

Modelling Contact in OrcaFlex

1. Introduction

Contact occurs between different objects in an OrcaFlex model in different ways. This document aims to explain the contact models used, the pros and cons of each, and gives examples of typical uses.

The table below summarises the objects in an OrcaFlex model between which contact can occur:

Object	Can Contact
3D & 6D Buoys	Elastic Solids, Seabed
Line	Elastic Solids, Seabed
Line	Lines (<i>clashing and contact</i>)
Line	Supports

Table 1.1: OrcaFlex Contact Summary

The contact code in OrcaFlex treats Elastic Solids and the Seabed as one and the same, but for the purposes of this document it is helpful to refer to them separately. Each of these options is discussed in turn below:

2. Contact between Lines and Elastic Solids and the Seabed

2.1. Common Uses

2.1.1. Line to Seabed

Here the Seabed is used to model flat, 2D or 3D seabed profiles, with a contact reaction which can be linear, non-linear or non-linear hysteretic.

2.1.2. Line to Elastic Solid

A variety of standard Elastic Solid Shapes is available in OrcaFlex. These can be connected to other modelling objects (e.g., other Vessels or Buoys) so that they provide physical boundary surfaces that these objects would not otherwise have. Multiple Elastic Shapes can be connected in this way to provide quite complex boundary surfaces if required.

Typical examples of Line-to-Elastic Solid contact are:

- Mid-water arch models - see Figure 2-1. Elastic Solids are used to model the contact surface of the arch body, as well as the guttering within which the risers or umbilicals lie.
- Bellmouths (see Figure 2-2).
- Floatover mating units
- Vessel decks, side or bow/stern structure or other physical structure that limits motion of lines e.g. vessel interaction with jetty structures, bow interaction with floating lines.
- Lay chutes
- Pulleys and sheaves
- Subsea towers
- Any other guide surface that limits the motion of a line.

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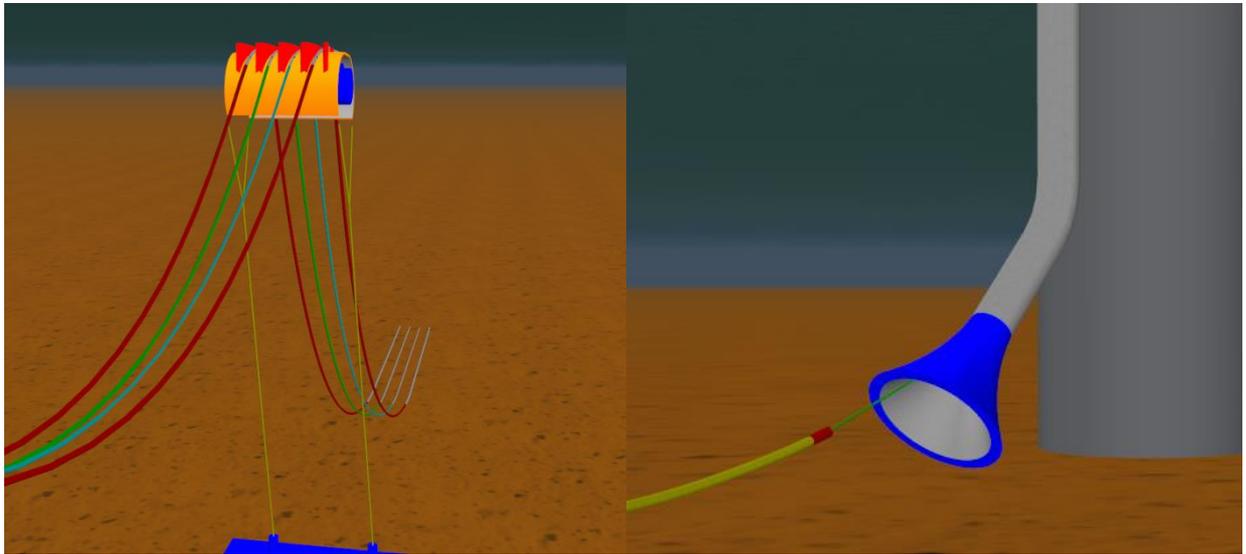


Figure 2-1: Mid Water Arch Model

Figure 2-2: Bellmouth Model

The contact reaction between the Line and Elastic Solid Shape can be linear or non-linear.

2.2. Interaction

Line nodes will experience a reaction force when they come into contact with any Elastic Solid and / or Seabed having a non-zero contact stiffness. Elastic Solids and the Seabed are therefore generally used to define physical boundaries that limit the motion of the lines in the model in some way.

Because these reactions occur at Line nodes, the Line's segmentation (i.e. number of nodes) is therefore critical in defining how it interacts with the Elastic Solid and / or Seabed - Figure 2-3 shows this for the case of a Line interacting with an Elastic Solid, but Line interaction with the Seabed exhibits the same characteristics.

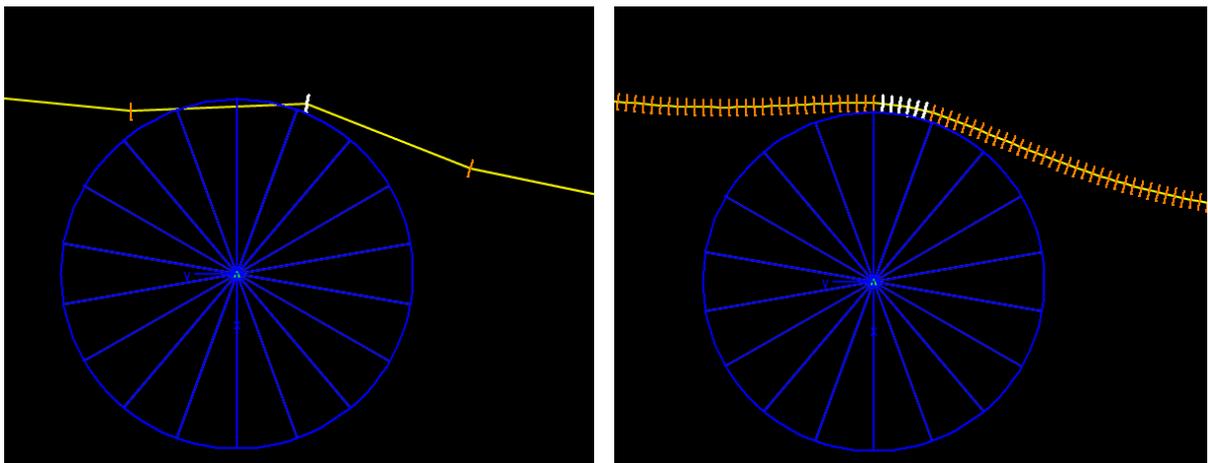


Figure 2-3: Line to Elastic Solid Contact (Coarse vs Fine Segmentation)

Consequently, the user must use the appropriate level of segmentation to correctly model the contact between a Line and an Elastic Solid and / or the Seabed.

When a node comes into contact with an Elastic Solid, the reaction force will push the node towards the closest surface of the Elastic Solid. Care is sometimes needed to ensure that the closest surface is the surface that you want the Line to interact with, to prevent the node being pushed towards the 'wrong' surface.

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2.3. Results

2.3.1. Line to Seabed

There are no results reported by the Seabed. The Line will report the Normal Resistance (= Seabed reaction force per unit length of the Line).

2.3.2. Line to Elastic Solid

In this case, contact results are reported for both the Line and the Elastic Solid. Elastic Solid results are the magnitude and components of the total force applied by the solid to other objects in the model. Results for the Line are the Solid Contact Force, which is the force per unit length due to the contact with the Elastic Solid.

2.4. Modelling Issues

For Line to Elastic Solid contact: if the size of the Elastic Solid is small compared to the Line diameter then very fine segmentation may be required to ensure that the Solid cannot pass between adjacent nodes. In this case, either the Line Clashing model or the Supports model may be more appropriate.

Very high shape stiffness can cause problems in dynamics, as a small change in position of a node can result in a very large change in reaction force.

As stated previously, nodes are pushed towards the nearest surface of the Elastic Solid with which they contact, therefore any surfaces of the Solid that you don't want the line to interact with need to be kept out of the way. Sometimes this means using shapes that are much bigger or thicker than the objects are in reality. If this is the case, it can be useful to use two sets of shapes to model an object; an over-large set to define the boundary surfaces (which are then hidden in the model), and a correctly sized set using the Drawing type of Shape to make it visually correct.

Multiple shapes can be used to create complex boundary surfaces; however care must be taken to ensure that small gaps are not present between shapes into which nodes could fall.

3. Contact between Buoys and Elastic Solids and the Seabed

3.1. Common Uses

In the same way as for Lines, contact between Buoys and Elastic Solids (or the Seabed) is used to define boundaries that limit the motion of the Buoy.

3.2. Interaction

Contact is modelled between Buoys (either 3D or 6D) and Elastic Solid shapes in a similar way to contact between Lines and Elastic Solids. The only difference is that Buoys interact with an Elastic Solid (or the Seabed) at the Buoy's vertices (instead of at the nodes for a Line). A 3D Buoy has a single vertex placed at the buoy origin. For a 6D Buoy, the contact area represented by each vertex is defined as the specified total contact area of the Buoy equally divided between all the Buoy's vertices.

3.3. Results

Buoy to Elastic Solid: Here both objects will report the force arising from any contact between them.

Buoy to Seabed: Here only the Buoy reports a contact force.

3.4. Modelling Issues

Care is sometimes needed when positioning the Buoy's vertices; for a Lumped Buoy you can specify the number and location of the vertices directly. For a Spar Buoy or Towed Fish the vertices are automatically created based on the cylinder dimensions that you have specified. Note that even if the 'draw circular cylinders' option is selected, OrcaFlex will still position the vertices as if the 'draw square cylinders' option is selected, with the vertices placed at the corners of each 'square' cylinder.

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Specifying a value of zero for the Buoy's total contact area will disable contact for the Buoy.

4. Line Clashing

4.1. Common Uses

Typical examples of where Line Clashing is used are:

- Interference analysis between lines i.e. risers, umbilicals, mooring lines etc.
- Reeling operations.
- Modelling impact between lines and vessel boundaries (i.e. moonpool edges, bow profiles etc.)

4.2. Interaction

Clashing between Lines occurs between the segments joining the nodes instead of at the nodes as for the Line to Elastic Solid (or Seabed) model. This means that the segment length does not affect whether clashing is detected or not (unlike the Line to Elastic Solid contact that we considered earlier, where segmentation is critical to how the contact is modelled), although it will affect the quality of the results.

By default, OrcaFlex does not have Line clash modelling enabled. This is because the algorithm to detect the distance between segments is computationally intensive (because a segment must detect its proximity to all other segments in the model), and clash modelling isn't required in the majority of analyses. Often just knowing that two lines have touched is all the information that is needed and this can be determined via the "Line Clearance" results without needing the clashing model to be enabled.

However, sometimes you will want to explicitly model the clashing between line segments to capture the clash energy, clash duration and post-contact behaviour. In this case, clash checking must be enabled for both of the lines involved, and the line types must have non-zero contact stiffness. If you know in advance which parts of the line(s) clash, then you have the option to limit which sections of a line have clash checking enabled, thus speeding up run times.

When OrcaFlex looks for clashing between two segments, those segments can be on different lines or on the same line – the latter allows interesting situations such as a line being coiled onto the seabed to be modelled, as shown in Figure 4-1.

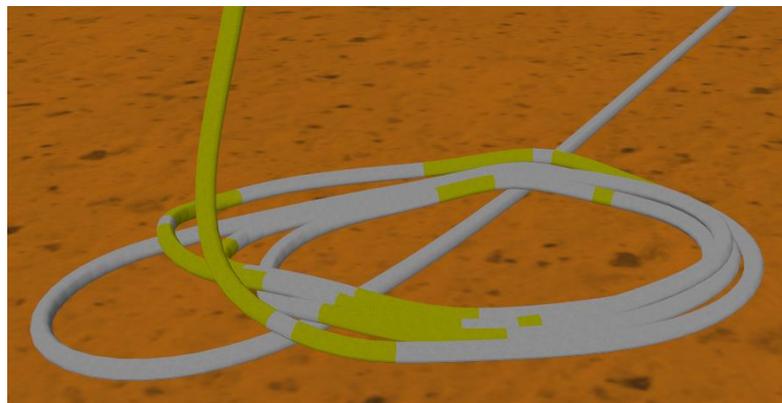


Figure 4-1: Line Clashing With Itself

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4.3. Results

Results reported from Line Clashing events are: Clash Force, Clash Impulse and Clash Energy. A Line Clashing Report is also available which will contain the above-mentioned results as well as other information about the clash events that occurred during the simulation.

4.4. Modelling Issues

Clash events, and in particular those that involve high-speed impact, are often time step sensitive. Short-duration events necessarily require a short time step in order to capture them; with the explicit integration scheme this is not normally an issue as the time step used will be short anyway, however with the implicit scheme it is recommended that a sensitivity study is carried out to ensure that a suitably short time step is being used.

Clashing between Lines is a dynamic event and is therefore not modelled during statics. The Line Clashing model does not include friction effects.

5. Line Contact

Line *Contact* was added to OrcaFlex in v9.6, Line *Clashing* is the long-standing line contact model in OrcaFlex, as discussed in Section 4. Line *Clashing* allows contact between OrcaFlex Line segments, treating each as elastic surfaces, whereas Line *Contact* is a different contact model, summarised below:

5.1. Common Uses

Typical examples of where line-in-line contact is used are:

- Pipe-in-pipe systems
- Pull-in operations
- Drilling riser choke and kill lines
- Installations guide wires
- Pipe-on-pipe / Piggy back risers
- Hybrid riser towers
- Bend stiffeners with friction
- Guide wire lowering operations

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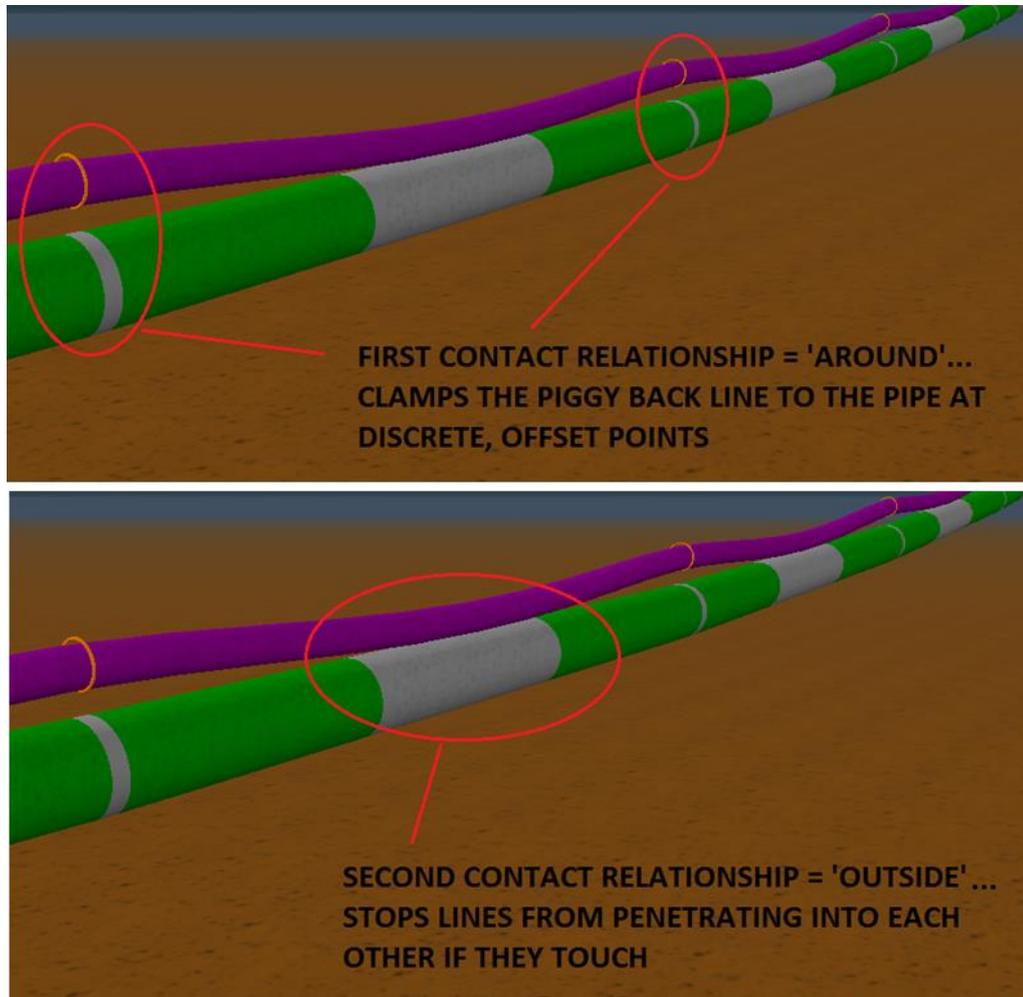


Figure 5-1: Line Contact used to model a Piggy Back Line

5.2. Interaction

Here contact between two distinct lines is modelled by defining a relationship between them. One line is identified as the 'splined line' and the other as the 'penetrator' line. The splined line has a spline curve fitted between the line nodes that allows OrcaFlex to represent the line as a smooth, deformable cylinder. The penetrator line has 'penetrators' attached to it (usually at the nodes but they can be positioned anywhere along the line, and offset from it if required). Contact occurs when the penetrators contact the cylinder of the splined line.

The relationship between the penetrating line and the splined line can be defined as 'Inside', 'Outside' or 'Around'. 'Inside' means that the penetrating line is contained within the bore of the splined line, 'Around' means that the penetrating line fits around the splined line, and 'Outside' means that the two outer diameters of the lines meet. Any line can be in multiple contact relationships e.g. a piggyback line (Figure 5-1), which uses two relationships between the two lines: an *Around* and an *Outside* relationship.

The relationship between the two lines is defined on the 'Line Contact Data' form, which is accessible from the model browser.

The penetrator-to-cylinder contact is modelled in the same way as contact between line nodes and elastic solid shapes, therefore this contact can be modelled in statics, and friction can be applied during dynamics. The contact stiffness can be either linear or non-linear.

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5.3. Results

Line Contact Force results are available, which report the force per unit length due to the line to line contact.

5.4. Modelling Issues

The splined line and the penetrator behave in different ways; choosing which line is which depends on static robustness, system response and the results that you need, but usually you can choose either.

When using a splined line that has low bending stiffness, fine segmentation can be required if the splined line relies on its axial stiffness for lateral restraint.

If the line contact penetrators and the splined line are of the same, or similar, diameter (e.g. when modelling a transition or interference fit) then discretisation of the penetrators may be required. This is because the true contact force in this situation occurs at all points around the circumference simultaneously, and this cannot be modelled with a single penetrator which can only represent contact at a single point. This results in a singularity in the force model and can lead to noisy or unstable simulations. The solution is to discretise the penetrators into multiple, scaled penetrators, which are placed around the original contact surface. This is done using the Count and Scale options on the Line Contact data form.

6. Contact between Lines and Supports

Supports were added to OrcaFlex in v9.8, with the purpose being to allow much simpler modelling of pipelay operations. Supports are therefore primarily used to model pipelay rollers, however their properties make them suitable for use in a number of other applications as well.

6.1. Common Uses

Typical examples of where supports can be used are:

- Pipelay stingers (Figure 6-1)
- Deck bollards
- Midwater arch gutters (Figure 6-2)
- Guides

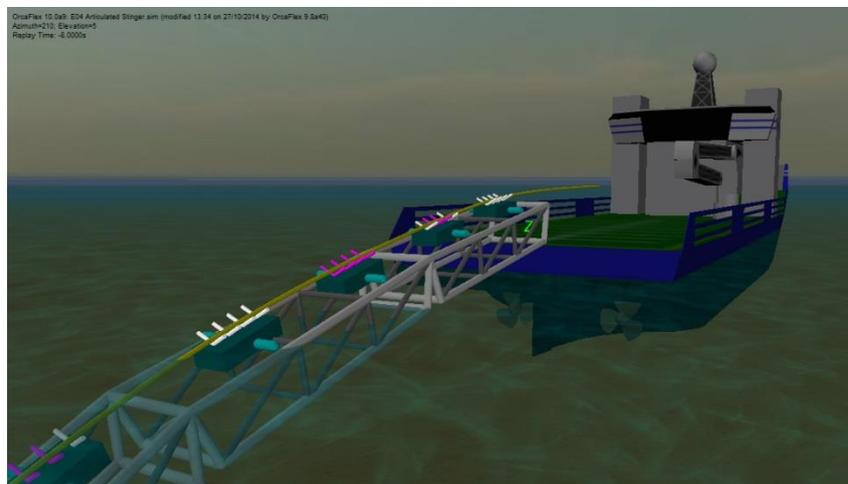


Figure 6-1: Supports on a Pipelay Stinger

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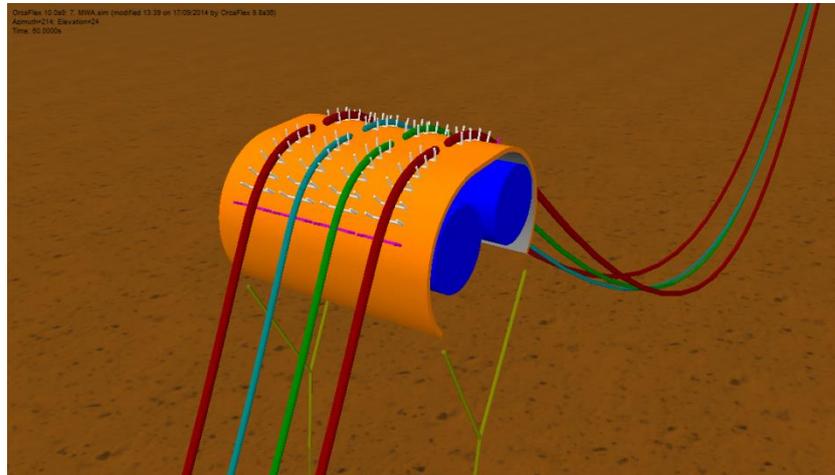


Figure 6-2: Supports Used to Model Mid Water Arch Gutters

6.2. Interaction

The Supports contact algorithm is based on the Line Contact model discussed in Section 5, with the difference that where the Line Contact model is *penetrator-to-spline*, the Supports model is *cylinder-to-spline*. Supports are built up of one or more rigid cylinders, each of which can contact a smooth, continuous spline surface, which is generated along the length of the *Supported Line*. This arrangement means that the segment length does not affect whether contact is detected or not (unlike the Line to Elastic Solid contact discussed in Section 2, where segmentation is critical to how the contact is modelled).

Each Support cylinder has infinite length, even though it is shown in the model with a user-defined finite length, and has a preferred contact side. These two features, coupled with the knowledge of which line in the model is 'supported' by the supports, is sufficient for OrcaFlex to position the line in contact with the supports, lying on the desired side. This makes for a very robust static calculation, even when the initial (reset) position of the line is a long way from the required equilibrium position.

Rollers can be easily defined as flat, V or U shaped sets, or as more complex user-specified arrangements. Supports can be added to both Vessel and 6D Buoy objects, and are positioned with a choice of Simple or Explicit geometry. The Simple option creates a path along which Supports can be placed, which is ideal for creating simple stinger geometry. The Explicit option gives the user full control of the position and orientation of each individual support. The connection between the Support and the Vessel or Buoy on which it is mounted is rigid, but of course this object can be free to move in whatever way it is required to, hence more complex mounting arrangements, such as pivoting roller boxes, can be modelled.

Friction is not included in this contact model. Contact stiffness can be either linear or non-linear.

Supports are created and positioned on the Supports page of the data form of the object on which they are mounted (i.e. the Vessel or 6D Buoy's data form). Support *types* e.g. V or U shaped support sets, are set up on the 'Support Types' data form, which is accessible from the model browser.

6.3. Results

Various results are available for Supports, including Contact Clearance, Lift Out, Reaction Force and its components, and the Arc Length of the point on the Supported Line that is in contact with a particular support. Results are also available for the total Supports Force and Moment applied by all the Supports onto the Vessel or Buoy on which they are mounted.

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6.4. Modelling Issues

The Supports model allows only one point on the Supported Line to be in contact with an individual Support at any one time. Therefore if a Line wraps around and passes over the same Support twice this will likely cause convergence problems as the contact force jumps from one contact point to the other and back again.

Similarly, because the Supports have infinite extent, there is a risk that part of the Supported Line might interact with a Support in places where you don't expect it to! Anywhere where the Supported Line potentially loops back under a Support is a potential problem. Look out for contact showing up (in white) in places that shouldn't be in contact with anything.

For example in Figure 6-3 you can see a set of U shaped supports mounted in an arch shape. The Support on the far left is coloured white, even though the Line is clearly not passing over this Support. The reason for this is because the three rollers that make up this support extend infinitely (as shown with blue lines in Figure 6-4), and one of them comes into contact with the Supported Line further along the catenary. When this happens, OrcaFlex will warn you that contact has been made with a Support at a point beyond its physical length. Clearly this situation is undesirable, so the way to prevent it happening in this situation would be to split the Supports into two sets, so that the green line is the Supported Line for only the right hand set of supports. Alternatively, this is one situation where the Supports model might not be the best choice of contact model and one of the other contact models described in this document might be more suitable.

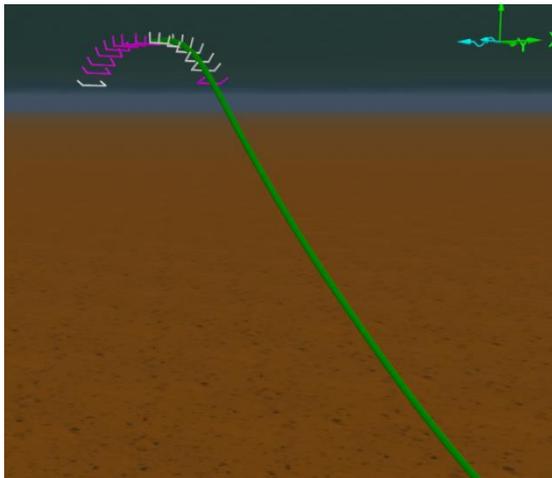


Figure 6-3: Contact showing on Left Hand Support

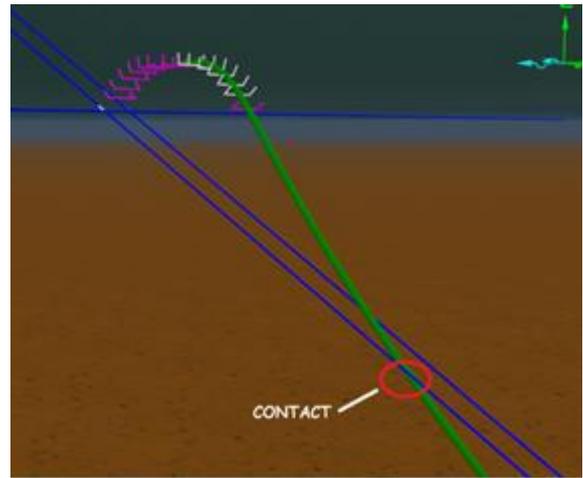


Figure 6-4: Location on Line Causing Contact