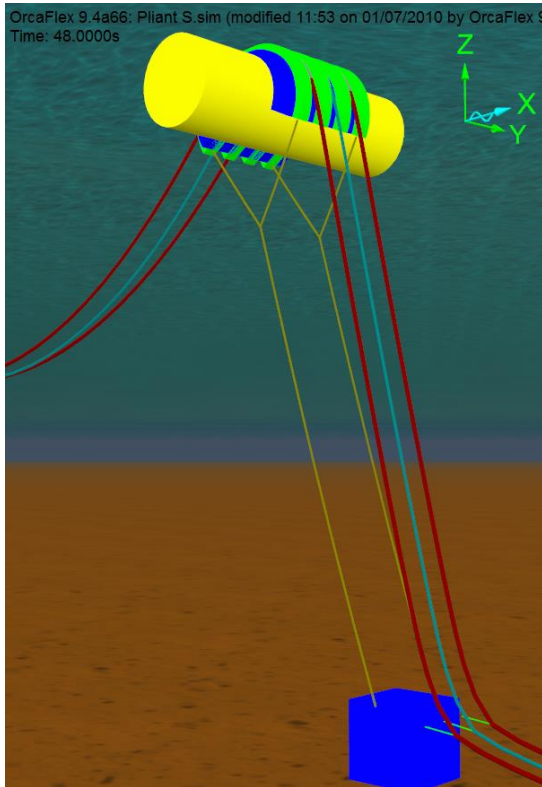
Run the replay ([replay](#) dropdown menu) and the tension distributions will also vary, matching what is happening in the views. The tension varies steadily in this case.

These instantaneous range graphs are also helpful in identifying where a line response originated. They will also show axial waves in the line that might not be observed with other plots.

Pliant S riser

A pliant S configuration ([A02 Pliant S.sim](#)) is a lazy S with the addition of a tether restraining the touchdown point. This example is the same as the Steep S but the lower termination has been changed to the lazy style with restraining tethers.

When you open this file, you will see a shaded elevation view of the arch arrangement.
 Make sure your model browser is in *view by groups* mode, as before.



Building the model

The line is built in the same manner as for the previous S models, therefore only the termination change will be discussed.

The line is made pliant by the addition of a tether close to touchdown. In this example, the tether has been modelled as an OrcaFlex link attached to the riser. No clamp details have been included.

This is the simplest way of modelling the tether and is sufficient for most cases. For discussion of the alternatives see the documentation for [A01 Catenary and wave systems | Pliant wave example](#).

Again, splines have been used to assist in static convergence. See the [Steep S](#) discussion earlier for details.

Results

Two plots are shown. The top right is a tension range graph for the umbilical lower catenary, *Umb Lower*. This shows the effective tension variation along the length through the final wave cycle. The tension step change at about 50m arc length is where the tether is attached.

The lower right is a time history of arch motion in the global Y direction. It shows a settled cyclic response has been achieved.