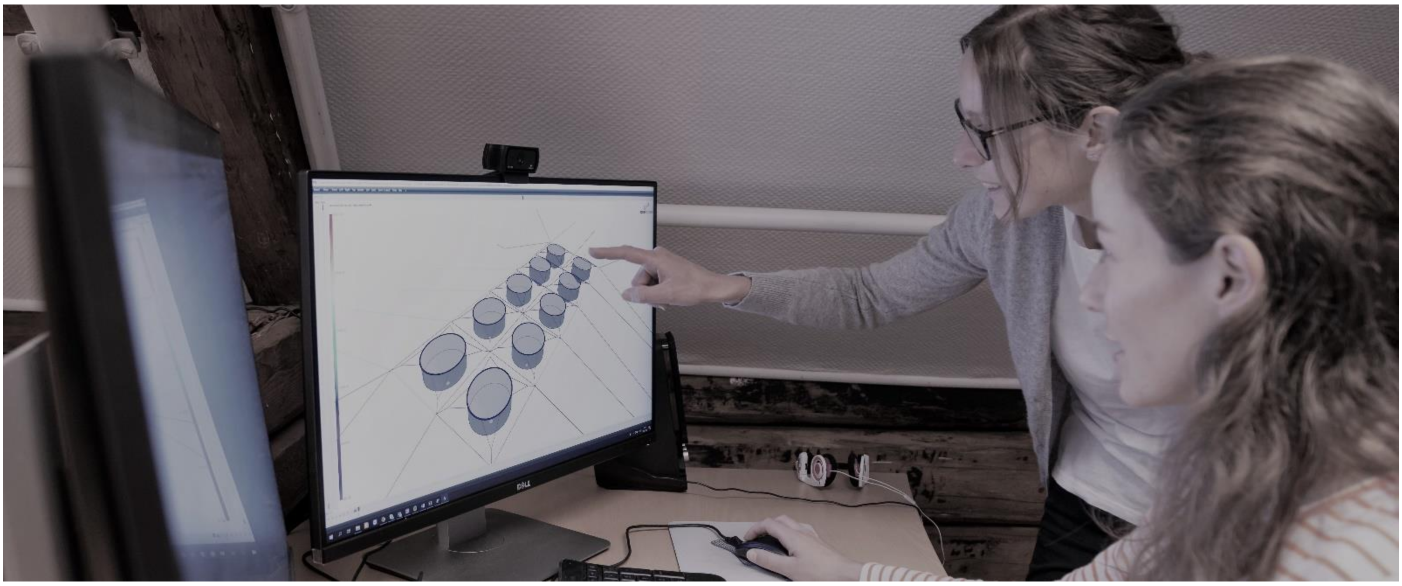
AquaSim training courses

- **Lice skirt**



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1 Prerequisites

The tutorial presents a simple case study with the purpose of demonstrating functionality in AquaSim.

It is assumed that the user is familiar with the basic principles of modelling and specifying material parameters in AquaEdit, as well as conducting analyses. If you are looking for an introduction to AquaSim we advise you to start with the Basic program tutorials.

2 Learning objectives

In this tutorial, you will be introduced to:

- Basic concept of lice skirt
- Lice skirt parameters in AquaSim
- Key result parameter in AquaView

3 Introduction

Salmon lice is a small parasite that is found in marine environment. It is a challenge for the aquaculture industry as it damages the salmon in terms of wounds and infections. A wide range of methods and devices has been developed through the time, to reduce the risk of infections in at the aquaculture facilities – lice skirts are one of them.

The lice thrive in the upper part of the water column, approximately down to 5-10 meters depth. The basic concept behind the lice skirt is to create a barrier between the salmon and the parasite in the part of the water column where the lice lives. If the parasite does not find a host, it will eventually die. The thought is that the lice skirts are permanently installed at the cages as a preventive measure.

Consider a conventional circular aquaculture cage with a net. The lice skirt is installed on the outside of the fish barrier and is attached to the floating collar. The skirt is commonly made by dense, water-resistant fabrics such as tarpaulins in P V C. In this tutorial you will be presented to the basic input-parameters when modelling a lice skirt – what they mean and how they can be applied. Some trouble-shooting aspects and suggested solutions are also included.

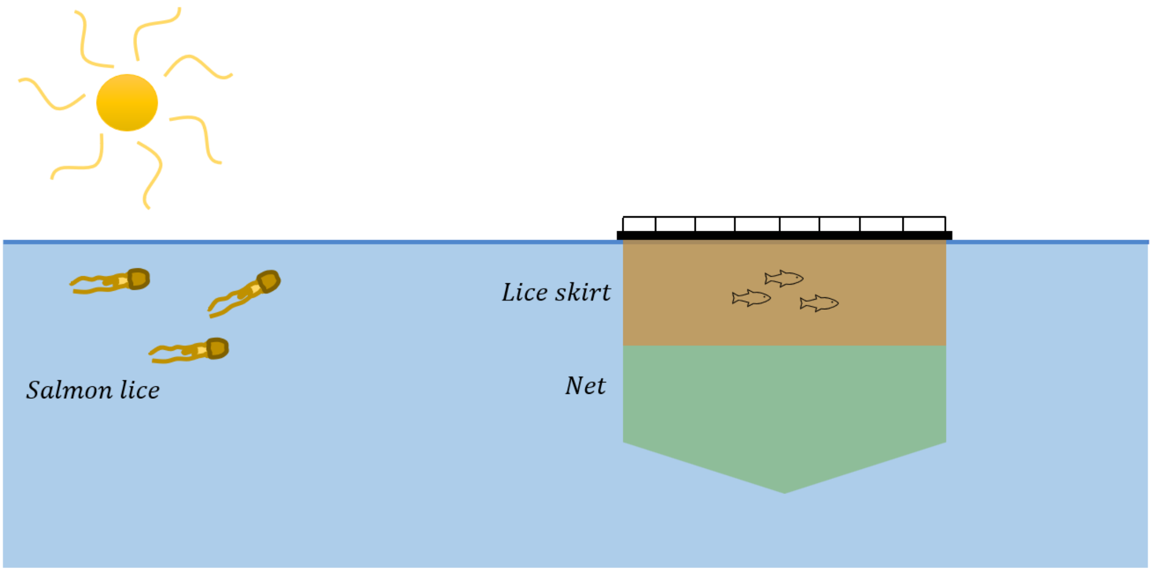

Figure 1

4 Hydrodynamical principles

Let's consider this from a hydrodynamical perspective. Conventional barriers such as nets have openings allowing water to flow through more or less unhindered.

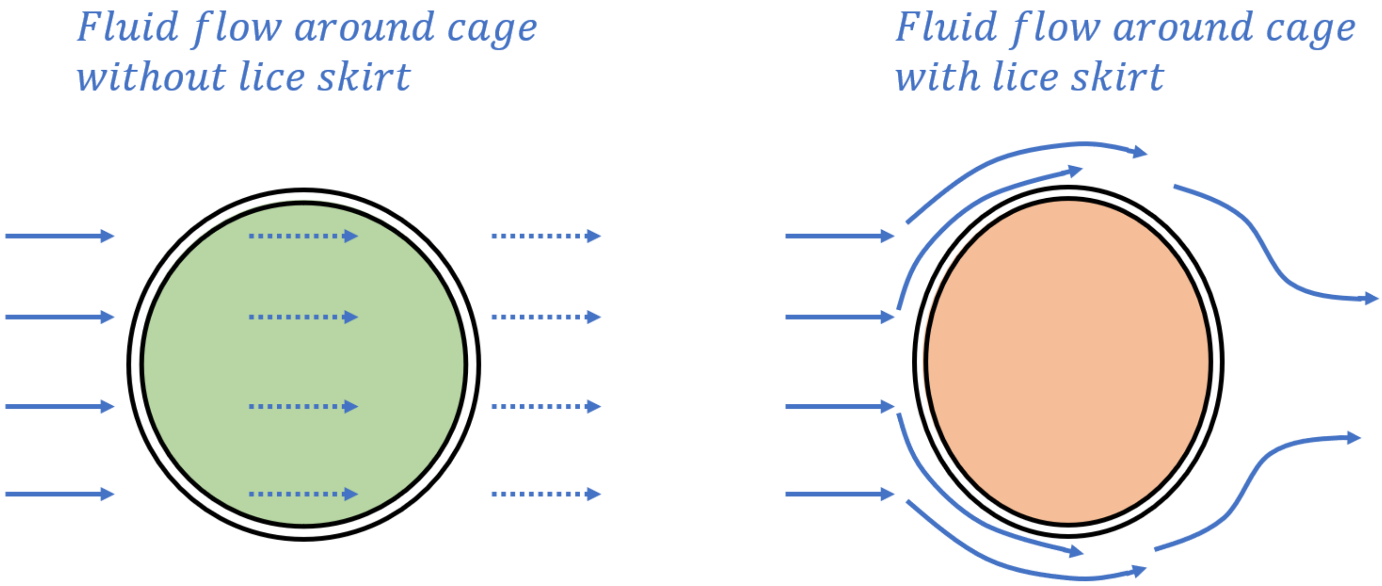

Figure 2

Introducing a lice skirt, the water particles are hindered from flowing through, and must pass on the sides of the barrier, or below. Waves that interact will be accompanied by diffraction and deformation of the lice skirt. Diffraction is the process where waves spread perpendicular to the direction of wave propagation. These effects will cause an increased pressure on the upstream side and the lice skirt will be deformed. This is commonly known as hydroelasticity – a time-dependent effect, where structures deform under the influence of fluids.

The pressure-increase on the upstream side of the skirt will be transferred to the cage, and in turn lead to increase loads in the anchoring system. This is something to be aware of when planning an anchoring system at a fish farm facility.

5 Case study – Lice skirt

5.1 Modeling principles

To model lice skirts in AquaSim, one can apply load formulation **Lice skirt** for the component type Membrane X (or Membrane).

AquaSim assumes that lice skirts always are modelled as a cylinder. Which membrane panels are upstream of waves and current, and which panels are downstream are kept track of. By this, AquaSim is able to distribute the pressure field around the lice skirt in a realistic manner. To illustrate this pressure field, let us simplify the problem and consider fluid flow around a cylinder. Upstream it will experience pressure drag force, and downstream suction drag. On the upper and lower sides, the cylinder will experience lift forces.

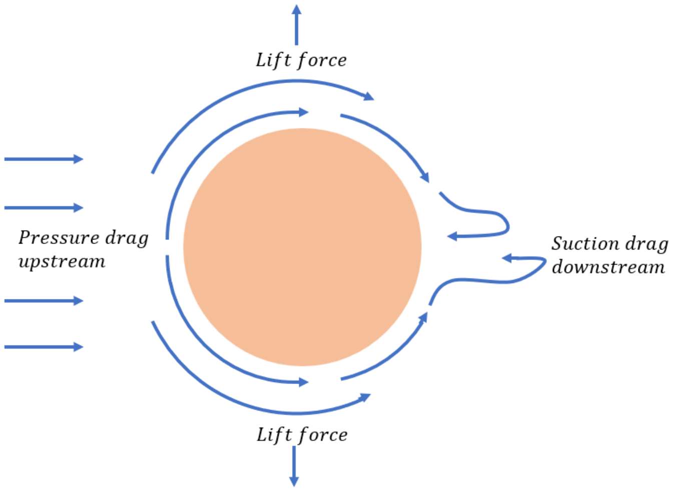

Figure 3

A consequence of AquaSim being able to keep track of what is upstream and downstream, is that each lice skirt must be modelled as its own component group. If you for example have a model of an aquaculture facility with 2 by 2 cages, you will need to model the lice skirts in 4 individual component groups. This is illustrated below.

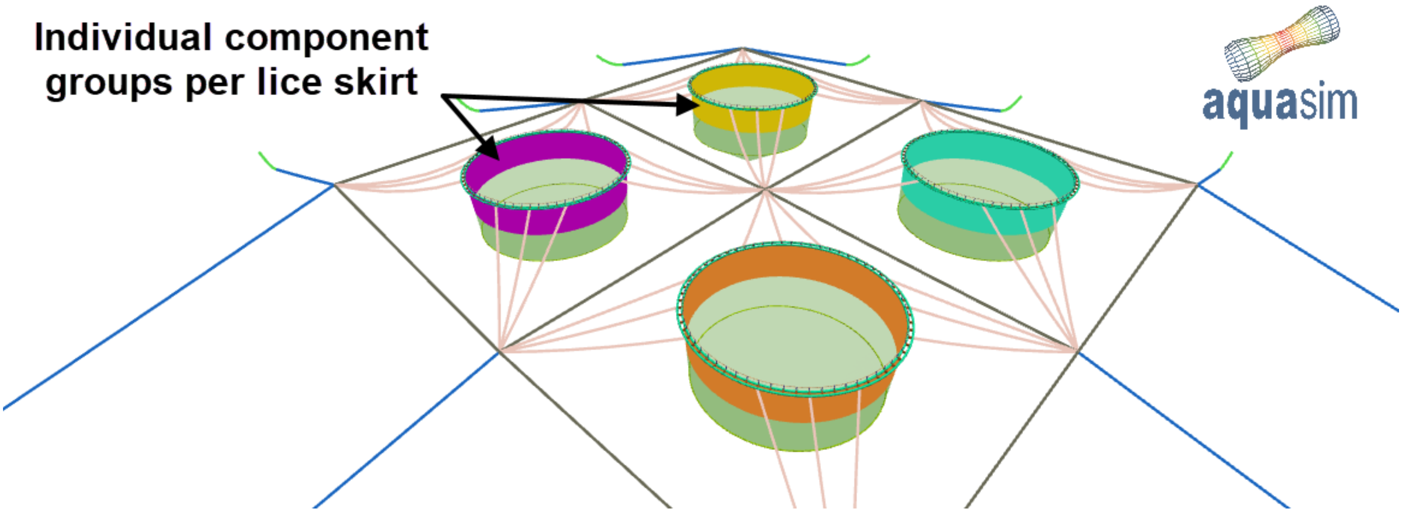

Figure 4

5.2 Lice skirt parameters

For the next steps, may use the AquaSim model *LiceSkirt.amodel*, following this tutorial. You are to finish the model by input appropriate parameters to the lice skirt.

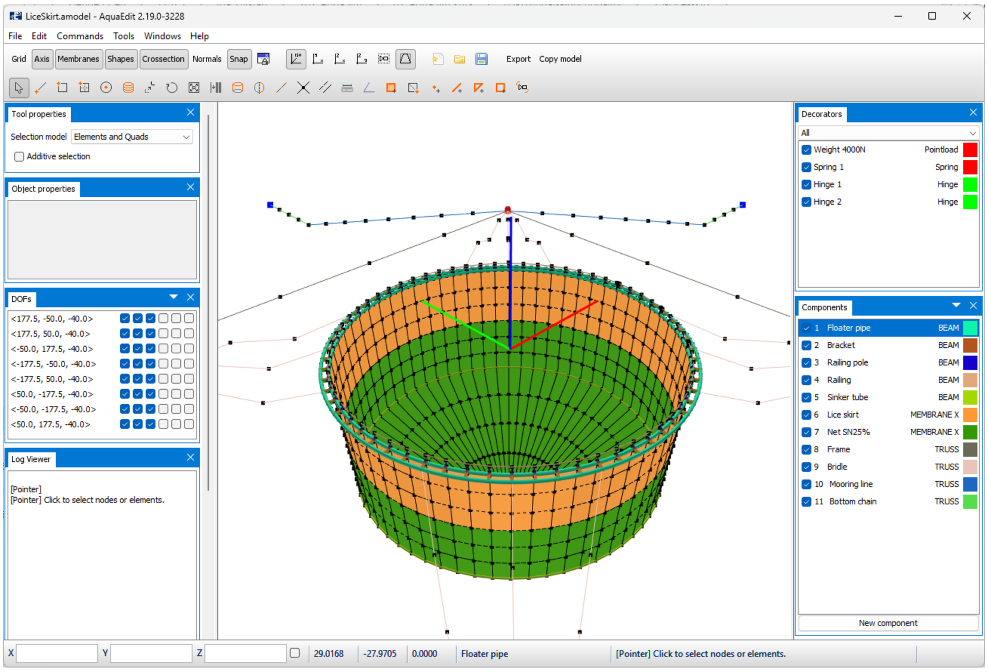

Figure 5

The model contains a classical configuration with a PE floating collar and a permeable net mounted in a frame anchoring system. Attached to the net, is the lice skirt. The lice skirt is modelled with membrane type *Normal* in combination with Load formulation *Lice skirt*.

Double click on the component type *6 Lice skirt*, in the components window, and navigate to the **Load properties** tab. This tab provides input parameters that is relevant for the type of dense fabrics as lice skirt.

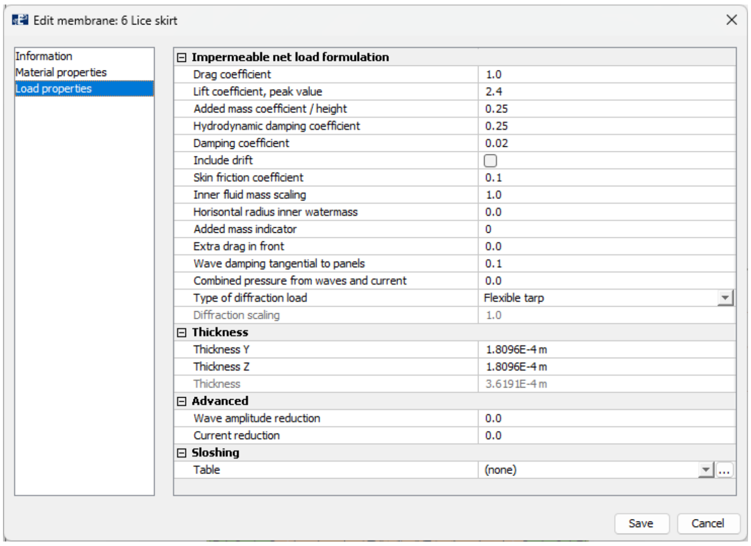

Figure 6

In the next sections, the different parameters are presented – what they mean and how they can be used. Please note that there is no conclusion at which level the different parameters should be at. Suggestions and what to have in mind when deciding upon the numbers are presented.

5.2.1 Drag coefficient

The drag coefficient C_d is a unitless quantity that decides the magnitude of the pressure drag resistance. Let us consider the cylinder: pressure drag resistance is a force that is exerted on the cylinder when exposed to fluid flow. Upstream one will have pressure drag and downstream suction drag. If we consider one cylinder panel, the flow velocity is decomposed into a normal- and tangential component. Then the appropriate drag- and lift force is found from this. The drag acts normal to the cylinder panel. Drag coefficient is normally determined empirically through experiments such as tank tests.

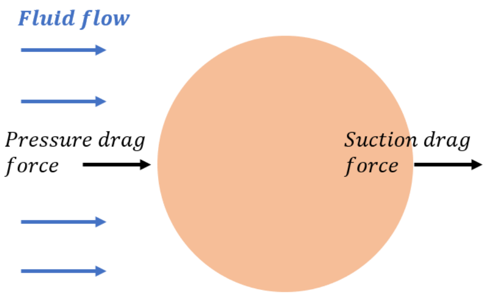

Figure 7

From the input drag coefficient C_d, AquaSim distributes the pressure drag on membrane panels upstream and downstream of the cylinder. The relation between input C_d, $C_{d\ UPSTREAM}$ and $C_{d\ DOWNSTREAM}$ that is found by AquaSim is illustrated in the figure below.

$$If\ 0 < C_d < \frac{2}{3}:\ C_{d\ UPSTREAM} = C_d \cdot \frac{3}{2}\ ,\ C_{d\ DOWNSTREAM} = 0$$

$$If\ \frac{2}{3} < C_d < 2.0: C_{d\ UPSTREAM} = 1.0\ ,C_{d\ DOWNSTREAM} = \left(C_d - \frac{2}{3}\right) \cdot \frac{3}{2}$$

$$If\ C_d > 2.0: C_{d\ UPSTREAM} = C_d \cdot \frac{1}{2}\ ,C_{d\ DOWNSTREAM} = C_d$$

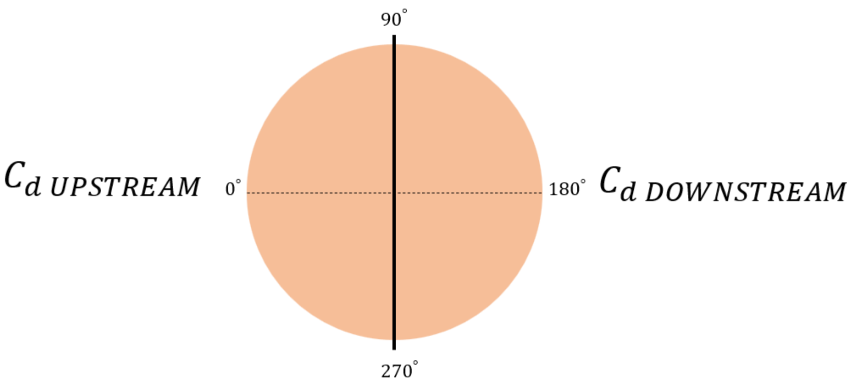

Figure 8

$C_{p\ UPSTREAM}$ is applied on cylinder panels that are located 0-90 degrees with respect to the fluid flow. $C_{p\ DOWNSTREAM}$ is applied from 90-180degrees. In our case, the drag coefficient C_d is set equal to 1.0.

5.2.2 Lift coefficient, peak value

The lift coefficient C_l is a unitless quantity that decides the lift force on the lice skirt. The lift force decides how much outwards force is exerted on the cylinder. Considering a cylinder panel: the lift force acts in normal direction.

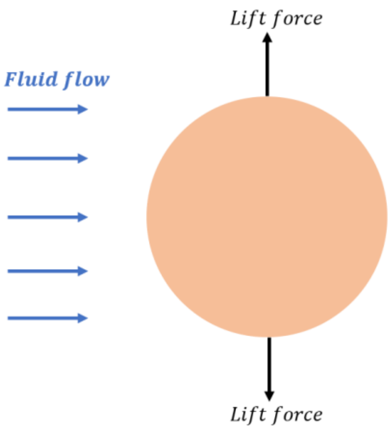

Figure 9

C_l is applied to each panel around the cylinder. In our case, the lift coefficient is set to 2.4.

5.2.3 Added mass coefficient/ height

Added mass is the amount of water the cylinder must move on the outside in order to displace. Such mass is often interpreted as an inertia added to the cylinder. This added mass acts normal to the cylinder panel.

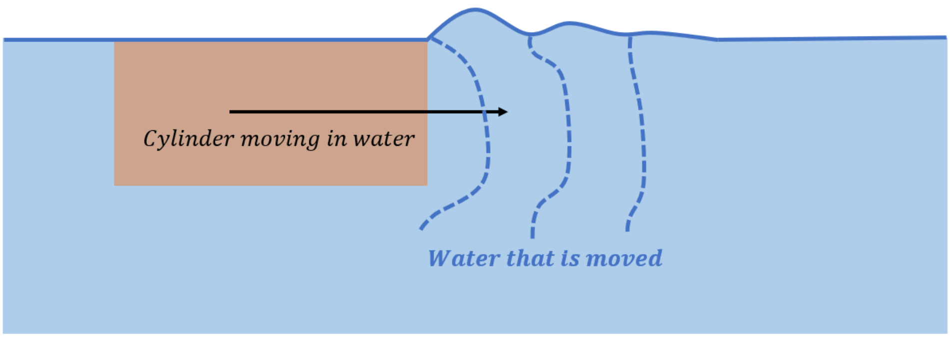

Figure 10

As AquaSim keep track of which panels are upstream and downstream, it also finds the radius R of the lice skirt. Let us call the Added mass coefficient/height C_{AMass}, and it is related to the 2D-volume V_{2D} of the cylindrical lice skirt. How this parameter should be interpreted depends on what you select as **Type of diffraction load** further down in the menu:

- MacCamy-Fuchs:
  If this method is selected, then **Added mass coefficient/ height** is interpreted as a unitless quantity that acts normal to the lice skirt panel. This coefficient is multiplied with the radius of the cylinder:

$$Added\ mass = V_{2D} \cdot \rho = \pi (R \cdot C_{AMass})^2 \cdot \rho$$

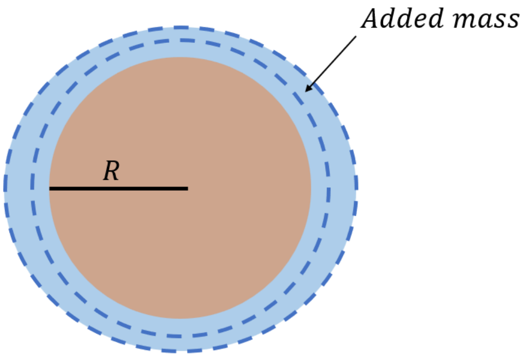

Figure 11

- Numerical diffraction:
  Selecting this method, the added mass is calculated automatically by AquaSim. The **Added mass coefficient/ height** should then be interpreted as a *scaling factor* with respect to the added mass AquaSim has found. If this parameter is equal to 1.0, then 100% of the added mass that AquaSim found is applied. If the parameter is set equal to 0.5, then 50% of the added mass is applied.
- Flexible tarp:
  Treats the added mass in the same manner as MacCamy-Fuchs.

5.2.4 Hydrodynamic damping coefficient

Both added mass and hydrodynamic damping is interpreted as inertia that is added to the cylinder. Hydrodynamic damping coefficient is a unitless quantity that dampen accelerations of the membrane panels in the cylinder.

Let us call the Hydrodynamic damping coefficient C_{HDamp}, and it is related to the 2D-volume V_{2D} of the cylindrical lice skirt. How this parameter should be interpreted depends on what you select as **Type of diffraction load** further down in the menu:

- MacCamy-Fuchs:
  If this method is selected, then **Hydrodynamic damping coefficient** is interpreted as a unitless quantity that acts normal to the lice skirt panel. This coefficient is multiplied with the radius of the cylinder:

$$Hydrodynamic\ damping = V_{2D} \cdot \rho = \pi\left(R \cdot C_{HDamp}\right)^2 \cdot \rho$$

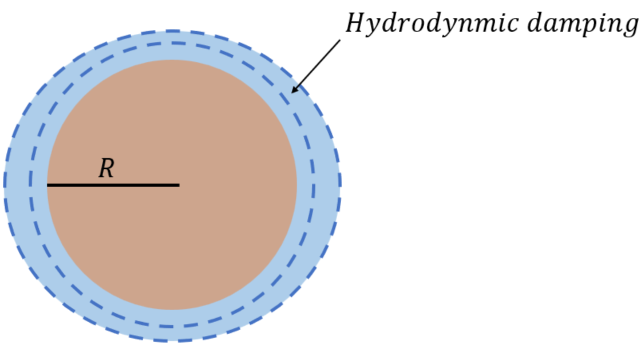

Figure 12

- Numerical diffraction:
  Selecting this method, the hydrodynamic damping is calculated automatically by AquaSim. The **Hydrodynamic damping coefficient** should then be interpreted as a *scaling factor* with respect to the added mass AquaSim has found. If this parameter is equal to 1.0, then 100% of the added mass that AquaSim found is applied. If the parameter is set equal to 0.5, then 50% of the added mass is applied.
- Flexible tarp:
  Treats the hydrodynamic damping in the same manner as MacCamy-Fuchs.

5.2.5 Damping coefficient

This coefficient is intended to describe the inertia that arise from waves and viscous effects. Viscous effects can be interpreted as friction due to the water particles close tend to stick to the cylinder surface, this friction contribute to slow down and dampen the acceleration of the cylinder.

This coefficient can be interpreted as an amplification factor, as it is multiplied with the total mass and added mass of the cylinder. This type of damping is acting normal to the cylinder panel.

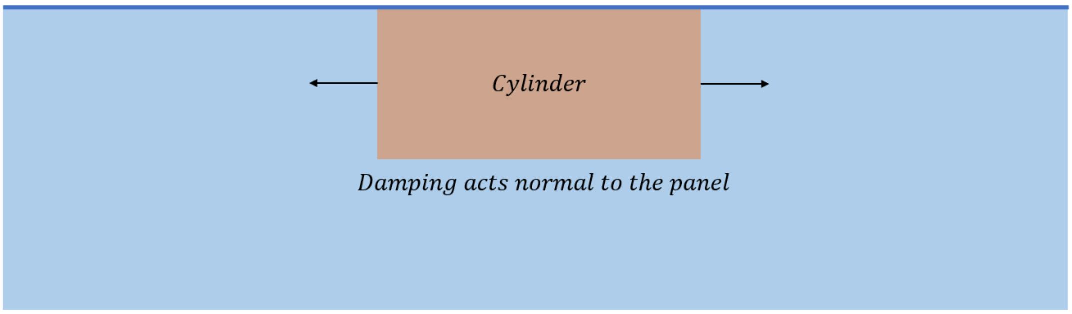

Figure 13

Damping can be introduced to reduce the acceleration and response of the cylinder. But be careful, so you do not “dampen out of trouble”. Too much damping will give a slow and unrealistic response of your structures.

Let us call the Damping coefficient for C_{Damp}. This type of damping is found as:

$$Damping = \frac{C_{Damp} \cdot A \cdot \rho \cdot g}{\omega}$$

where A is area of the cylinder panel, ρ is fluid density, g is gravity and ω is the frequency of the wave peak period.

Having selected the **Type of diffraction load** to **Hybrid flexible tarp/ Numerical diffraction** and Diffraction scaling = 0.25: letting **Damping coefficient** = 1.0 will be consistent with having selected the Flexible tarp method.

5.2.6 Include drift

Drift forces are the mean forces that act on the cylinder by incoming waves. These forces are nonlinear and are due to the cylinder absorb or reflect the waves. How much drift force that acts on a structure depends on aspects such as water plane area and the stiffness of the structure. A structure with a small waterplane area is less likely to reflect waves than a structure of larger area. Similar, a stiff and rigid structure has larger potential to reflect incoming waves than flexible structures that deforms easily. Over time, this force will contribute to the cylinder slowly moving.

Due to loads being calculated to the instantaneous free surface, drift forces will always occur. But when the **Include drift** is selected, all load parts that contribute to drift is accounted for, this also include the velocity-term in Bernoulli's equation.

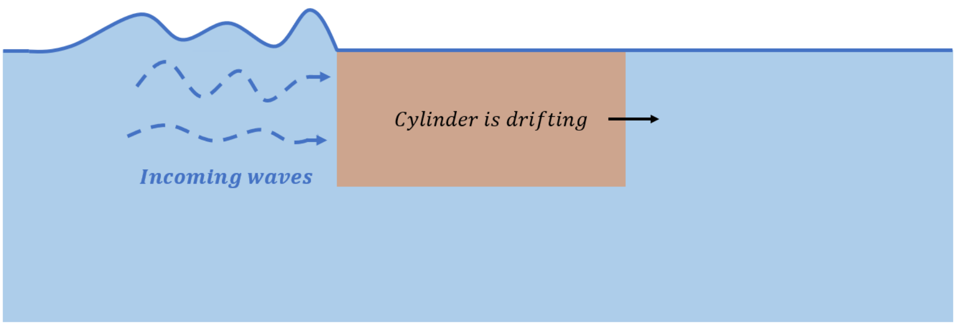

Figure 14

5.2.7 Skin friction coefficient

Skin friction drag is a resistance force that is exerted on the cylinder when exposed to fluid flow. It is caused by the viscosity in the fluid flow. The skin friction coefficient is a unitless quantity that decides the magnitude of the skin friction drag. In oppose to the pressure drag that acts normal to the cylinder panel, the skin friction drag acts in tangential direction of the cylinder panel.

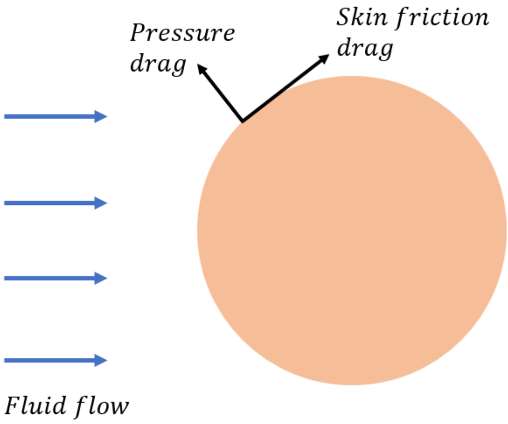

Figure 15

5.2.8 Inner fluid mass scaling

This factor regulates how much of the water inside the cylinder is accelerated due to cylinder motions. If this factor is 1.0 then 100% of the water volume inside the cylinder is accelerated. If 0.2, then 20% of the volume is considered, and so on. Hence, this parameter should be between 0 and 1.0.

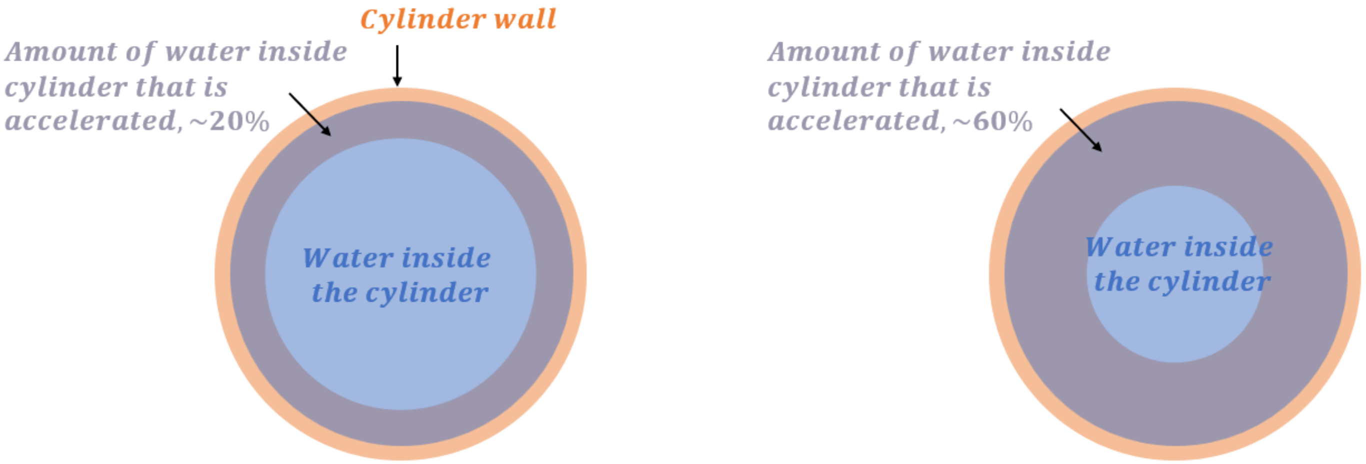

Figure 16

The larger this factor the slower the cylinder response becomes, because more water mass must be moved. The cylinder also become stiffer since more water must be accelerated to move the cylinder.

5.2.9 Horizontal radius inner watermass

As explained in the section **Added mass coefficient/ height**, AquaSim find the radius R of the cylinder automatically. The user may encounter situations where this radius is not applicable, for example if the lice skirt is not shaped as a cylinder. The user may override this radius by using **Horizontal radius inner watermass**.

If this parameter is equal to 0, then the radius found by AquaSim is applied. If any other number is inserted, this is interpreted as the radius in meters.

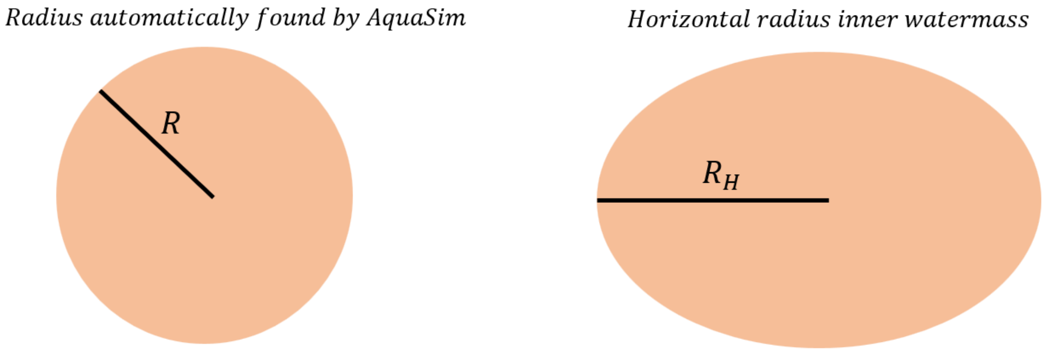

Figure 17

5.2.10 Added mass indicator

This parameter decides how the added mass should behave. You may choose to find the added mass calculated to the mean free surface in steady state condition. Or, to the actual water line, including wave elevation, during the analysis.

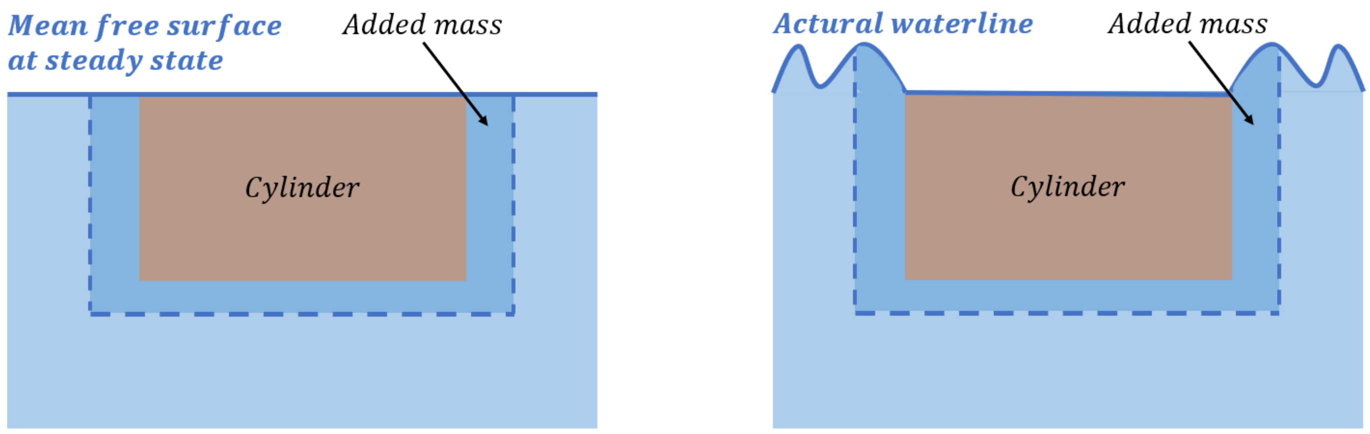

Figure 18

5.2.11 Wave damping tangential to panels

The inertia force **Damping** works in the direction normal to the cylinder panels. Normally, due to convergence issues, one may choose to introduce wave damping also in tangential direction to the cylinder panels. **Wave damping tangential to** panels is the tangential part of the force from **Damping**. This parameter is a factor that indicates how large portion of **Damping** that also should work in tangential direction. If 0.2, then 20% of the Damping force should also work tangential to the panels.

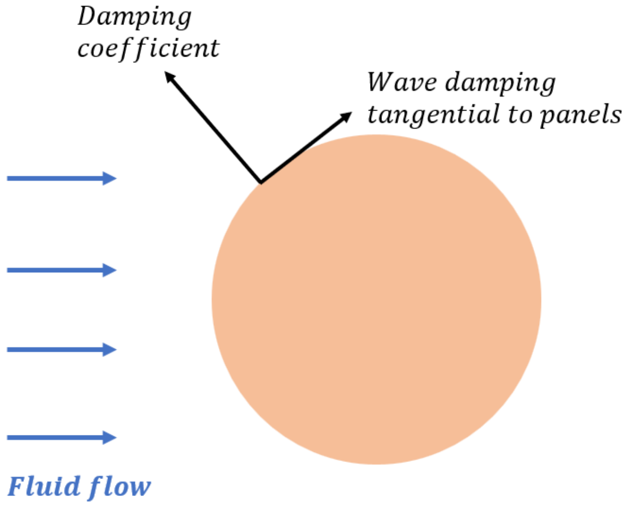

Figure 19

It is expected that our lice skirt will experience some deformation due to the waves and is set to 0.1.

5.2.12 Combined pressure form waves and current

This parameter says something about how the relative velocity between the cylinder and the fluid flow (due to current and waves) should be treated on each cylinder panel in your model. It can be a number between 0 and 1.0.

If this parameter is 0, then the 'raw' relative velocity at each of the panels is used as basis for finding the pressure drag. This is illustrated in the figure below (leftmost), where the pressure drag on each of the cylinder panel is based on the relative velocity each individual panel experience itself.

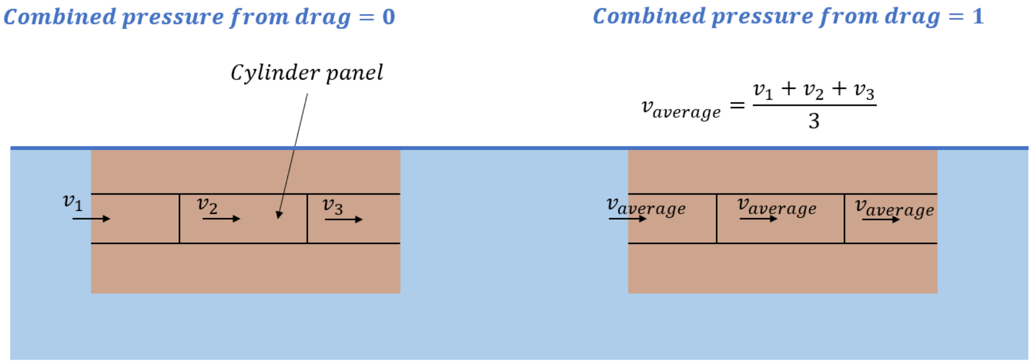

Figure 20

But if this parameter is 1.0 (see rightmost cylinder in the figure above), then AquaSim first averages the relative velocity over all cylinder panels at the same vertical position. Then the pressure drag is found for each panel.

5.2.13 Type of diffraction load

Diffraction force arise due to waves are reflected from the cylinder. Hydrodynamic problems are normally dealt with by splitting them up in two sub-problems:

1. Cylinder is restrained: forces and moments on the cylinder when it is restrained from moving, and current and waves are present. Diffraction forces are a part of this.
2. Cylinder is moving: forces and moments on the cylinder when it is forced to move in water. Added mass and damping is a part of this.

The two sub-problems are illustrated below.

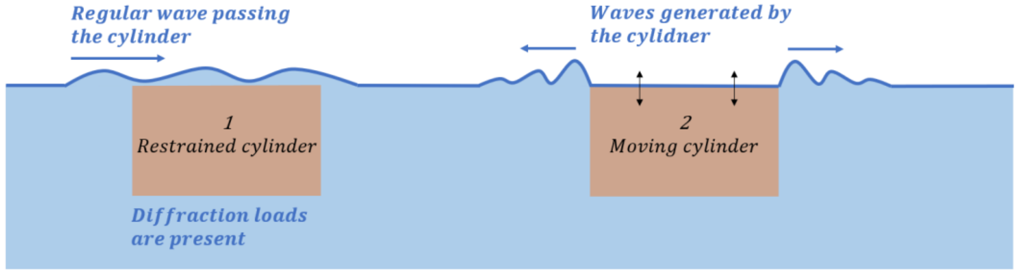

Figure 21

AquaSim has several methods for calculating the diffraction force, and the different methods are adapted to different types of structures. The MacCamy Fuchs and Numerical methods are adapted for rigid and stiff structures, while Flexible tarp is developed for soft and deformable fabrics such as lice skirts. There are also possible to combine the different methods. The hybrid solution between two methods has shown beneficial for lice skirts: Hybrid flexible tarp/ Numerical diffraction, where the Flexible trap is weighted 75% and Numerical diffraction 25%. This is evident from tank tests with a dense tube, see Loads from waves and current on flexible tarps (Berstad, Marine 2021).

5.2.14 Diffraction scaling

If you chose one of the hybrid solutions in Type of diffraction load, this parameter becomes editable. This parameter weights how much of the different methods should be applied. Let us exemplify by considering the **Hybrid flexible tarp/ numerical diffraction**:

> If diffraction scaling is 0.25, then 25% of the total diffraction load is calculated from the Numerical diffraction-method and 75% by the flexible tarp. If 0.5, then the two methods are weighted 50%-50%.

5.2.15 Wave amplitude reduction

This parameter reduces the amplitude of the incoming wave on the cylinder. Useful if you have certain objects upstream of your cylinder, that will reduce the wave exposure. This is a unitless factor where 0.0 correspond to no wave reduction – the wave amplitude will be equal to the input value. If 1.0, then the wave is fully reduced, the wave amplitude will be equal to zero.

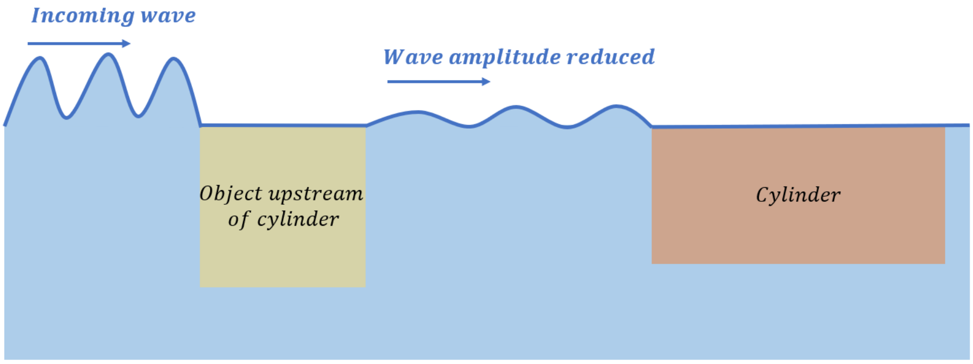

Figure 22

This could be applied on lice skirts that are downstream of other cages. But remember that the direction of the waves changes with the different load conditions. So, the potential wave sheltering effect will not be the same for all lice skirts for all load conditions – it changes.

5.2.16 Current reduction

As for wave amplitude reduction, one may reduce the current velocity on the cylinder. Useful if you have certain objects upstream of your cylinder, that will contribute to reduced exposure to current.

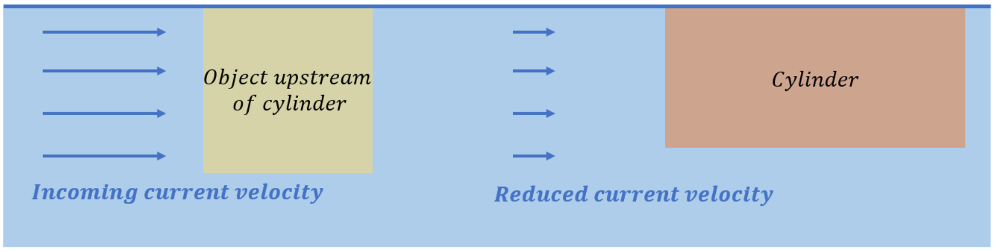

Figure 23

5.3 Analysis

Now that you are introduced to the different parameters and what they mean, we should run an analysis and then have a look at key result parameters in AquaView.

A load condition is prepared, go the **Export** and the tab **Normal**. A wave amplitude of 1.4 meters and -period of 4 seconds is applied. Also, current along x-direction is used.

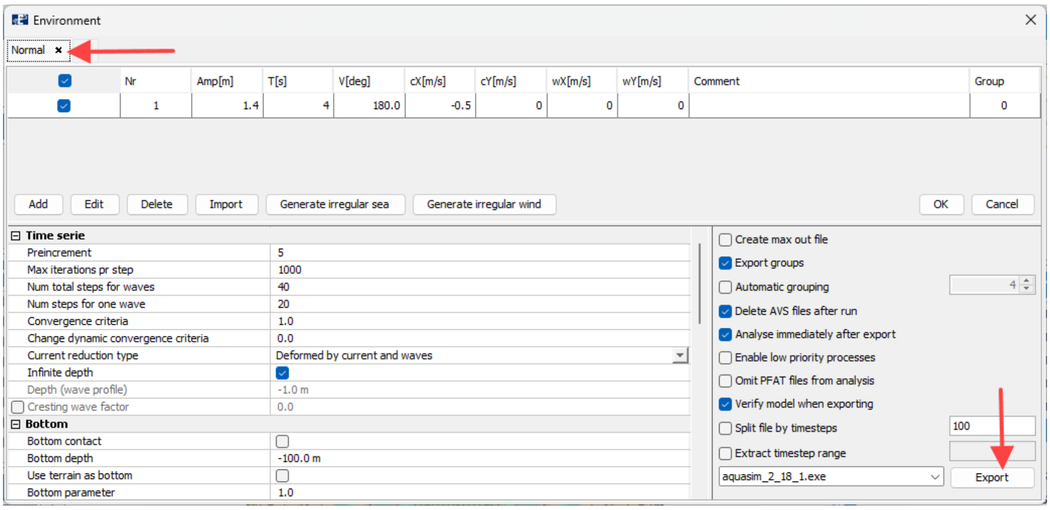

Figure 24

Export the model and start the analysis. This analysis will take 3-5 minutes to complete, depending on your computer capabilities. We named the analysis *liceskirt_*.

5.4 Post processing

Load the result-file, the one that ends with .avz. If you have not run your own analysis, you may open the *liceskirt_01.avz* that is associated with this tutorial.

Impermeable nets, such as lice skirts are in AquaView viewed as a membrane but with a darker rendering.

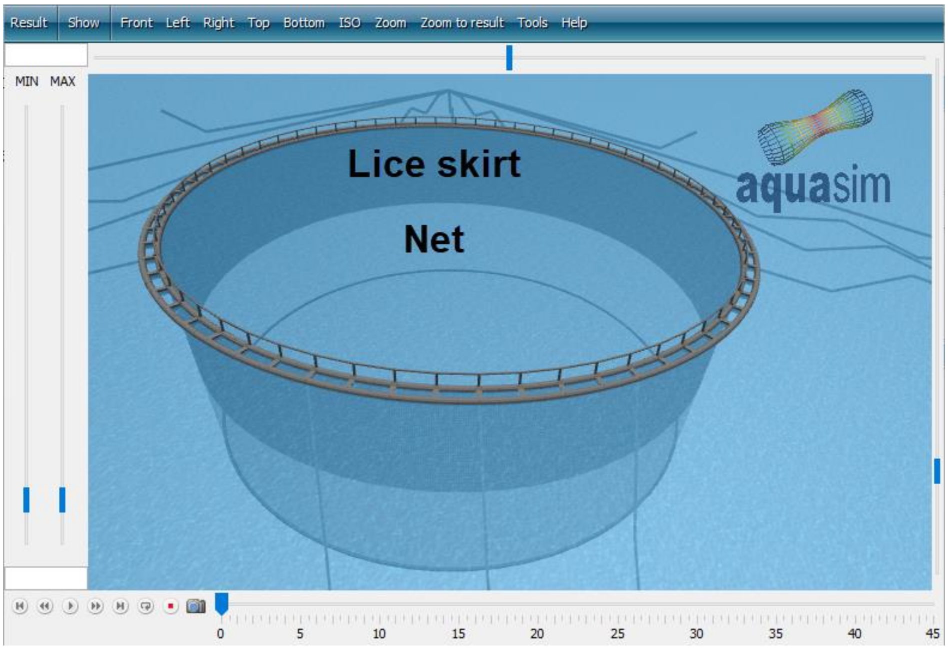

Figure 25

When you apply *Lice skirt* in your model, some additional results are available in AquaView. They are found under **Result** > **Impermeable net**. Here you can view different forces that is relevant for impermeable nets, for example damping. Select **Result** > **Impermeable net** > **Mass normal per m2 [m3]**. This is the amount of water normal to the inside of the lice skirt that is accelerated due to motions. These result-options are useful for self-validation of your model. Meaning that you can check these parameters with respect to input and what seems logic.

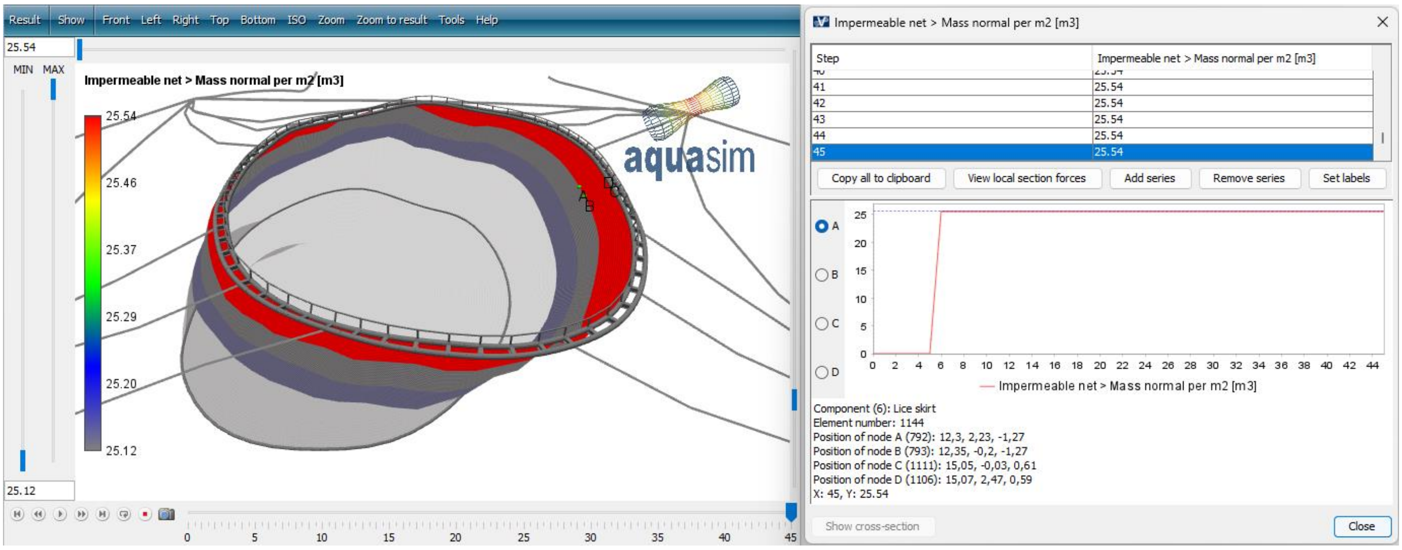

Figure 26

5.5 Comparison models with and without lice skirt

One interesting point is to investigate the effect the lice skirt has on response of the aquaculture cage and force distribution in the anchor lines. In this section we shall present and illustrate the effect lice skirt has.

Load the AquaSim model *Net.amodel*. This model is identical to *LiceSkirt.amodel*, only that the load formulation of the lice skirt is changed from *Lice skirt* to *Normal*. This will result in a conventional net that is permeable.

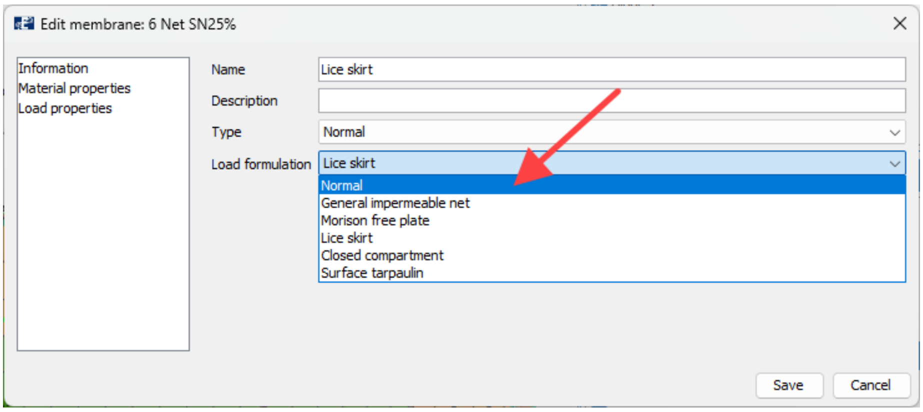

Figure 27

Select **Export** and the tab **Normal**. If you compare the two models, you may see that the load conditions are identical. With a wave amplitude of 1.4 meters, period 4 seconds and current along x-axis 0.5m/s.

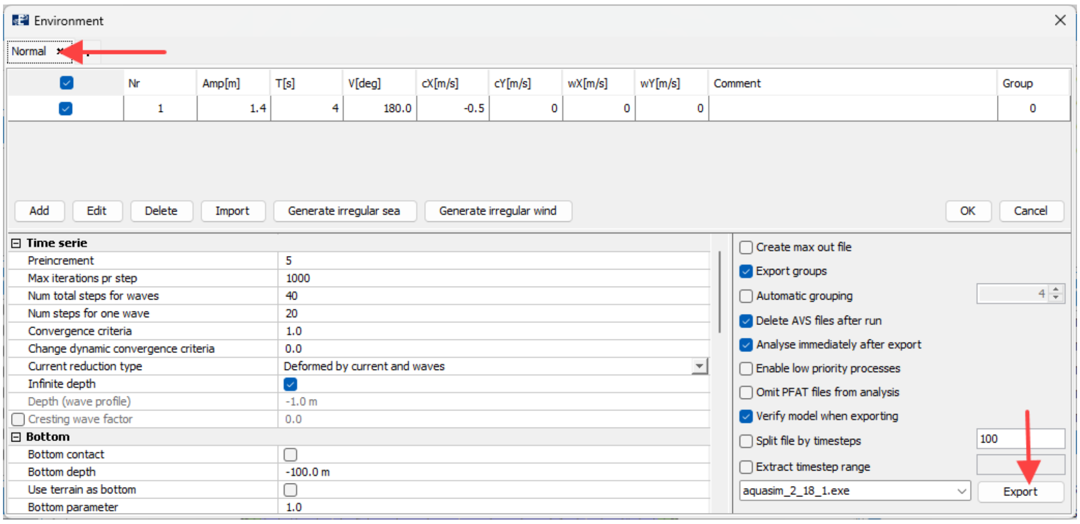

Figure 28

Export the model and **run an analysis**. We named the analysis *net_*, and will result in an avz-file that is named *net_01.avz*. When the analysis is finished, open this file.

You may have the *liceskirt_01.avz* and *net_01.avz* open parallel to compare more easily.

5.5.1 Response and deformations

The two models are presented side-by-side in the figure below.

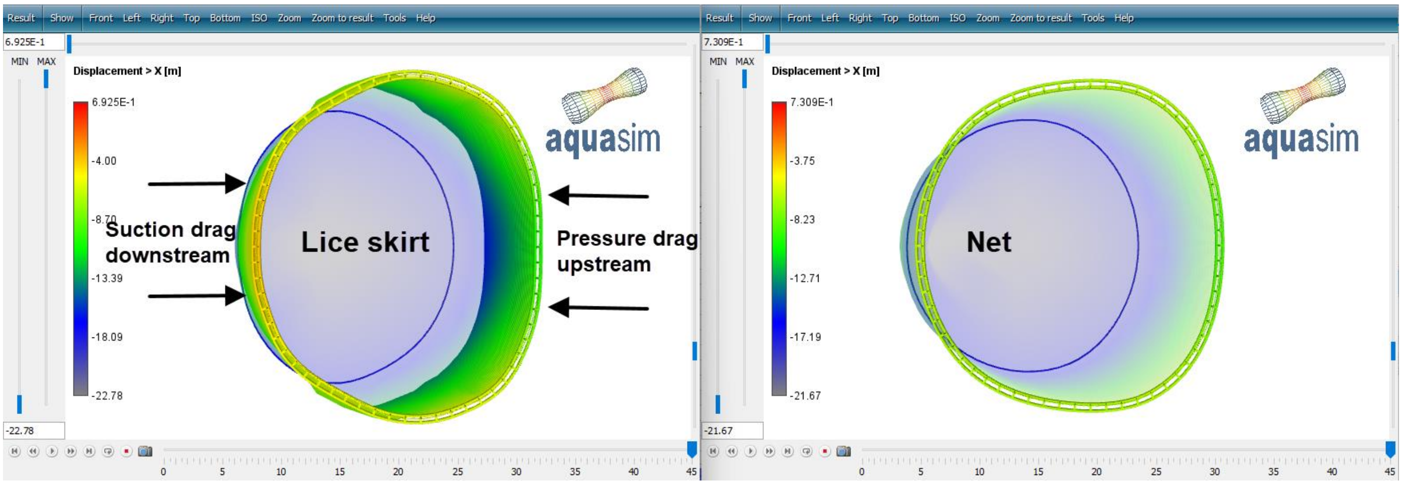

Figure 29

You can see that the model with the lice skirt has slightly more deformed shape upstream compared with the model without the lice skirt. This is due to the fluid particles are not able to flow through the impermeable lice skirt, and induces larger pressure drag upstream. At the same time, a larger suction drag is induced downstream – leading the floating collar to be pushed towards the centre of the circle that forms the lice skirt.

You may also see that the response of the floating collar is somewhat slower and more rigid in the case with the lice skirt. This is due to the trapped water inside the lice skirt – but also the water on the outside – that has to be accelerated in order for the floating collar to displace.

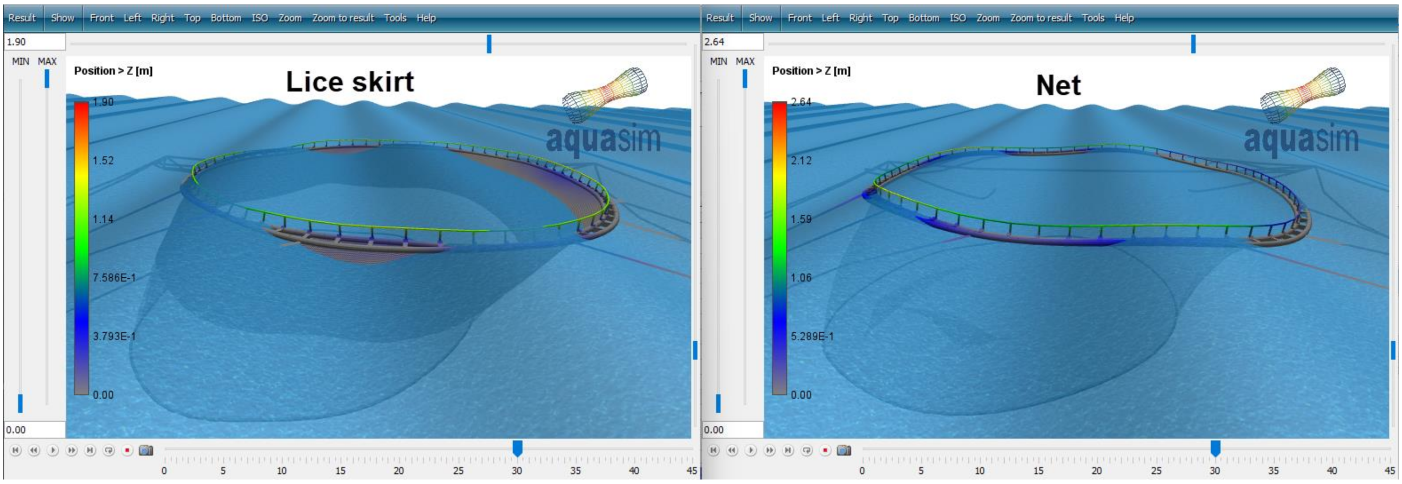

Figure 30

5.5.2 Forces in the floating collar and anchor system

Comparing von Mises stress in the floating collar, one can clearly see in the figure below that the introduction of a lice skirt has increased the load on this construction part.

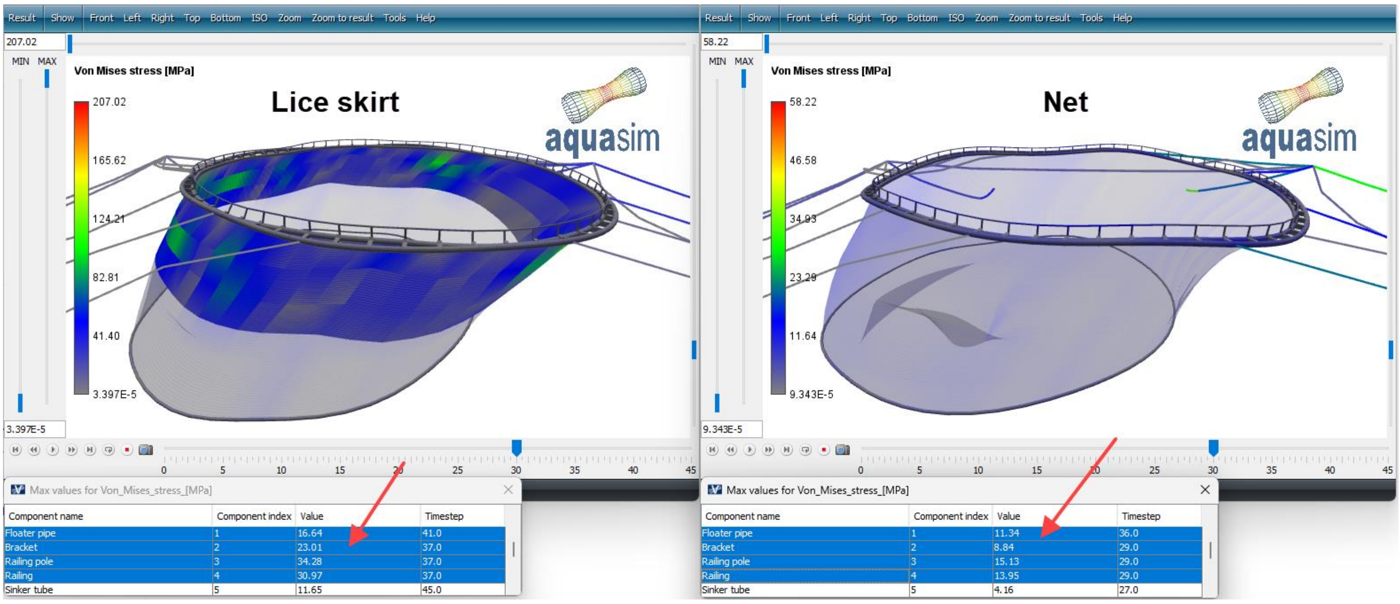

Figure 31

The same apply for the axial force in the bridles. It is important to have that in mind when planning for an anchor system.

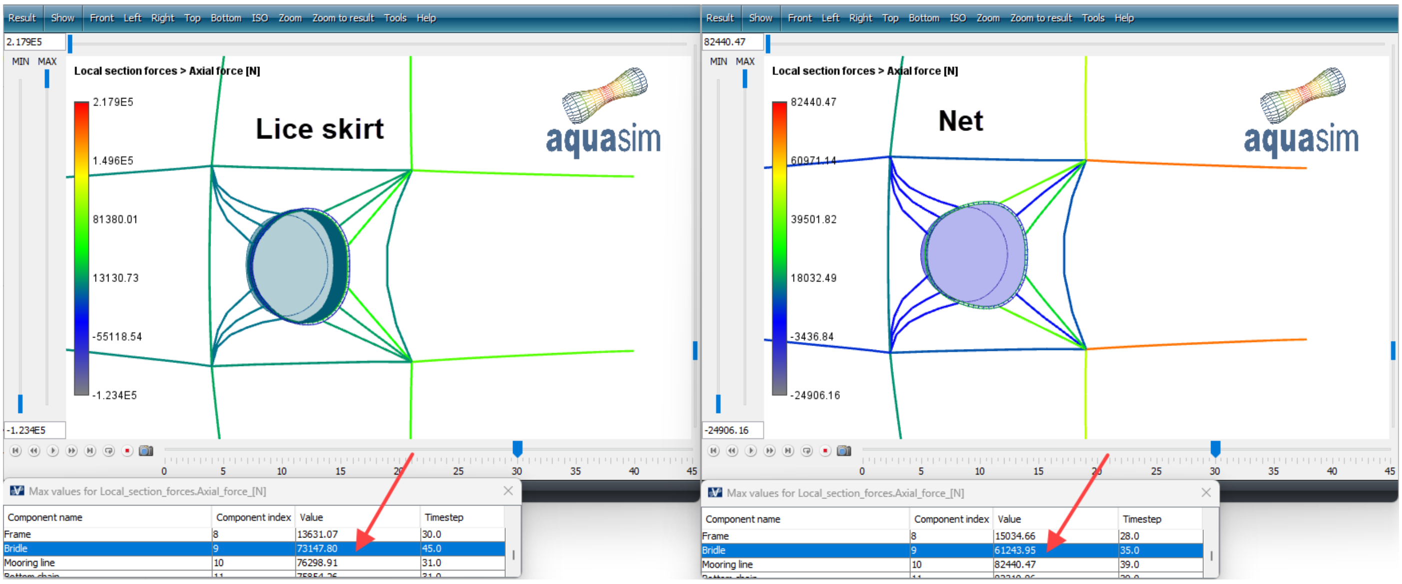

Figure 32

6 Trouble-shooting

As with all types of FEM modelling and analyses, one may encounter some challenges in terms of convergence issues and subsequent poor reliability in the analysis results. The cause of the convergence issues may be countless – it may span from improper discretization, human errors such as incorrect material data, lack of damping in your model, too much damping in your model and so on.

There is unfortunately no quick fix, or one fix for all problems that you may encounter when working with dynamic analysis. In the following sections, some suggestions to improve the quality of convergence in your model is presented. These suggestions assume that you have control over the material data for your lice skirt (and other components in your model as well).

When trouble-shooting, the user is encouraged to simplify the problem and the model in order to reduce possible sources of errors. Then conduct one change at a time, to keep track of the effect of the introduced changes.

6.1 Discretization of lice skirt panels

Building FEM-models one will always encounter the trade-off between the level of details, number of elements and access to computer power. The more comprehensive the model, the more time and effort is needed to solver the differential equations.

In some situations, too few elements (that is, membrane panels) representing the lice skirt may cause the model to be too stiff, especially in the water line where waves contribute to large response. The user may then introduce additional elements on the lice skirt in the vicinity of the water line. This is illustrated in the figure below.

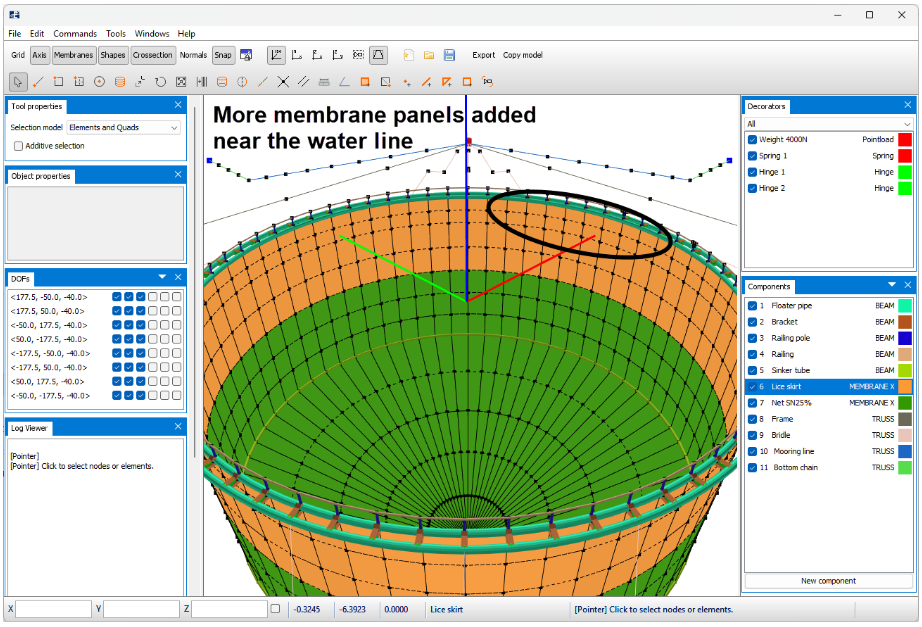

Figure 33

Have in mind, the convergence issue might as well be due to too many elements in the lice skirt. Making it to soft may introduce unrealistic large response. The user is encouraged to try either increase or decrease the number of elements in the vicinity of the water line.

6.2 Discretization of time-domain analysis

The discretization of the time-domain analysis is governed by **Num total steps for waves** and **Num steps for one wave**.

⊟ Time serie	
Preincrement	5
Max iterations pr step	1000
Num total steps for waves	40
Num steps for one wave	20
Convergence criteria	1.0
Change dynamic convergence criteria	0.0

Figure 34

For hydrodynamic problems that encounter large deformations over short period of time, it can help to increase the number of steps. This better enables AquaSim to capture differences in forces and displacements between iterations.

However, this will only have a limited effect. You will come to a point where increasing the number of steps does not have any effect – you will also have the trade-off that increased number of steps will affect the computational time of your analysis.

6.3 Convergence criteria

The **Convergence criteria** (and **Change dynamic convergence criteria**) simply explained, is the tolerance that regulates when AquaSim should be satisfied with one analysis-step and move to the next. The larger this value, the larger difference in forces and displacements are allowed between each iteration in an analysis-step.

Having this too strict or too spacious, this can make it difficult to achieve convergence in the analyses. The user may try to tighten the convergence criteria – or vice versa – to see if this improves convergence.

7 Summary

In this tutorial you have been presented in detail the different parameters that determines the loads on lice skirts, comparison of loads with and without lice skirts, and at last some trouble-shooting suggestions for your model.

The user must have in mind that dealing with hydrodynamical problems in FEM software can be a challenging task due to large deformations and complex load transfers between components. There are no one-fix for all issues that may arise. When trouble-shooting, the user is encouraged to simplify the problem and the model in order to reduce possible sources of errors. Then conduct one change at a time, in order to keep track of the effect of the introduced changes.

8 Revision comments

Revision no.	Comment
1.0	First publication

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