aquasim

Surface Tarpaulin

- Impermeable properties in AquaSim

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Summary:

This document presents the hydrodynamic parameters and modelling assumptions for the Surface Tarpaulin load formulation in AquaSim. It explains how impermeable membrane panels at the water surface interact with waves and current. This document aims to clarify how key coefficients affect drag-, suction-, added mass- and damping forces.

This document is valid for AquaSim version 2.22.0.

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Content

1 Introduction

This document presents the parameters found in the Impermeable properties section of the Edit membrane in AquaEdit, and how they work. The descriptions are valid for the load formulation Surface Tarpaulin. References to more in-depth information are included where this is available.

These descriptions are valid for AquaSim version 2.22.0.

1.1 Surface tarpaulins

A surface tarpaulin is a thin, flexible, impermeable structure designed to interact with water at the free water surface. They often appear in floating solar plants, environmental protection barriers and aquaculture among others.

Because they are highly flexible and situated at the water surface, their response is highly coupled to the fluid motions.

1.2 Basic assumptions in AquaSim

One of the fundamental assumptions for the Surface Tarpaulin in AquaSim is that it is positioned along the water surface in the global xy-plane. In horizontal direction, the hydrodynamic loading is assumed to be dominated by tangential (in-plane) forces from horizontal wave- and current velocities. In vertical direction, the hydrostatic and -dynamic pressure variations are the main contributors to forces.

Please note as AquaSim assumes the Surface Tarpaulin to be situated in the global xy-plane, this load formulation is unsuitable for analysing structures where panels are oriented vertically (along global z-axis). For such cases, other load formulations are better suited.

1.3 Hydrodynamic principles

This section presents some basic hydrodynamical principles for loads on structures in regular waves. The aim is to provide the user an overview of the different load terms. 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 waves that impact a structure 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 structure moving due to waves, and are normally expressed in terms of added mass and damping:

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

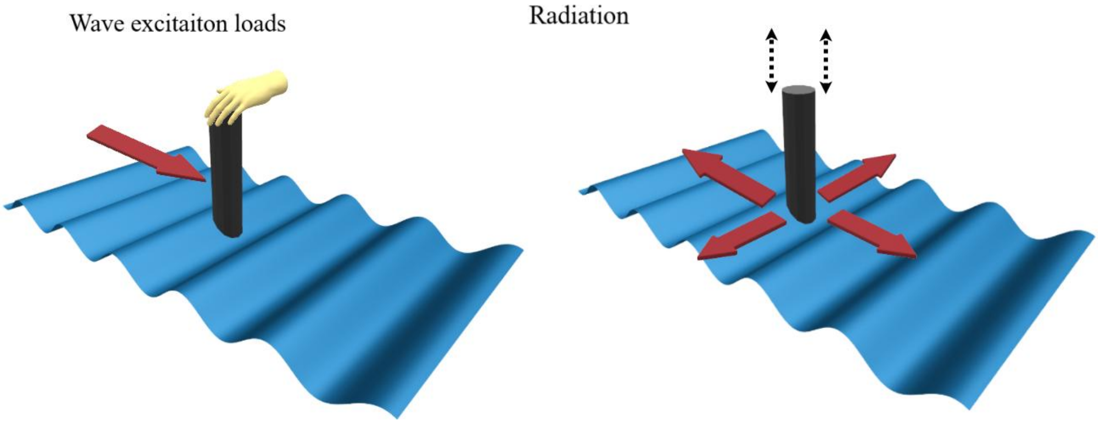

Figure 1 Wave excitaiton loads (structure restrained) and radiation (structure forced to move)

1.4 Coordinate system definition

Consider a membrane panel of a surface tarpaulin as shown in Figure 2. A right-handed local coordinate 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.

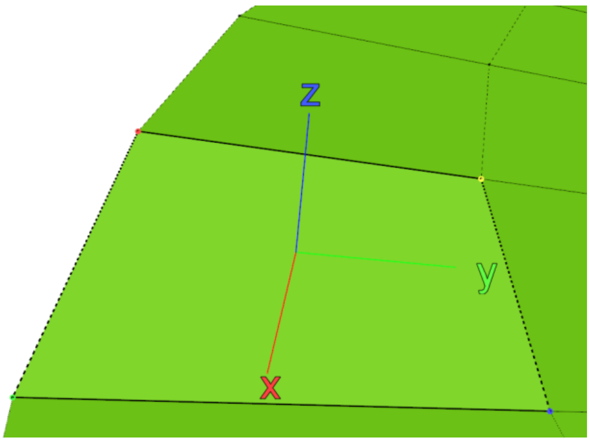

Figure 2 Local coordinate system of membrane panel

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 Drag

The *Drag* section defines the hydrodynamic resistance characteristics acting on the panels due to fluid flow from current and waves. Surface tarpaulin account for both pressure drag (normal/crossflow direction) and skin friction drag (tangential direction). The drag force in normal direction is often of negligible magnitude since the panel's surface spring stiffness provides resistance in vertical direction.

2.1 Drag coefficient

The *Drag coefficient* scales the pressure drag force on the panels. The pressure drag are acting normal to the panel, as illustrated in Figure 3.

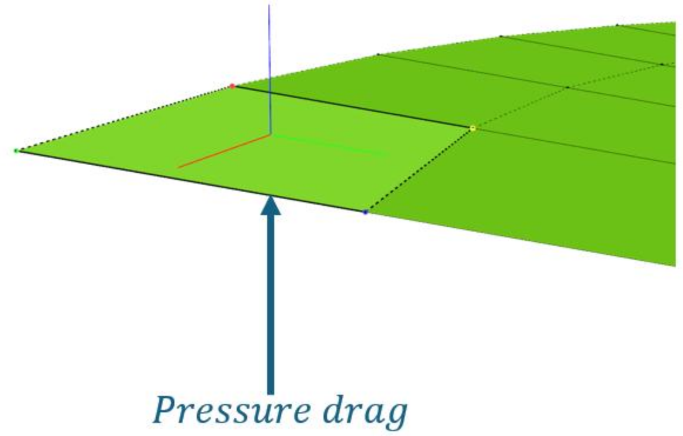

Figure 3 Pressure drag normal to membrane panel

2.2 Skin friction coefficient

The *Skin friction coefficient* account for tangential (viscous) resistance due to e.g. surface roughness of the structure.

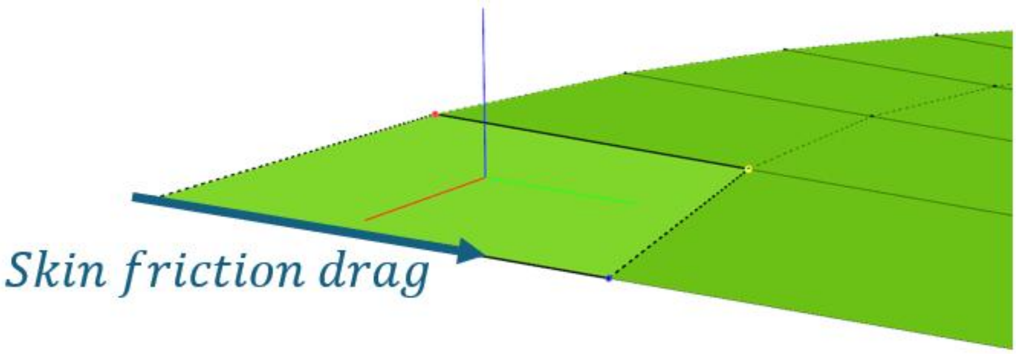

Figure 4 Skin friction drag on membrane panel

3 Surface suction

3.1 Surface suction coefficient

For *Surface Tarpaulins* in waves, one may assume a suction effect between the tarpaulin and water surface. This effect may be compared to the capillary effect due to intermolecular forces. Applying the *Surface suction coefficient* scales this force between the tarpaulin and water surface. Since it is a scaling factor, the natural range for this is between 0.0 and 1.0. The higher this coefficient, the stronger the binding between the water surface and tarpaulin. And the stronger the binding, the more the tarpaulin will follow fluid motions.

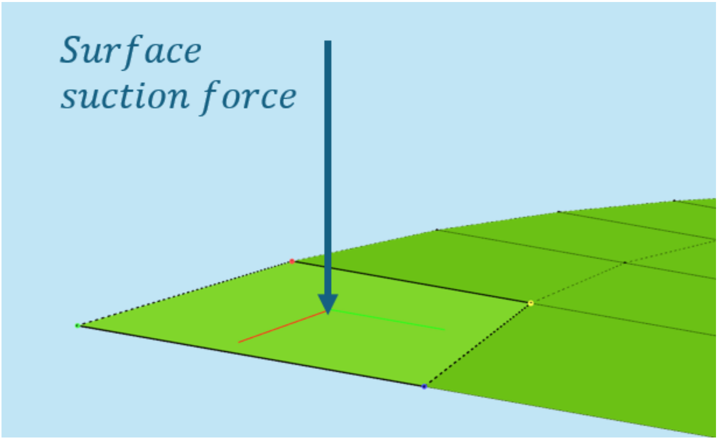

Figure 5 Surface suction force between panel and water surface

3.2 Tangential added mass suction coefficient

Consider a tarpaulin situated at the water surface where waves are moving along under it, as illustrated in Figure 6.

Figure 6 Surface tarpaulin exposed to waves

The wave will try to move the tarpaulin with the same velocity as the wave. This happens because a boundary layer in the vicinity of the tarpaulin arises due to viscosity. If we close up to the tarpaulin and the water surface, the boundary layer can be illustrated as in Figure 7.

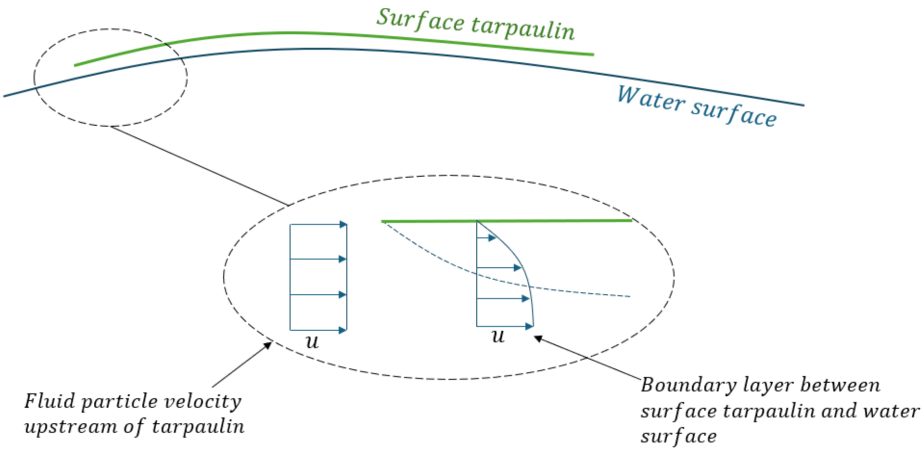

Figure 7 Boundary layer between surface tarpaulin and water surface

A no-slip condition (fluid particle velocity at the tarpaulin surface equals 0 m/s) is assumed and fluid particles then tend to 'stick' to the tarpaulin. This can be interpreted as a tangential added mass situation. The boundary layer between the tarpaulin and water will create mass distribution when the tarpaulin is set in motion due to waves. This mass is assumed to be proportional to the wavelength. The *Tangential added mass suction coefficient* scales this added mass force. Since it is a scaling factor, the natural range for this is between 0.0 and 1.0. And as the name imply, this force acts tangential to the panel.

This added mass force tangential to the panel can be expressed as:

$$F_{am-T} = C_{am-T} \frac{\rho}{\omega^4} A \cdot a_1 \quad [N]$$

where

- ρ is density of sea water (1025kg/m^3),
- C_{am-T} is the *Tangential added mass suction coefficient*, note that the unit of this is [m],
- ω is the frequency of the wave*,
- A is the wetted area of the panel,
- a_1 is fluid particle acceleration due to waves in horizontal direction.

*Note that for irregular waves the peak period of the spectrum, $\omega = \omega_p$, is applied in the calculations. In the event of an irregular wave spectrum, applying the peak frequency will make calculations and computational time more effective.

4 Diffraction

This section presents the input parameters for wave induced forces. AquaSim provides two methods for how this should be calculated.

4.1 Type of diffraction load

This section provides options for how the pressure-part of wave excitation loads should be calculated. Each method defines a set of equations and numerically how these should be applied to each panel.

4.1.1 Froude-Kriloff

This method only account for the Froude-Kriloff force in the calculation of wave excitation loads. The diffraction term (see overview in section 1.3) is omitted. The consequence of omitting the diffraction part of the pressure is that one assumes that no waves are scattered from the structure's surface.

The wave excitation loads are then described by the Froude-Kriloff pressure:

$$F_{EXC} = F_{FK} = -\iint_{SW} p \cdot \overrightarrow{n_z} ds$$

where SW is the wetted area of the structure, p is the total pressure, $\overrightarrow{n_z}$ is the unit vector normal to the panel. The pressure is found as:

$$p = p_d - \rho g z + p_{atm}$$

p_d is the dynamic pressure and can be found in table 2.1 in (Faltinsen, 1990), ρ is density of sea water (1025kg/m3), g is gravitational acceleration, z is vertical position of the panel (in global coordinate system) and p_{atm} is the atmospheric pressure. The Froude-Kriloff force is calculated by numerical integration over the wetted surface. Since the linear wave pressure field is in quadrature of the free-surface elevation, the resulting vertical Froude-Kriloff force exhibit a phase shift of 90 degrees relative to the wave elevation. More information about the load formulation is available in (Aquastructures, 2025b).

4.1.2 Numerical diffraction

This method calculates hydrodynamic wave 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 this method, both pressure forces from Froude-Kriloff and diffraction is accounted for.

5 Added mass and damping

When a structure accelerates in a fluid, it must also accelerate some of the surrounding fluid. This makes the structure behave as if it had extra mass – so called added mass. Hydrodynamic damping represents energy dissipation due to the fluid surrounded by the structure moves. One may say that the added mass the inertial response of the structure, while the hydrodynamic damping says something about how quick the motions decay.

5.1 Added mass coefficient normal

How this parameter is operated by AquaSim depends on the *Type of diffraction load* that is selected. As the name imply, this force acts normal to the panel.

5.1.1 Froude-Kriloff

When the Froude-Kriloff method is applied the added mass force normal to the panel can be expressed as:

$$F_{am-N} = \rho C_{am-N} \frac{1}{\omega_p^4} A \cdot a_3 \quad [N]$$

where

- ρ is density of sea water (1025kg/m3),
- C_{am-N} is the *Added mass coefficient normal,* note that the unit of this is [m],
- ω_p is the peak frequency of the wave,
- A is the wetted area of the panel,
- a_3 is fluid particle acceleration due to waves in vertical direction.

Note that the peak period of the wave is applied in the calculations. In the event of an irregular wave spectrum, applying the peak frequency will make calculations and computational time more effective.

5.1.2 Numerical diffraction

Applying *Numerical diffraction,* the *Added mass coefficient normal* acts as a scaling factor for the added mass returned by the NEMOH algorithm. Since it is a scaling factor, the natural range for this parameter is then between 0.0-1.0. Where 1.0 represents applying 100% of the added mass found by NEMOH.

5.2 Hydrodynamic damping coefficient normal

How this parameter is operated by AquaSim depends on the *Type of diffraction load* that is selected. As the name imply, this force acts normal to the panel.

5.2.1 Froude-Kriloff

When the Froude-Kriloff method is applied the added mass force normal to the panel can be expressed as:

$$F_{damp-N} = AC_{b-N}\frac{\rho g}{\omega}$$

where

- A is the wetted area of the panel
- C_{b-N} is the *Hydrodynamic damping coefficient normal*, note that the unit is [m/s],
- ρ is density of sea water (1025kg/m3),
- g is gravitational acceleration,
- ω is wave frequency.

5.2.2 Numerical diffraction

Applying *Numerical diffraction,* the *Hydrodynamic damping coefficient normal* acts as a scaling factor for the added mass returned by the NEMOH-algorithm. Since it is a scaling factor, the natural range for this parameter is then between 0.0-1.0. Where 1.0 represents applying 100% of the hydrodynamic damping found by NEMOH.

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.

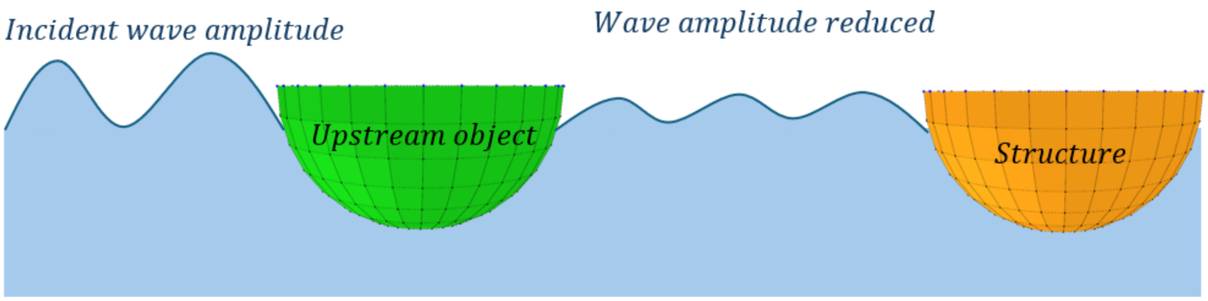

Figure 8 Wave amplitude reduction

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.

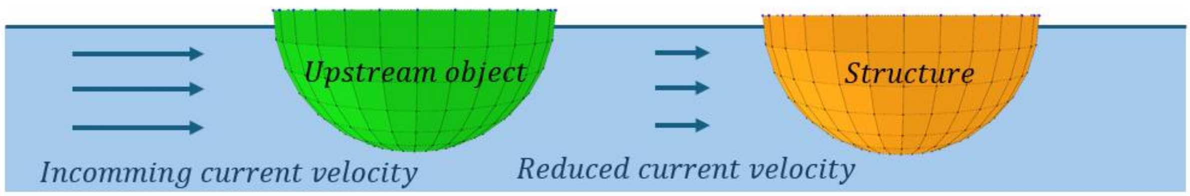

Figure 9 Current reduction

7 References

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Faltinsen, O. M. (1990). *Sea loads on ships and offshore structures.* Cambridge University Press.