Lice skirt and Closed compartment

- Impermeable properties in AquaSim

TN-FOU-100004-7

Revision 2

Report no.:	TR-FOU-100004-7		
Date of this revision:	04.02.2026		
Number of pages:	29		
Distribution:	Open		
Author:	Ida Hystad	Keywords:	Lice skirt, Closed compartment

Summary:

This document presents parameters found in Impermeable properties for membrane components. This includes the following load formulations:

- Lice skirt
- Closed compartment

These are all based on the classical "Impermeable net" (Aquastructures AS, 2024) load formulation, but with individual adaptions.

Revision 2:
This version of the document is valid for AquaSim 2.22.0.

1	10.04.2024	HNM	-	First revision
2	04.02.2026	ISH	HNM	New descriptions
Revision no.	Date	Author	Verified by	Description

Content

1 Introduction

1.1 Notes on AquaSim version

This document presents the parameters found in the Impermeable properties section of the Edit membrane in AquaEdit. The descriptions are valid for the load formulations *Lice skirt* and *Closed compartment*.

As of AquaSim 2.22.0 some adjustments have been made in how the input works and consequently their names. This document provides an overview of all the parameters and information about how they work. References to more in-depth information are included where this available.

1.2 Hydrodynamic principles

In AquaSim, membrane components can be assigned impermeable characteristics. Meaning that no fluid is allowed to pass through the structure, it must find a way around or under. Let us consider some of the basic hydrodynamic principles that follow such structures. To explain these principles, we consider fluid flow around a circular structure, as shown in Figure 1.

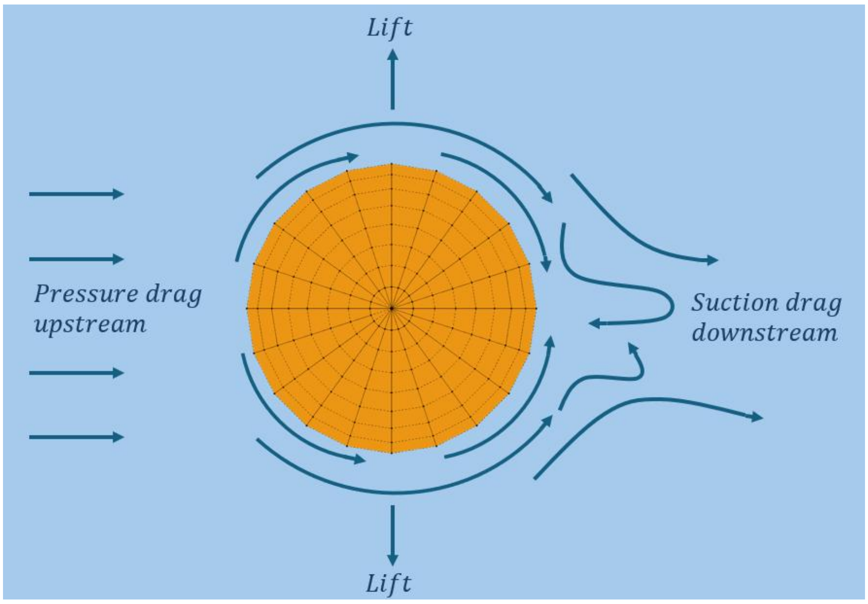

Figure 1 Pressure distribution around a circular structure

Under influence of fluid flow the cylinder will be exposed to drag- and lift forces. Drag force is exerted on the cylinder and acts in the direction of the fluid flow. It can be divided into two components: pressure drag (form drag) and skin friction drag (viscous drag). Lift force acts perpendicular to the fluid flow.

Waves that interact with the structure will be accompanied by diffraction and deformations. Diffraction is the process where waves spread perpendicular to the direction of wave propagation. These effects cause an increased pressure upstream on the structure.

1.2.1 Wave excitation loads

Hydrodynamic loads in regular waves can be categorized into two main types: *wave excitation* loads and *radiation* loads (Faltinsen, 1990):

$$F_{Hydro} = F_{EXC} + F_{RAD}$$

where F_{EXC} is the wave excitation loads and F_{RAD} is radiation.

Wave excitation loads originate from the interaction between the structure and the incident waves and are composed of *Froude-Kriloff* force (F_{FK}) and *diffraction* force F_{DIFF}:

$$F_{EXC} = F_{FK} + F_{DIFF}$$

Radiation loads originate from the motions of the structure and no incident waves, and are normally expressed in terms of added mass and damping:

$$F_{RAD} = -F_{AddedMass} - F_{Damping}$$

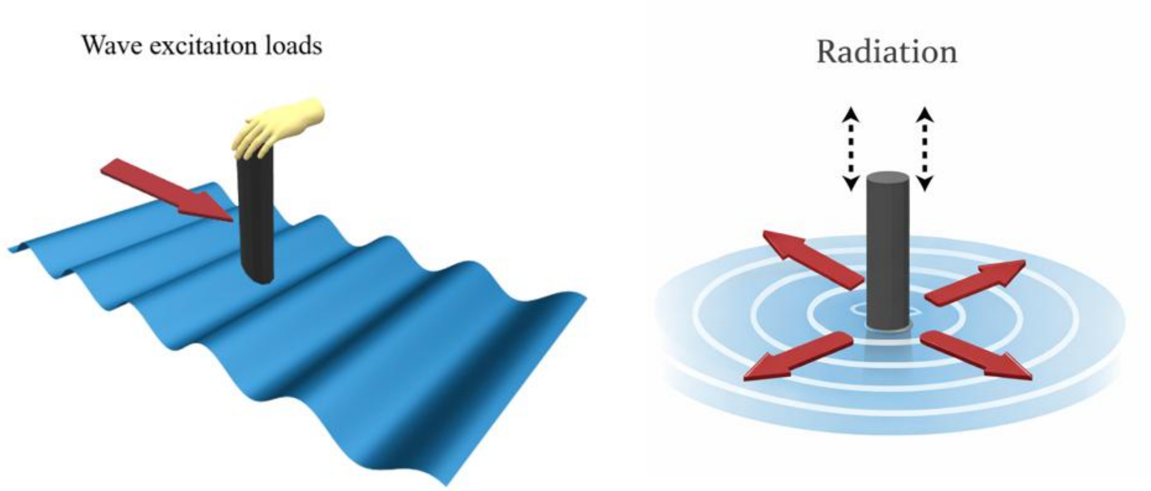

Figure 2 Wave excitation loads (structure restrained) and Radiation (structure forced to move)

1.3 Modelling principles

AquaSim keeps track of every membrane panel's position and whether they are located upstream of downstream of a fluid flow. One of the basic assumptions for *Lice skirt* and *Closed compartment* are circular structure. By this, AquaSim is able to distribute the pressure field around the structure in a realistic manner.

A consequence of AquaSim being able to keep track of what is upstream and downstream, is that each structure must be modelled as its own component group. This is exemplified by a model of aquaculture cages with lice skirts modelled in separate component groups in Figure 3.

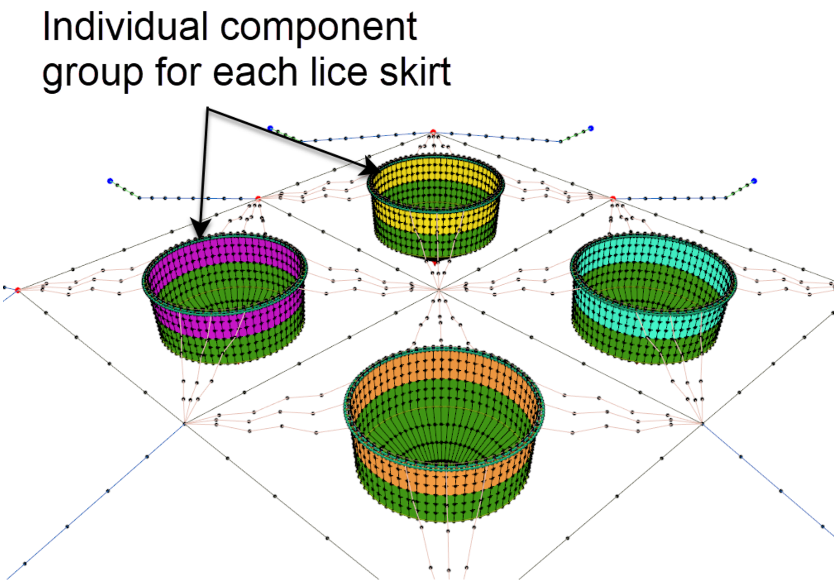

Figure 3 Example of modelling structures in individual component groups

2 Definitions

2.1 Coordinate system

AquaSim operates with a global coordinate system and local for each modelled membrane panel. Consider a membrane panel as shown in Figure 4. For the membrane panel a right-handed local system is defined, where the local z-axis points out of the plane (blue line). This is the crossflow direction (also known as the normal direction). The x- and y-axis is in-plane and defines the tangential direction. The numerical model is defined with respect to the global coordinate system.

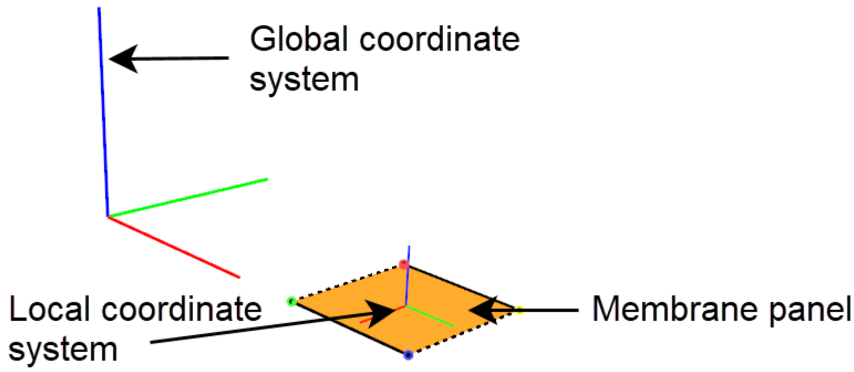

Figure 4 Global and local coordinate systems

Forces that are calculated with respect to the local coordinate system are denoted **normal** and **tangential**. Forces calculated with respect to the global coordinate system are denoted **horizontal** (global xy-plane) and **vertical** (z-axis).

2.2 Inside and outside definition

When working with models with enclosed volumes – such as lice skirts, tanks etc. – it is important to keep track of what is considered the inside and outside of the volume. This is because AquaSim facilitate defining hydrostatic- and -dynamic parameters for fluid within the enclosure and outside.

The normal vector (blue line) of each panel should **point into the interior** of the system, as illustrated in Figure 5.

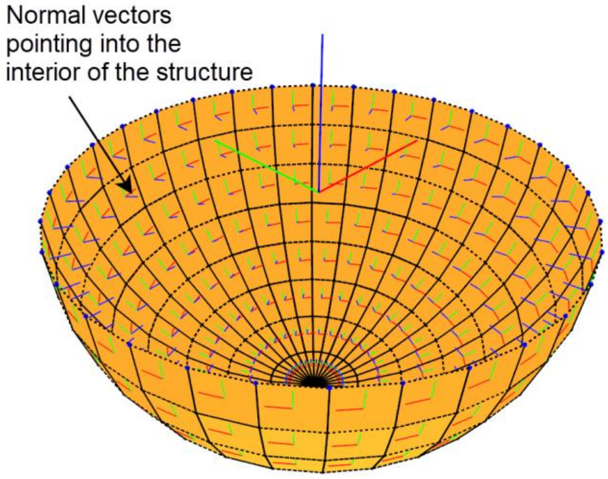

Figure 5 Normal vectors (small blue lines) pointing into the interior

Another useful tool to verify orientation of all panels, is the function *Membrane side* found in AquaEdit. Where the side that faces out towards the external fluid will be coloured with a shade of blue, and the sides facing towards the interior will be coloured with a shade of red.

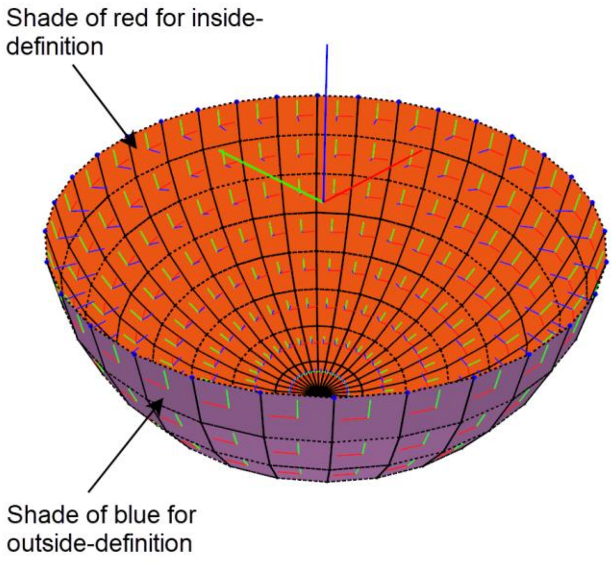

Figure 6 Inside- and outside definitions

3 Fluid parameters inside tank

The *Fluid parameters inside tank* specifies the properties of the fluid enclosed by an impermeable structure. These parameters define how the internal fluid contributes to the overall hydrostatic pressure, internal dynamic mass and response between the structure and fluid inside it.

3.1 Density of fluid inside enclosed volume

This is the density of the fluid inside the enclosed volume. Consider a closed tank as shown in Figure 7, the fluid on the inside of this tank can be assigned another density than on the outside. Default in AquaEdit is that this corresponds to the density of seawater of 1025 kg/m^3, but this can be changed.

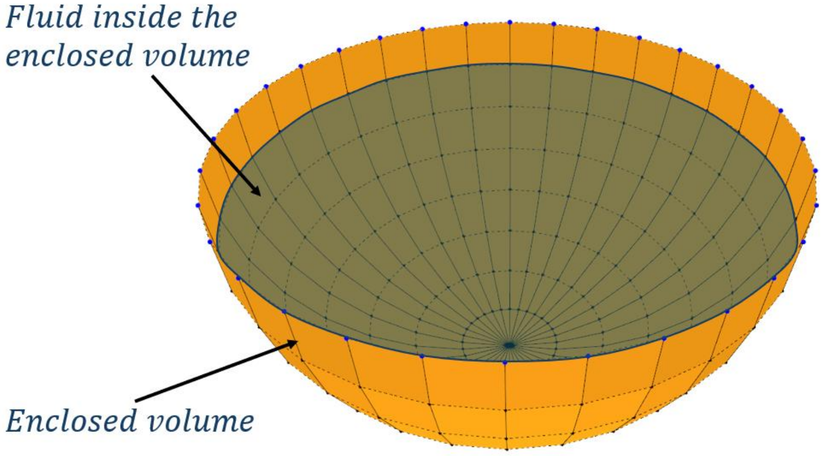

Figure 7 Density of fluid inside enclosed volume

The pressure on the outside is calculated based on this value. The external pressure is calculated based on density of sea water, 1025 kg/m^3. The mass of the fluid inside the enclosed volume is distributed to the panel elements, such that all mass acts normal to each panel. Horizontally the mass is distributed evenly on the sides of the enclosed volume. Vertically, the height of the waterline on the inside is derived, and the mass is the amount of water to this surface.

3.2 Height of fluid level inside enclosed volume relative to sea level

This defines the height of the water line (positive upwards) inside the enclosed volume relative to the outside waterline. It contributes to determine the volume of the fluid inside. It is the water line in the drawn non-deformed structure. The fluid volume is considered constant through the analysis, such that if the structure deforms the height of this fluid level will increase or decrease. In Figure 8, this height is denoted h.

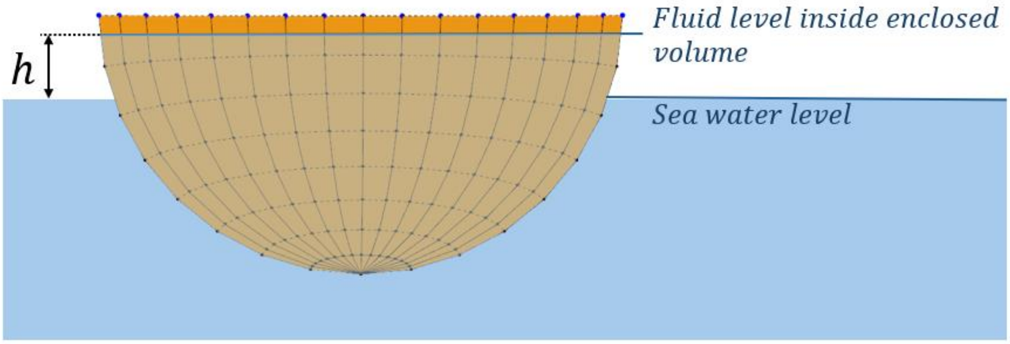

Figure 8 Heigh of fluid level inside enclosed volume relative to sea level, 'h'

Positive values mean the inside water level is higher relative to the outside sea water. Negative values mean the inside water level is lower relative to the outside sea water. Zero means that both fluid levels are aligned.

3.3 Free surface area of internal waterline

When the enclosure deform – due to e.g. waves and current – it will deform and the volume changes. This change in volume will in turn cause the water level of the fluid inside to either increase or decrease. The *Free surface area of internal waterline* is then the area the fluid is assumed to be pushed through.

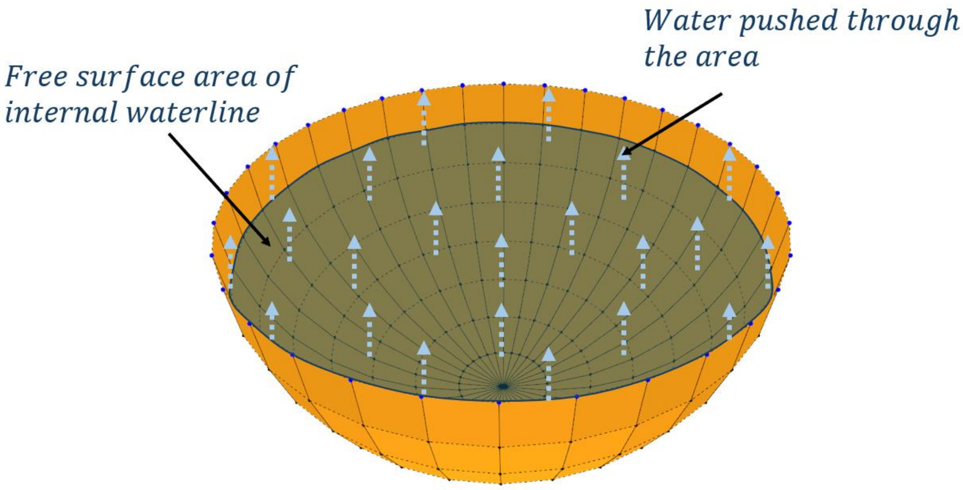

Figure 9 Free surface area of internal waterline

This parameter is important to achieve correct stiffness of your structure.

3.4 Distance from water line to panel edge

This parameter is useful in situations where you want the inside fluid to be able to pour out of the enclosure. The water will pour out if this value is exceeded (this is relative to the lowest point of the upper edge across the enclosure). This height can exceed the actual modelled panel height. Note that there is no mechanism working the other way, meaning that the total water volume in the enclosure can only decrease during the analysis. Consider section view of the closed volume in Figure 10, this distance is denoted H.

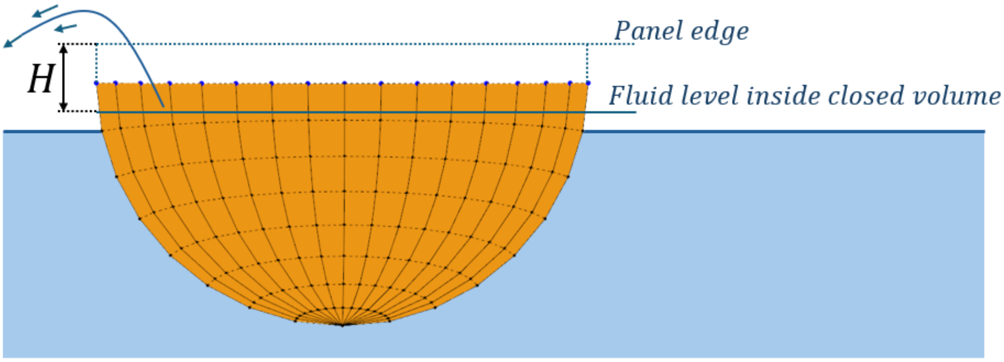

Figure 10 Distance from water line to panel edge, 'H'

By default, this parameter is 0.0. In this case the height of the panel edge is numerically interpreted as infinite in heigh.

3.5 Scaling factor, fluid mass horizontal

This parameter determines how much of the fluid inside the enclosed volume that should move **horizontally** (in the global xy-plane) with the structure, see Figure 11.

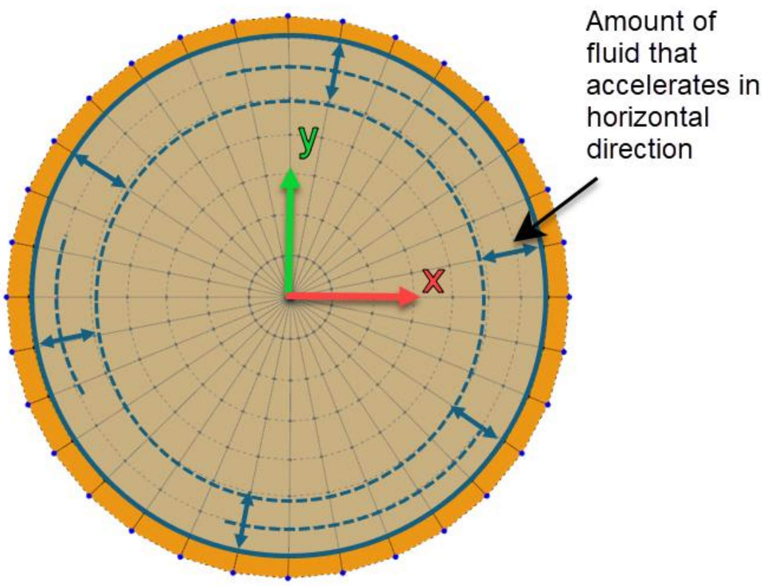

Figure 11 Fluid inside enclosed volume that move horizontally with the structure

AquaSim keeps track of the panel's position and finds the distance to the structure's geometric centreline (see Figure 12), this is called the "horizontal radius inner fluid mass". This distance forms the basis for how much fluid mass is applied to the element in horizontal direction. The parameter *Scaling factor, fluid mass horizontal* scales this radius and is a number between 0.0 and 1.0. Meaning, if this factor is 0.0 no fluid mass is added to the panel, and if 1.0 the full radius is applied for adding fluid mass to the element.

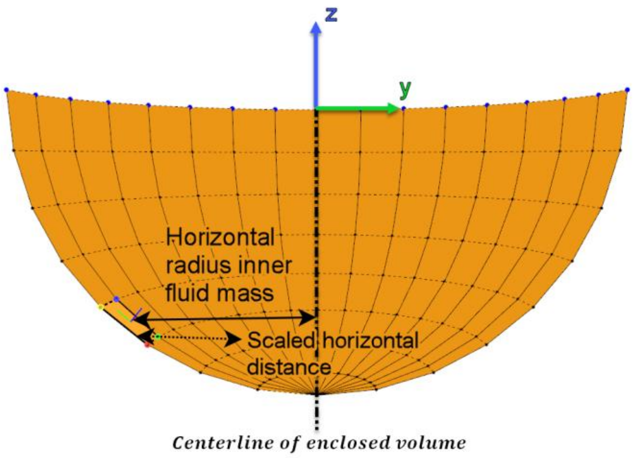

Figure 12 Horizontal distance from a panel to the geometric centreline

3.6 Scaling factor, fluid mass vertical

This parameter determines how much of the fluid inside the enclosed volume that should move **vertically** (in the global z-direction) with the structure, see Figure 13.

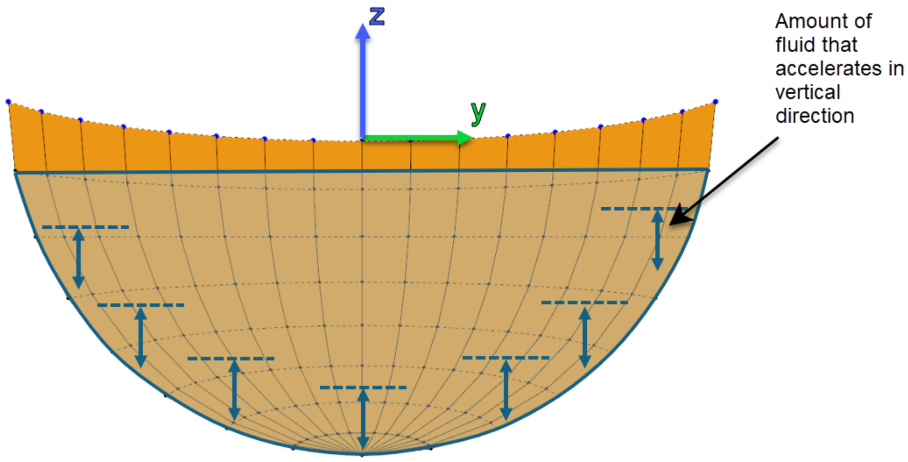

Figure 13 Fluid inside enclosed volume that moves vertically with the structure

AquaSim keep track of the panel's position and finds the vertical distance to the water line inside the structure (see Figure 14). This distance forms the basis for how much fluid mass is applied to the panel in vertical direction. The parameter *Scaling factor, fluid mass vertical* is a factor that scales this distance and is a number between 0.0 and 1.0. If this factor is 0.0 no fluid is added to the panel, and if 1.0 the full distance is applied for adding fluid mass to the element.

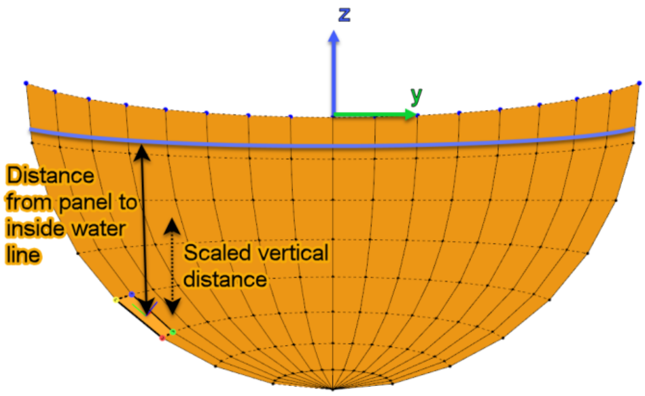

Figure 14 Vertical distance from a panel to the waterline of inside fluid enclosed volume

3.7 Horizontal radius inner fluid mass

This is the horizontal distance from each panel to the geometric centreline of the structure. It is applied to calculate added mass on the outside of the structure. It works as follows:

- If set to 0.0: it means that AquaSim calculates where the geometric centreline of the structure is and then finds the horizontal distance (or radius) from each panel to the centreline. This distance is applied in the calculation of the internal dynamic mass of the enclosed volume for each panel. See the leftmost illustration in Figure 15. Note that the distance to the centreline of the structure horizontally is weighted by multiplying the normalised horizontal position vector with the normalised horizontal normal vector of the element, such that for a square box, the radius is equal to the horizontal main dimensions.
- If this is a positive value: then this value is applied as the horizontal inner radius for all panels, irrespectively as to where the panels are located with respect to the centreline. See the rightmost illustration in Figure 15.

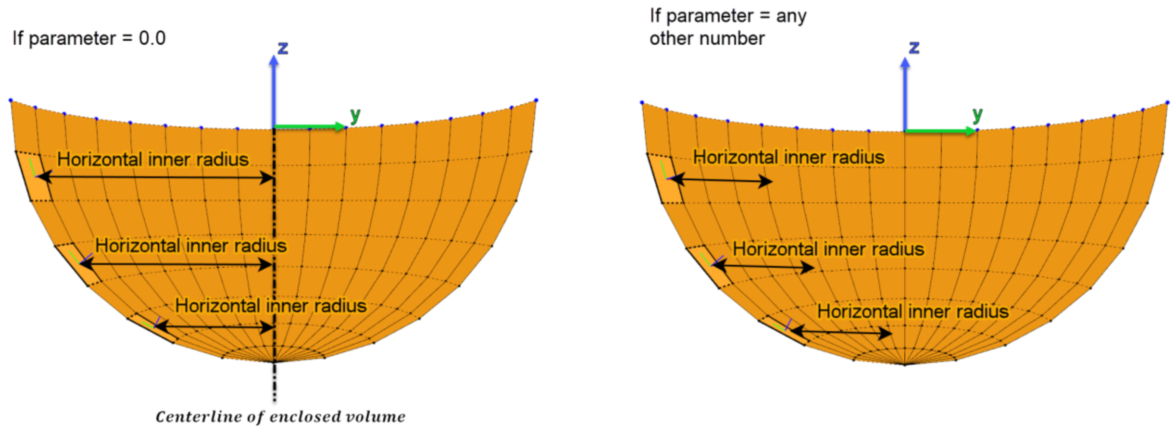

Figure 15 Horizontal radius inner fluid mass

4 Drag

Drag loads arise due to viscosity (frictional drag), flow separation and pressure differences (form drag).

The *Drag* section defines the hydrodynamic resistance and lift characteristics acting on the panels due to fluid flow. The upstream- and downstream drag coefficients represents the form drag associated with the fluid flow on the outside of the enclosed volume. The skin friction coefficient account for drag that arise tangential to the panel. The lift coefficient accounts for any transverse or lifting forces that arise due to flow asymmetry or panel orientation.

Drag-, frictional- and lift force definitions, as well as upstream and downstream definitions are presented in Figure 16.

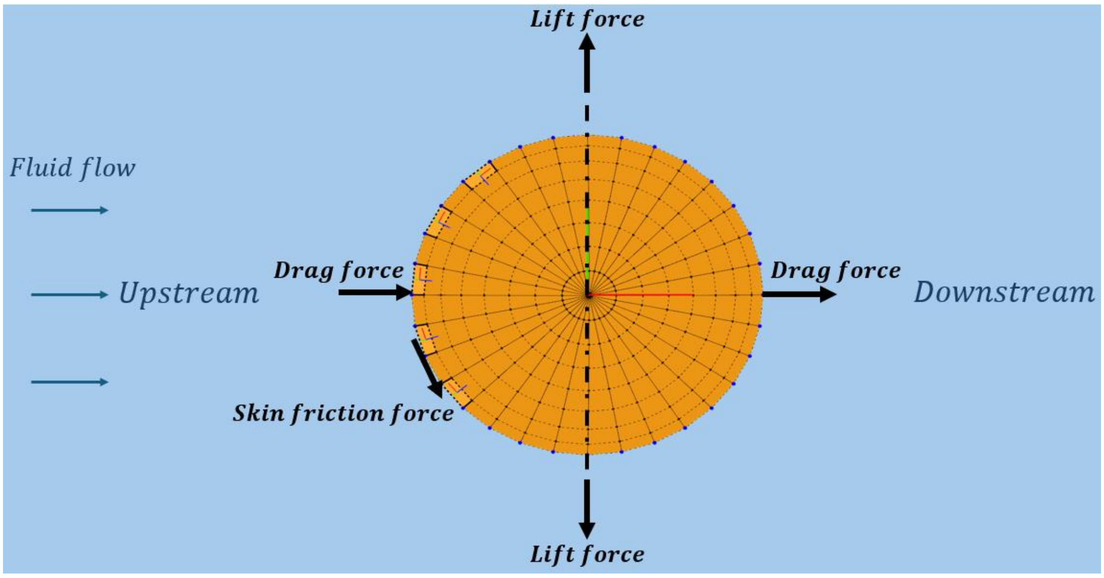

Figure 16 Definition of forces global on the structure

The **relative velocity** between the fluid flow and structure forms the basis for calculation of drag-, frictional- and lift forces.

4.1 Drag coefficient upstream

The *Drag coefficient upstream* scales the form drag on panels that are upstream of a fluid flow. AquaSim decompose the relative velocity to a normal- and tangential component for each panel, as illustrated in Figure 17. *Drag coefficient upstream* then scales the drag force due to the normal component of the relative velocity, as well as the total relative velocity, on the upstream side of the structure.

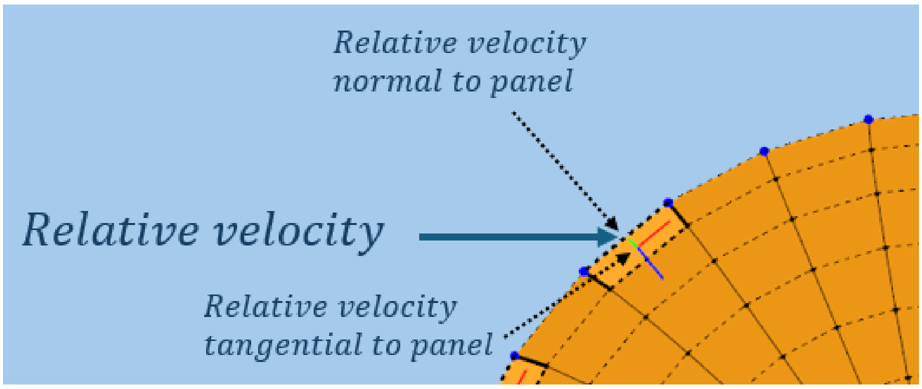

Figure 17 Relative velocity normal- and tangential to panel

4.2 Drag coefficient downstream

The *Drag coefficient downstream* scales the form drag on panels that are downstream of a fluid flow. AquaSim decompose the relative velocity to a normal- and tangential component for each panel, as illustrated in Figure 17. The *Drag coefficient downstream* then scales the drag force due to the normal component of the relative velocity, as well as the total relative velocity, on the downstream (leeward side) side of the structure.

4.3 Skin friction coefficient

The *Skin friction coefficient* accounts for tangential resistance from viscous resistance due to e.g. surface roughness of the structure. AquaSim decompose the relative velocity to a normal- and tangential component for each panel, as illustrated in Figure 17. The *Skin friction coefficient* then scales the skin friction force applying the tangential component of relative velocity on the structure.

4.4 Lift coefficient

The *Lift coefficient* scales the lift force that acts perpendicular to the fluid flow direction. Lift force arises when a flow around a structure is asymmetric, creating a pressure difference between structure sides. AquaSim apply the normal component of the relative velocity, as well as the total relative velocity, to calculate the lift force on a panel. The direction of the lift force is illustrated in Figure 16.

4.5 Notes on drag, skin friction and lift

The total drag-, skin friction- and lift forces is then found by integrating the local force over the entire structure. More theoretical description of how this works is found in (Aquastructures AS, 2024).

5 Wave excitation loads

This section presents the input parameters for wave induced forces. AquaSim provides several methods for how this can be calculated, based on the rigidity of the investigated structure. Some of the methods are adapted to highly flexible structures, other for rigid-body structures, and semi-rigid structures.

For more in-depth information, reference is made to (Aquastructures AS, 2024) or our library of tutorials on the AquaSim webpage https://aquasim.no/documentation.html.

5.1 Load formulation

A load formulation defines how loads should be calculated. For example, how external forces, pressure and other types of loads should be applied to the structure. The different load formulations are adapted for specific purposes or structures. In AquaSim the load formulations found in *Impermeable properties* defines a set of equations and numerically how these equations should be applied to each panel, in addition to what type of forces is accounted for.

The different types of load formulations are summarized in tabular form in Table 1.

Table 1 Load formulations found in Impermeable properties

Aspects	**Flexible tarp**	**MacCamy-Fuchs**	**Numerical diffraction**	**Hybrid flexible tarp/ Numerical diffraction**	**Hybrid flexible tarp/ MacCamy-Fuchs**
Theory	Adapted for flexible woven textiles. Follows wave fluid particle motion.	Adapted for rigid structures. Apply theory from (R. MacCamy, 1954). Apply Bessel functions to model diffraction effects.	Numerical method NEMOH (A. Babarit, 2015) applied to calculate. Surface is discretized to calculate velocity potential (potential theory).	Combination of Flexible tarp- and Numerical diffraction methods. The methods are weighted through “Diffraction scaling”.	Combination of Flexible tarp- and MacCamy-Fuchs methods. The methods are weighted through “Diffraction scaling”.
Load terms included	Froude-Kriloff pressure horizontally and modified Froude-Kriloff pressure vertically. Flexible tarp damping horizontally and vertically. Simplified added mass and hydrodynamic damping.	Froude-Kriloff pressure and diffraction horizontally. Only Froude-Kriloff pressure vertically. Simplified added mass and hydrodynamic damping.	Froude-Kriloff pressure, diffraction, added mass and hydrodynamic damping.	Weighted fraction of Froude-Kriloff (Flexible tarp) and Froude-Kriloff, diffraction, added mass and damping (Numerical diffraction).	Weighted fraction of Froude-Kriloff (Flexible tarp) and Froude-Kriloff and diffraction (MacCamy-Fuchs)

Limitations	Diffraction forces are omitted. Hence, this formulation is not suitable for rigid structures. Loads may be underestimated if applied to rigid structures. With option of adding radiation (added mass and damping) separately.	Fully rigid structures. Solves wave potential around a fixed, bottom mounted vertical cylinder in infinite water depth. With option of adding radiation (added mass and damping) separately.	Handles complex geometries and multi-body interactions at finite water depth. More flexible compared to analytical methods. Radiation forces are found numerically, meaning added mass- and damping coefficients works as scaling factor. Factors of 1.0 means the proposed solution from NEMOH is applied.	Accuracy depends on the structures' rigidity/ flexibility and chosen scaling factor for weighing the two methods.	Accuracy depends on the structures' rigidity/ flexibility and chosen scaling factor for weighing the two methods. With option of adding radiation (added mass and damping) separately.
Linear/ nonlinear	Linear but includes the nonlinear effect arising from in and out of water. Option to add the nonlinear velocity term in Bernoulli which means that the terms for calculation of mean drift are included except from the velocities originating from radiation. .	Linear but includes the nonlinear effect arising from in and out of water, assuming small wave amplitudes and that fluid motion and pressure field vary linearly with wave amplitude. Corresponding option to add drift, as for Flexible Tarp.	Linear but includes the nonlinear effect arising from in and out of water, assuming linear waves. Corresponding option to add drift, as for Flexible Tarp.	Linear but includes the nonlinear effect arising from in and out of water. Corresponding option to add drift, as for Flexible Tarp.	Linear but includes the nonlinear effect arising from in and out of water. Corresponding option to add drift, as for Flexible Tarp.
Implementation	Analytical formulas	Analytical, closed form series	Numerical results calculated from NEMOH.	Analytical (Flexible tarp) and numerical (Numerical diffraction)	Analytical
Typical areas of application	For highly damping-dominated structures such as lice skirts, tarpaulins, tubes and so.	Stiff vertical cylinders, monopiles, other stiff floating containers.	Large volume structures, rigid bodies such as pontoons, barges, cages.	Semi-flexible structures.	Semi-flexible circular structures.

5.2 Scaling factor (Hybrid) and Hybrid load formulation

This parameter is available when one of the two hybrid load formulations are selected. It scales how much of each method should be applied in the calculation of wave excitation loads, added mass and damping. Two hybrid options are available:

- **Hybrid flexible tarp/ Numerical diffraction:** combines the Flexible tarp method with the Numerical diffraction load formulation.
- **Hybrid flexible tarp/ MacCamy-Fuchs:** combines the Flexible tarp method with the MacCamy-Fuchs load formulation.

Both hybrid methods work with the same principle: the wave excitation loads are calculated as a weighted combination of the two load formulations. The weighting, or scaling, is defined through the factor “Diffraction scaling” in AquaSim. For example, selecting Hybrid flexible tarp/numerical diffraction with a “Diffraction scaling” factor of 0.25 imply:

- 75% of wave excitation loads are found from the “Flexible tarp” method.
- 25% wave excitation loads are found from the “Numerical diffraction” method.

The same relation is applied for radiation loads (added mass and damping) in AquaEdit. That is, if diffraction scaling is 0.25 then added mass- and hydrodynamic damping coefficients will be 0.25. The damping coefficient (flexible tarp) normal will be 0.75. This is illustrated in Figure 18.

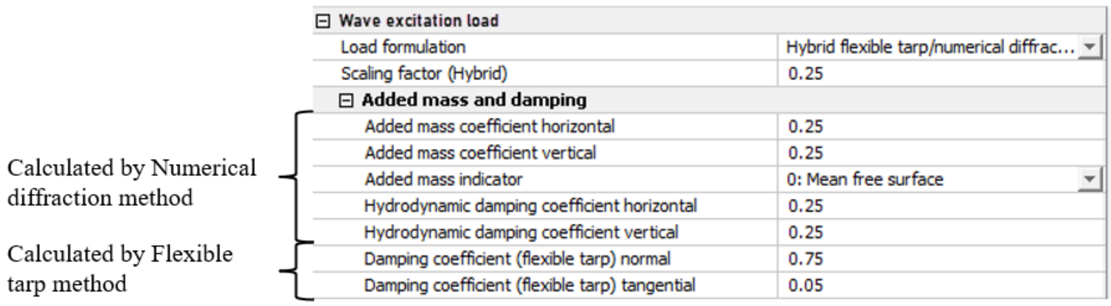

Figure 18 Hybrid model for calculation of wave excitation- and radiation loads

5.3 Added mass coefficient horizontal

This parameter is a scaling factor for the added mass force outside of the enclosed volume in **horizontal** direction (global xy-plane). Added mass occurs because when a structure moves in a surrounding fluid, it also has to **accelerate** some of the fluid, see Figure 19. The accelerated fluid will move with the structure. This is an inertial force.

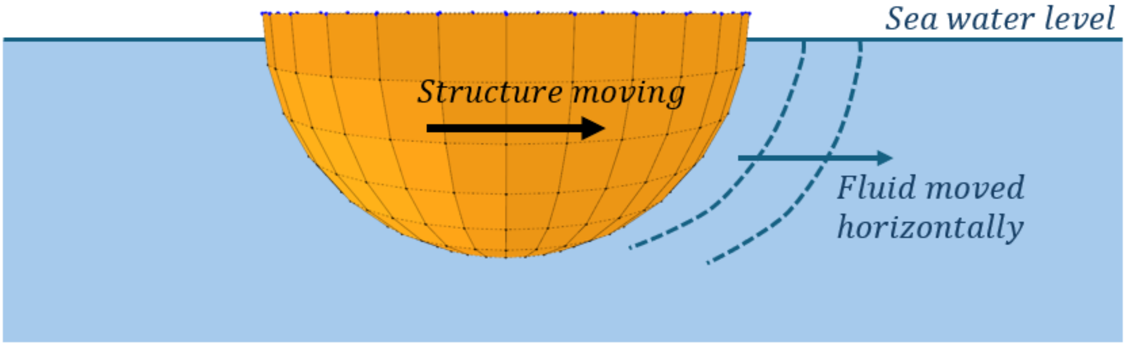

Figure 19 Added mass in horizontal direction (global xy-plane)

5.3.1 Flexible tarp and MacCamy-Fuchs

When applying the load formulations *Flexible tarp* and *MacCamy-Fuchs* the horizontal added mass can be expressed as:

$$F_{Amass-XY} = \frac{F}{a} = \rho C_{a-XY} RA \ \ [Ns2/m]$$

where ρ is density of sea water (1025kg/m3), C_{a-XY} is the added mass coefficient in horizontal direction, R is the *Horizontal radius inner fluid mass*, and A is the wetted area of an individual panel.

5.3.2 Numerical diffraction

Numerical diffraction calculates hydrodynamic forces applying the open-source NEMOH algorithm. It is based on linear potential flow theory and solves the hydrodynamic boundary value problem by distributing sinks and sources on the panels.

Applying *Numerical diffraction,* the *Added mass horizontal* acts as a scaling factor for the horizontal part of the added mass returned by NEMOH.

5.4 Added mass coefficient vertical

This parameter is a scaling factor for the added mass force outside of the enclosed volume in the **vertical** direction (global z-direction), see Figure 20. This added mass occurs when the structure moves in the vertical direction and **accelerates** surrounding fluid.

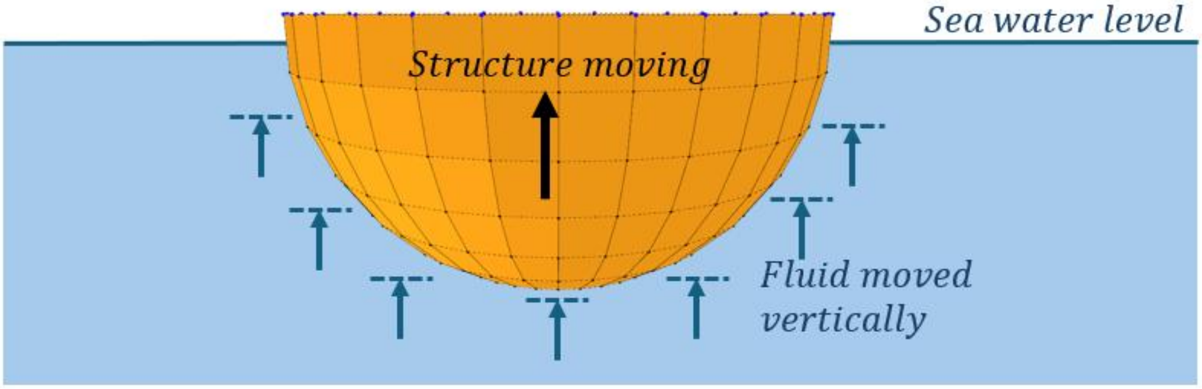

Figure 20 Added mass in vertical direction (global z-direction)

5.4.1 Flexible tarp and MacCamy-Fuchs

When applying the load formulations *Flexible tarp* and *MacCamy-Fuchs*, the vertical added mass can be expressed as:

$$F_{Amass-Z} = \frac{F}{a} = \rho C_{a-Z} H A \;\; [Ns2/m]$$

where ρ is density of sea water (1025kg/m3), C_{a-Z} is the added mass coefficient in vertical direction, H is the vertical distance from an individual panel to the sea water line, and A is the wetted area of an individual panel.

5.4.2 Numerical diffraction

Numerical diffraction calculates hydrodynamic forces applying the open-source NEMOH algorithm. It is based on linear potential flow theory and solves the hydrodynamic boundary value problem by distributing sinks and sources on the panels.

Applying *Numerical diffraction,* the *Added mass vertical* acts as a scaling factor for the vertical part of the added mass returned by NEMOH.

5.5 Added mass indicator

The *Added mass indicator* decides how the added mass should behave with respect to the waterline on the outside of the enclosed volume. Several options are available – the user can choose to find the added mass calculated to the mean free surface in steady state condition or use the actual water line including the wave elevation during the analysis. The two methods are illustrated in Figure 21.

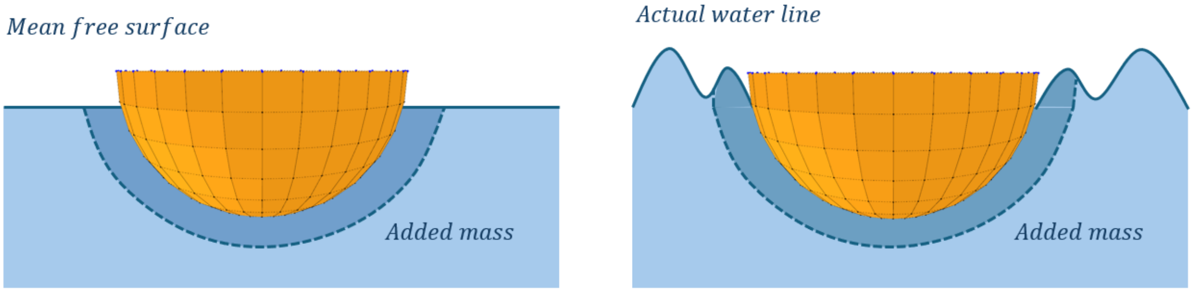

Figure 21 Added mass indicator

5.6 Hydrodynamic damping coefficient horizontal

The *Hydrodynamic damping coefficient horizontal* scales damping force outside the enclosed volume in **horizontal** direction (global xy-plane). Hydrodynamic damping is a force that opposes the motion of the structure in fluid. This type of damping is considered a resistive effect that arise from fluid motion relative to the structure and wave generation; hence it depends on **velocity**.

5.6.1 Flexible tarp and MacCamy-Fuchs

When applying the load formulations *Flexible tarp* and *MacCamy-Fuchs*, the horizontal damping can be expressed as:

$$F_{Damp-XY} = \frac{F}{u} = \rho C_{b-XY} RA \; [Ns/m]$$

where ρ is density of sea water (1025kg/m3), C_{b-XY} is the hydrodynamic damping coefficient in horizontal direction, R is the *Horizontal radius inner fluid mass*, and A is the wetted area of an individual panel.

5.6.2 Numerical diffraction

Numerical diffraction calculates hydrodynamic forces applying the open-source NEMOH algorithm. It is based on linear potential flow theory and solves the hydrodynamic boundary value problem by distributing sinks and sources on the panels.

Applying *Numerical diffraction,* the *Hydrodynamic damping coefficient horizontal* acts as a scaling factor for the horizontal part of the hydrodynamic damping returned by NEMOH.

5.7 Hydrodynamic damping coefficient vertical

The *Hydrodynamic damping coefficient vertical* scales the damping force outside the enclosed volume in **vertical** direction (global z-direction). This damping force occurs due to relative **velocity** between the fluid flow and structure, and wave generation.

5.7.1 Flexible tarp and MacCamy-Fuchs

When applying the load formulations *Flexible tarp* and *MacCamy-Fuchs*, the vertical damping can be expressed as:

$$F_{Damp-Z} = \frac{F}{u} = \rho C_{b-z} HA \; [Ns/m]$$

where ρ is density of sea water (1025kg/m3), C_{b-z} is the hydrodynamic damping coefficient in vertical direction, H is the vertical distance from an individual panel to the sea water line, and A is the wetted area of an individual panel.

5.7.2 Numerical diffraction

Numerical diffraction calculates hydrodynamic forces applying the open-source NEMOH algorithm. It is based on linear potential flow theory and solves the hydrodynamic boundary value problem by distributing sinks and sources on the panels.

Applying *Numerical diffraction,* the *Hydrodynamic damping coefficient vertical* acts as a scaling factor for the vertical part of the hydrodynamic damping returned by NEMOH.

5.8 Damping coefficient (flexible tarp) normal

The *Damping coefficient (flexible tarp) normal* acts as a scaling factor for damping on structural response. This damping force is applied normal to each panel, in the local coordinate system. A value of 1.0 corresponds to a condition where the panel motion follows the wave particle motions, implying that there is no relative motion between the panel and the surrounding fluid in normal direction.

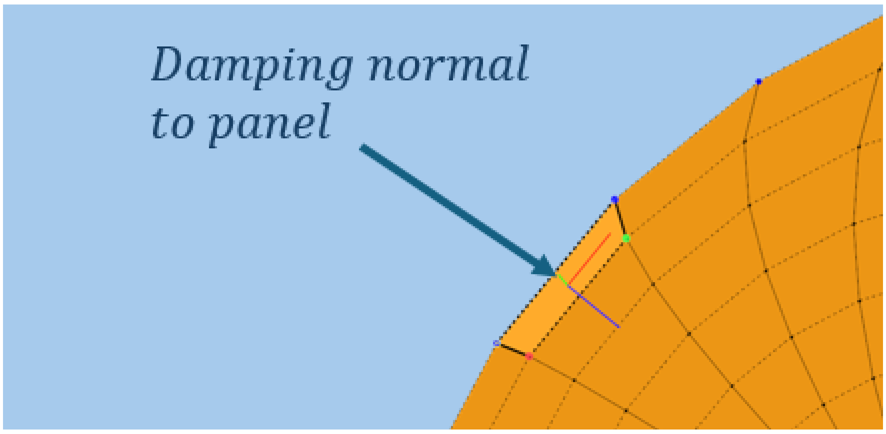

Figure 22 Damping coefficient (flexible tarp) normal

Generally, this damping can be expressed as:

$$F_{Damp-N} = \frac{F}{u} = AC_{b-N}\frac{\rho g}{\omega}\ [Ns/m]$$

where A is the wetted surface area of the panel, C_{b-N} is the *Damping coefficient (flexible tarp) normal*, ρ is density of sea water (1025kg/m3), g is gravitational acceleration, and ω is wave frequency.

5.9 Damping coefficient (flexible tarp) tangential

The *Damping coefficient (flexible tarp) tangential* acts as a scaling factor for damping on structural response. This damping is applied tangential to each panel, in the local coordinate system. Generally, damping in this direction is considered small compared to the normal direction. However, for numerical stability of the analysis it is recommended to apply some damping in tangential direction, for example a coefficient of 0.05.

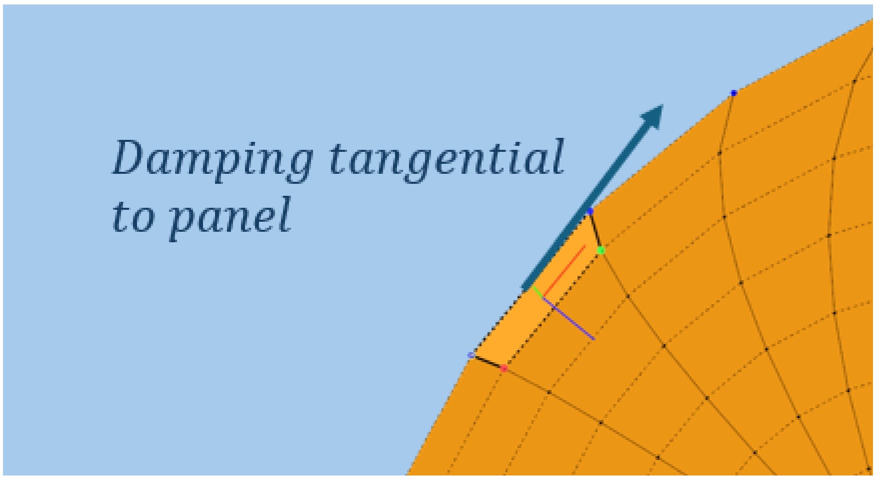

Figure 23 Damping coefficient (flexible tarp) tangential

This damping is derived from the damping in normal direction:

$$F_{Damp-T} = \frac{F}{u} = F_{Damp-N} \cdot C_{b-T}\ [Ns/m]$$

$$F_{Damp-T} = \frac{F}{u} = AC_{b-T}\frac{\rho g}{\omega}\ [Ns/m]$$

where F_{Damp-N} is damping force normal to the panel, and C_{b-T} is the *Damping coefficient (flexible tarp) tangential*. A is the wetted surface area of the panel, C_{b-T} is the *Damping coefficient (flexible tarp) tangential*, ρ is density of sea water (1025kg/m3), g is gravitational acceleration, and ω is wave frequency.

6 Advanced

The *Advanced* section contains parameters to modify how environmental loads from waves and current should be applied to the structure. These options allow the user to adjust or refine the hydrodynamic load model beyond the standard methods.

6.1 Wave amplitude reduction

The *Wave amplitude reduction* is a scaling factor for decreasing the incident wave amplitude acting on a structure due to the presence of other objects in the surrounding environment. The factor is dimensionless, and ranges between 0.0 and 1.0:

- A value of 0.0 indicates no reduction of the incident wave amplitude on the structure.
- A value of 1.0 represents full reduction of the incident wave amplitude.

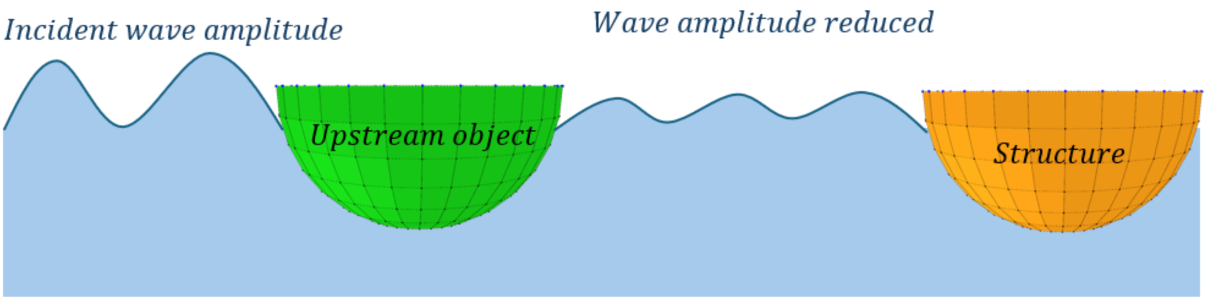

Figure 24 Wave amplitude reduction

6.2 Current reduction

The Current reduction is a scaling factor that decrease the current velocity acting on a structure due to the presence of other objects in the surrounding environment. The factor is dimensionless, and ranges between 0.0 and 1.0:

- A value of 0.0 indicates no reduction of the current velocity.
- A value of 1.0 represents full reduction of the current velocity.

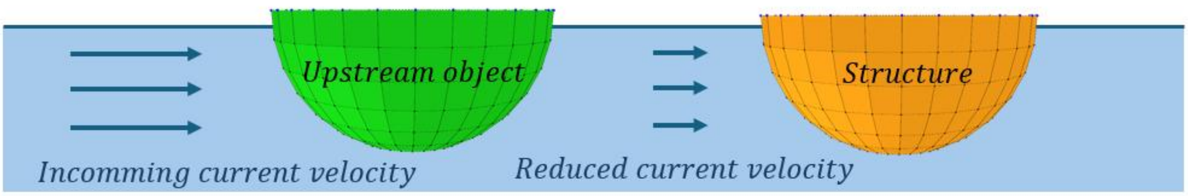

Figure 25 Current reduction

6.3 Include drift

Drift forces refer to the time-average (mean) second-order hydrodynamic forces exerted on a structure. These forces arise from non-linear wave-structure interactions, mainly due to reflection of wave energy. The magnitude of these forces depends on amongst others the waterplane area, geometry and structural stiffness. Slender structures relative to the wavelength and flexible structures tend to not disturb the incident waves and thus transmit more of the incident wave energy and therefore experience smaller drift forces. Whereas large and stiff structures reflect a greater portion of the wave energy and consequently results in greater drift forces. Over time, these forces can lead to a slowly varying displacements, or drift motion, of the structure, as well as the drift forces themselves might vary over time resulting in slowly varying drift forces.

Since hydrodynamic loads are computed to the instantaneous free surface, some of the drift force will always be included in the analysis. However, when selecting *Include drift*, AquaSim also includes the velocity-squared term from Bernoulli's equation. The drift forces calculated in AquaSim are based on the combined pressure from incident and diffracted waves, meaning that the contribution from radiated waves is not accounted for.

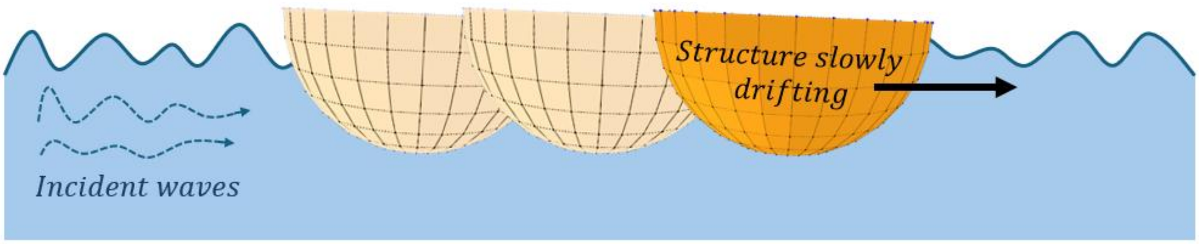

Figure 26 Include drift

Note that *Water volume correction* in the Export-window must be set to *With slamming* to include the drift-terms in the calculations. For more information about drift force on panels, see (Aquastructures AS, 2024).

6.4 Combined pressure from waves and current

This parameter says something about how the relative velocity between the structure and fluid flow should be treated on each panel on your structure, when calculating pressure from drag. It can be a number between 0 and 1.0:

- A value of 0.0 indicates that the 'raw' relative velocity at each panel is used as basis for finding the pressure drag. See leftmost illustration in Figure 27.
- A value of 1.0 indicates that AquaSim will average the relative velocity over all panels situated at the same vertical position. See rightmost illustration in Figure 27.

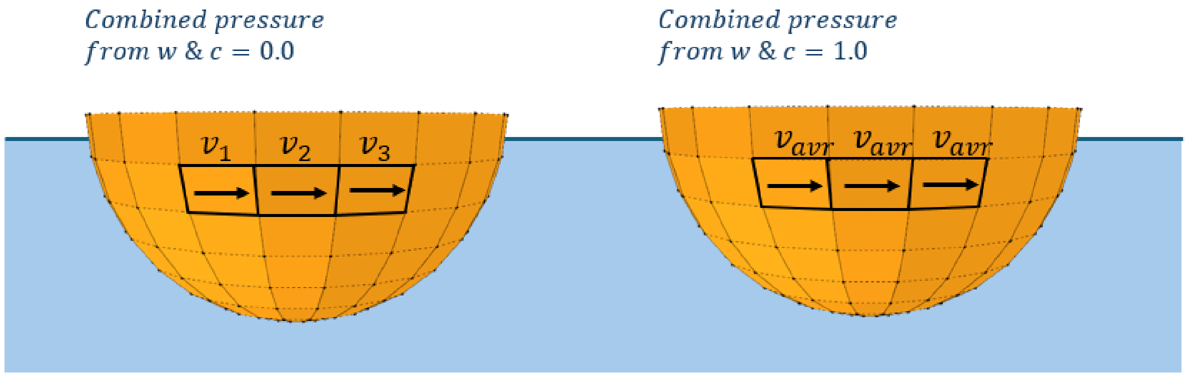

Figure 27 Combined pressure from waves and current

6.5 Enable convolution integral

When *Enable convolution integral* is activated, AquaSim includes memory effects in the hydrodynamic load calculation. This means that the radiation forces, which are forces due to the structure's past motions disturbing the surrounding fluid, are calculated using a time-domain convolution integral.

This option accounts for how previous velocities and accelerations of the structure influence the current response. This allows for more accurate prediction of the forces from frequency-dependent added mass and hydrodynamic damping, compared with applying constant coefficients.

Enable convolution integral requires an irregular sea state and is available when using the load formulation *Numerical diffraction*. More information about convolution integral is found in (Aquastructures, 2025).

6.6 Negative damping handling

Negative damping handling controls how AquaSim should treat situations where negative added mass and damping may arise. These effects can appear for structures when there is a strong coupling between modes of motions, resonant interactions, or numerical irregularities in the frequency-domain data that is used in calculation of the radiation kernel. Under such conditions, the hydrodynamic coefficients can become negative. Especially when the structure's motions are close to resonant frequencies or complex flow interactions between the structure and fluid.

- Negative added mass and damping set to 0: automatically removes the negative values. This ensure numerical stability and is recommended for most analysis cases.
- Negative added mass and damping allowed: keep the originally calculated hydrodynamic coefficients.

A radiation kernel is a memory function that describe how a structure's past motions affect the current hydrodynamic forces acting on it. In AquaSim, this is applied inside the convolution integral.

7 Sloshing

Sloshing is oscillatory motions of a free surface inside an enclosed volume. It is caused by the structure's motions and can generate significant dynamic pressure loads on the structure's sides.

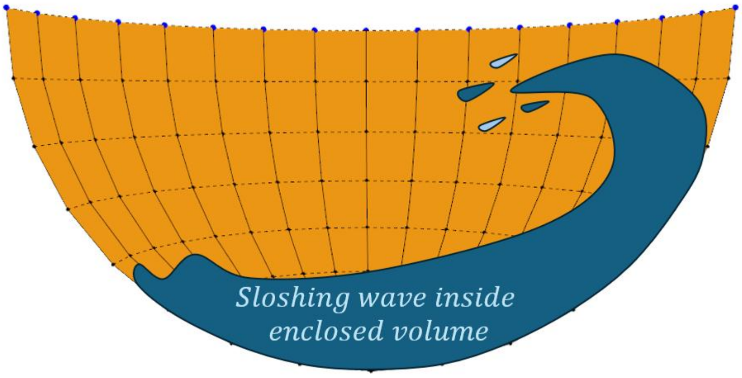

Figure 28 Sloshing

In AquaSim, one may include this through a simplified parametric approach. This is treated as an additional dynamic load on the structure, and the hydrodynamic response is then calculated by including these extra terms.

Sloshing is included by defining a table where each row represents one sloshing mode, meaning a certain combination of sloshing wave amplitude, direction and phase.

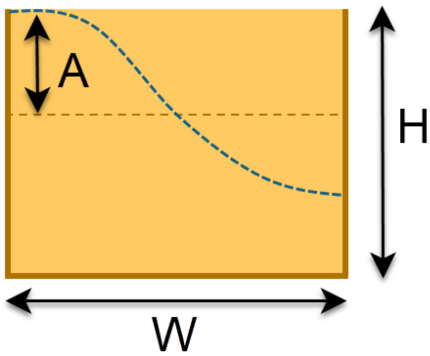

Figure 29 Sloshing parameters

- **Amplitude (A):** is sloshing wave amplitude inside the enclosed volume.
- **Direction:** is the direction of the sloshing wave relative to the global x-axis. From the Type section, one can choose to either input the direction in degrees or radians.
- **Tank width and – depth (W/ D):** defines the effective volume of the sloshing fluid.
- **Period:** period of the sloshing wave. This is automatically calculated by AquaSim.

More information about sloshing in AquaSim is found in (Aquastructures, 2021).

8 References

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