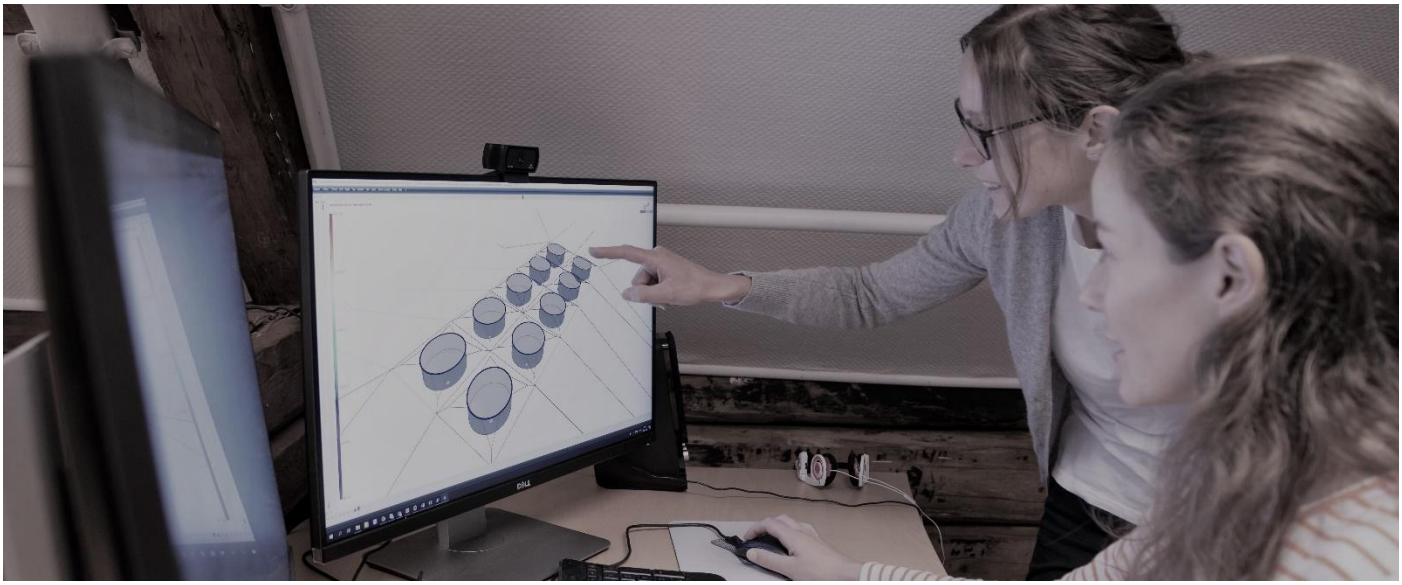
AquaSim training courses

- **Hydrodynamic analysis in AquaSim using NEMOH**



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Aquastructures AS
Kjøpmannsgata 21, 7013 Trondheim
Norway

Content

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. Furthermore, it is assumed that the user has some experience with linear potential flow theory, and numerical sink-source algorithms.

2 Introduction

This tutorial introduces how wave excitation forces and radiation forces (hydrodynamic damping and added mass) are calculated numerically in AquaSim based on the "diffraction module" and "radiation module" from NEMOH, respectively.

The purpose is to provide an introduction to the load formulation, how these results are presented in AquaSim, both locally on each element in AquaView and globally in the "Hydro-file", as well as provide some insight to relevant effects, corrections and considerations that are performed in the time-domain simulations in AquaSim with respect to drift forces, added mass distribution, wave-current interaction, irregular waves, water depth and more.

You will be introduced to:

- The basics of linear potential flow theory.
- Practical considerations with respect to hydrostatic forces and structural deformations, with respect to the geometry that is sent to and evaluated in the NEMOH solver.
- How to initiate the NEMOH solver in AquaSim.
- Best practice with respect to mesh size and orientation of panels (especially concerning normal vectors).
- How the total wave excitation pressure (Froude Kriloff + diffraction), diffraction pressure phase, hydrodynamic damping and added mass are distributed on each panel on the structure.
- How the numerically calculated added mass, and hydrodynamic damping might be scaled horizontally and vertically.
- How the total global wave excitation force (Froude Kriloff + diffraction), wave excitation force phase (Froude Kriloff + diffraction), hydrodynamic damping and added mass is presented in the "Hydro-file".
- Present some comparisons between results obtained from AquaSim, compared to known analytical solutions and to results from other numerical software, for verification.
- Options for how to account for infinite or finite water depth in numerical calculations.
- Considerations with respect to current-wave interactions.
- Different options for how to handle added mass and hydrodynamic damping in irregular waves.
- How drift forces are accounted for and how these are presented in the "Hydro-file".
- Different options for how to handle added mass, with respect to the mean wetted surface and the instantaneous wetted surface, as well as how to handle negative added mass and damping.
- How added mass and hydrodynamic damping are accounted for with respect to rigid body rotations and arbitrary motions (hydroelasticity).
- Other things to be aware of e.g. vertically oriented elements close to water surface, irregular frequencies and other possible singularities.

3 Basics of linear potential flow theory

The load formulation "Numerical diffraction" in AquaSim is based on the open-source code NEMOH, which is a linear potential flow theory algorithm using the Boundary Element Method (BEM), along with the source-formulation to solve the hydrodynamic boundary value problem. In broad terms the numerical algorithm solves the hydrodynamic boundary value problem by distributing sinks/sources on each panel, assuming constant panel strength on each panel, and calculating the strength of each sink/source to satisfy the boundary conditions on the structure (5). Note that the sinks/sources themselves could be thought of as representing known "unit-waves" propagating away from the panel in all directions, that already satisfy the conditions (1) to (4) below, but with unknown amplitudes/strengths that needs to be solved for.

The algorithm is based on linear potential flow theory. Linear potential flow theory assumes an inviscid, irrotational, incompressible fluid, which in turn implies that the flow can be described using velocity potentials (Φ). In linear potential flow theory, the hydrodynamic problem is divided into two main problems, commonly referred to as the "diffraction problem" and the "radiation problem". The entire solution to the hydrodynamic problem is found by linear superposition of the solution of each of these two problems. In the "diffraction problem" the structure is assumed to be stationary and subjected to incident waves, while in the "radiation problem" the structure is free to move, but is not subjected to incident waves.

Overall, the numerical algorithm ensures the following is satisfied for both problems:

1. The governing Laplace equation is satisfied in the entire fluid domain, implying that conservation of mass is obtained.
2. The far-field radiation condition is satisfied, meaning that the waves generated by the structure (from diffraction/radiation), propagates away from the structure and dies out far away from the structure.
3. The boundary condition on the seabed (assumed to be flat/horizontal) is satisfied, meaning that the normal (i.e. vertical) fluid flow velocity acting on the seabed is zero, meaning there is no fluid flow through the seabed.
4. The combined (kinematic and dynamic) linearized boundary condition on the free-surface is satisfied, implying that water particles on the free-surface remain on the free-surface (kinematic) and that the pressure on the free-surface is equal to the atmospheric pressure (dynamic).
5. The boundary condition on the structure is satisfied, meaning that the total normal fluid flow velocity acting on each panel is zero, meaning there is no fluid flow through the structure.

For practical purposes, the "radiation problem" provides us with hydrodynamic damping and added mass, while the "diffraction problem" provides us with the wave excitation force and the wave excitation force phase. The different hydrodynamic quantities represent the following:

- **Hydrodynamic damping:** represents damping due to energy being transported away from the structure, because of waves generated by the motion of the structure.
- **Added mass:** represents the acceleration of water particles due to the motion of the structure.
- **The wave excitation force and the wave excitation force phase:** represents the disturbance of the incoming waves due to the presence of the structure.

For more details regarding NEMOH and its theoretical background, see (A. Babarit, 2015), (R. Kurnia G. D., 2022) and (R. Kurnia G. D.-C., 2022).

4 Practical considerations for hydrodynamic analysis in AquaSim

In AquaSim it is important to note that the AquaSim solver performs a static analysis before the geometry from the static analysis is sent into the NEMOH solver. The NEMOH solver is first initiated, when running the dynamic steps. This implies that you need to at least perform both one static step and one dynamic step to perform a "pure" hydrodynamic analysis in AquaSim, as shown in Figure 1.

Furthermore, one needs to be aware of that it is not the modelled/drawn geometry that is used as input to NEMOH, but the deformed geometry after the static steps have been calculated. In case there is a current present in the analysis, the deformed geometry from when 2/3 of the current velocity has been applied, is sent to the NEMOH solver.

The important takeaway for this is that you need to be aware that you still need to think about the structural aspects, like deformations and translations, of your model, since this can affect the geometry evaluated in the hydrodynamic analysis, in addition to the fact that you need to analyse a minimum of one static step and one dynamic step.

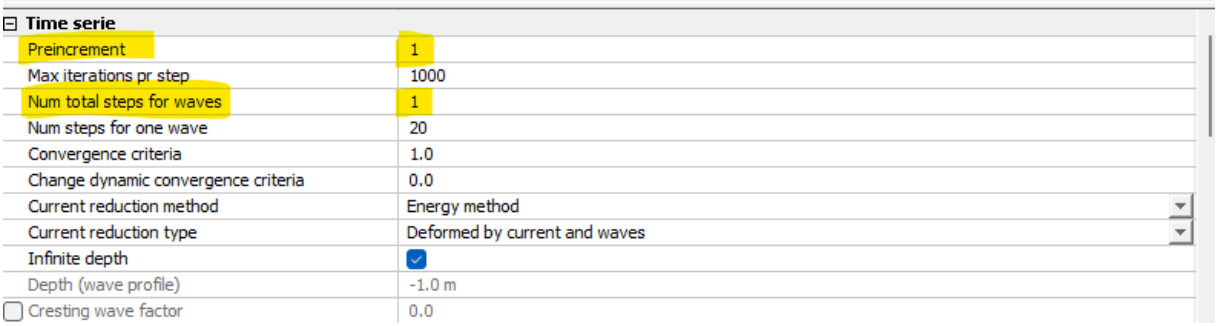


Figure 1 Minimum required analysis steps to perform hydrodynamic analysis in AquaSim.

5 How to initiate the NEMOH solver in AquaSim

There are mainly two different ways to initiate the NEMOH solver in AquaSim, and both of them requires that the component group, representing the geometry and elements you want to calculate the hydrodynamic properties of, is either set to element type “Membrane” or “Membrane X”, as shown in Figure 2.

The next step is then to go to the dropdown menu for “Load Formulation” and choose either “Lice skirt” or “Closed compartment” as shown in Figure 3. You then go to the dropdown menu for “Wave excitation load” and choose “Numerical diffraction”, as shown in Figure 4.

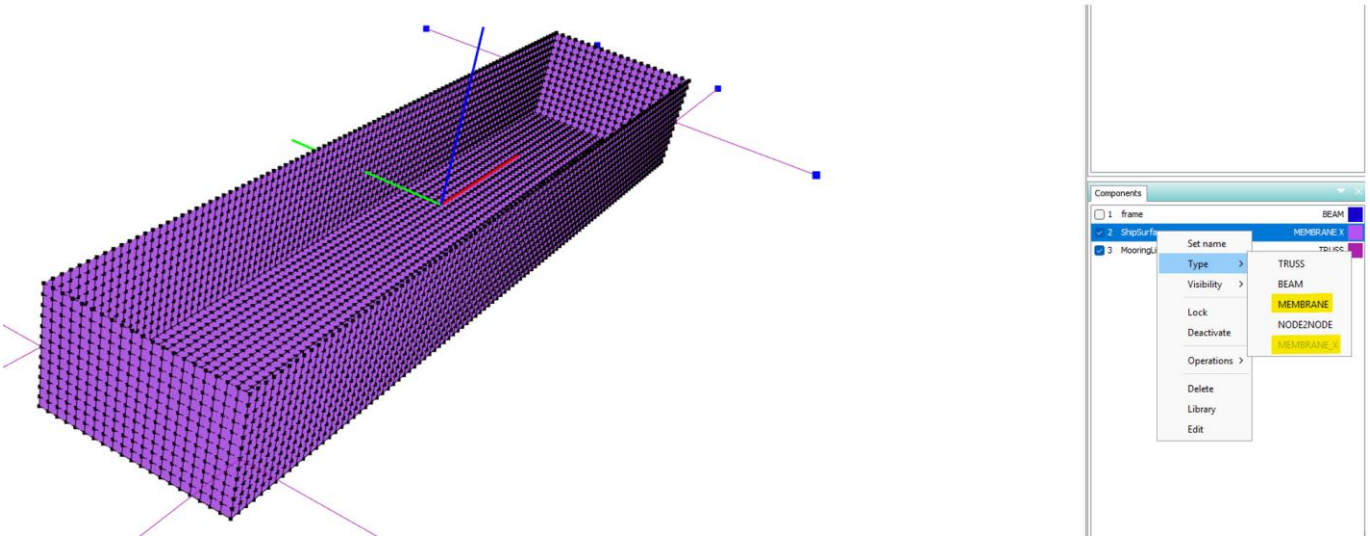


Figure 2 Membrane panels of barge, element type set to “Membrane X”. Note orientation of global coordinate system in model, with global x-axis (red) oriented longitudinally relative to barge, global y-axis (green) oriented transversally relative to barge and global z-axis (blue) oriented vertically.

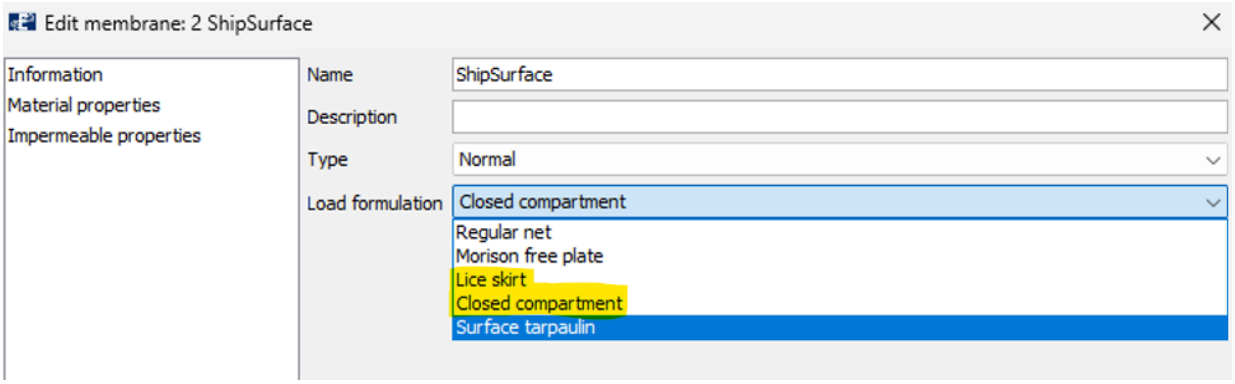


Figure 3 Load formulations that can be used to initiate the NEMOH solver in AquaSim, highlighted in yellow.

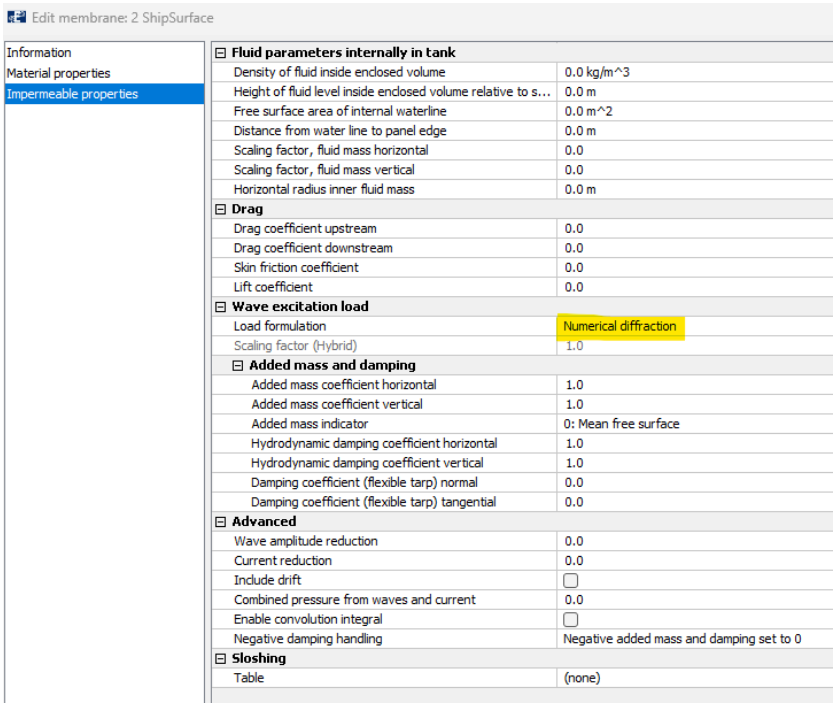


Figure 4 How to initiate NEMOH in AquaSim using "Lice skirt" or "Closed compartment".

6 Panel orientation and meshing

When using the NEMOH solver in AquaSim, it is important to note that it is required that the normal vectors (blue axis of local coordinate system) of each panel points into the interior of the structure.

To verify that the orientation of all panels is as desired, one might activate the "Membrane side" function. The side that faces out towards the external fluid will then be coloured with a shade of blue, while the side facing towards the interior of the structure will be coloured with a shade of red. In addition, one might also select a few, or all, of the elements in the component, while having activated the "Normals" function, which will show you the orientation of the blue local normal vector of each selected element. Both functionalities are shown in Figure 5.

If you find that your model does not have all panels oriented with their normal vectors into the interior of the structure, one can obtain this quickly by selecting all elements, then right-click and choose "Align membranes to center", as shown in Figure 6. All selected elements will then point towards their geometric centre.

With respect to the mesh size, a rule-of-thumb is to use elements with a diagonal that is 1/6 or smaller than the shortest wavelength you want to model, to obtain sufficient accuracy (DNV AS, 2021). As an example, the barge presented in this tutorial has a uniform mesh size of 1.0m x 1.0m. Meaning that the length of the diagonal is equal to $d = \sqrt{2}\ m \approx 1.41m$, which will result in sufficient accuracy for wavelengths of $\lambda \geq 6 * d = 8.49m$, corresponding to wave periods $T \geq \sqrt{\frac{2\pi\lambda}{g}} = 2.33s$. If you are then considering performing analyses with wave periods shorter than this, care must be taken, and you should consider decreasing the mesh size.

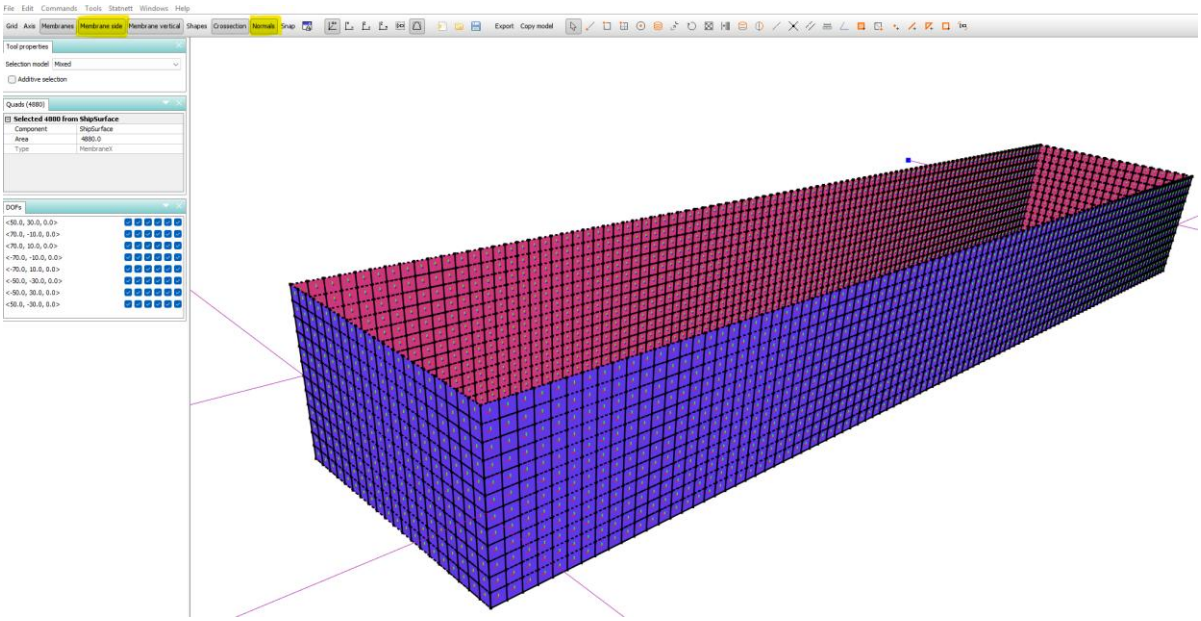


Figure 5 Membrane panels of barge, "Membrane side" and "Normals" activated to verify panel orientation in AquaSim.

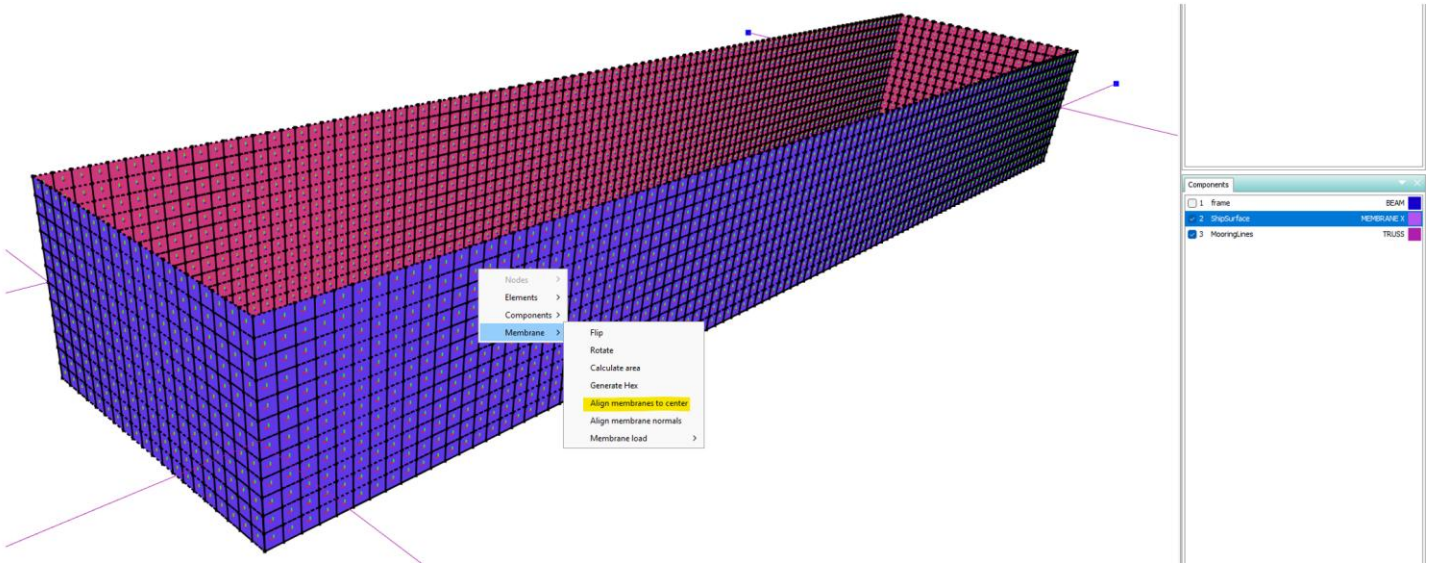


Figure 6 Select all elements in the component group, right-click and choose "Align membranes to center", to make sure all element points towards the geometric center.

7 Analysis model

The analysis model presented in this tutorial is a simple box-shaped barge with length of 100m, width of 20m, height of 12m and a draft of 6m. As previously mentioned, the "Membrane X" panels have a uniform mesh size of 1.0m x 1.0m. The analysis model is shown in Figure 7.

To provide buoyancy, hydrostatic stiffness and sufficient structural stiffness in the model, there is also used "Beam" elements in a 2.0m x 2.0m frame with element lengths of 1.0m. The "Beam" element frame is shown in Figure 8. This is only done for the sake of simplicity and calculation efficiency, and you could easily obtain buoyancy, hydrostatic stiffness and sufficient structural stiffness by using "Membrane" elements only. However, that is out of the scope of this tutorial, as this tutorial will mainly focus on performing hydrodynamic analysis in AquaSim, using the NEMOH solver.

Furthermore, the model has 8 mooring lines, each with a length of 20m and oriented horizontally at $z = 0.0m$, with 4 lines being oriented along the global x-axis and 4 lines oriented along the global y-axis. The model is fixed in all degrees of freedom (DOFs) at the ends of the mooring lines.

The properties of the frame, membrane panels and the mooring lines are provided in Figure 9 - Figure 11.

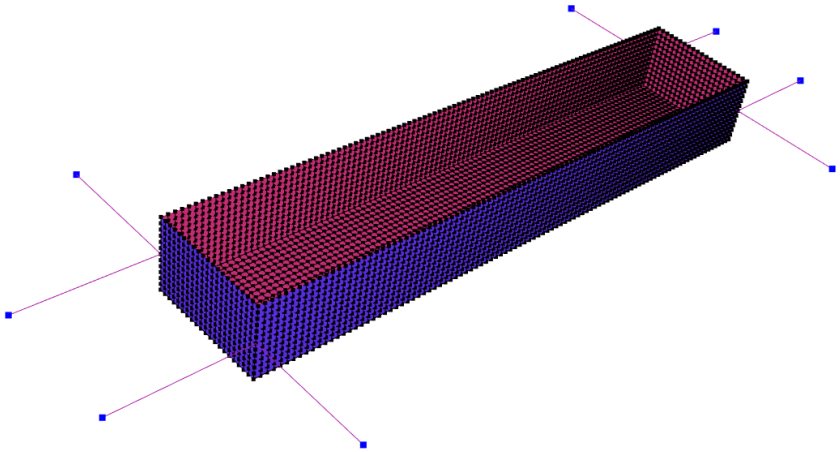


Figure 7 Analysis model (AquaSim) used as basis for tutorial.

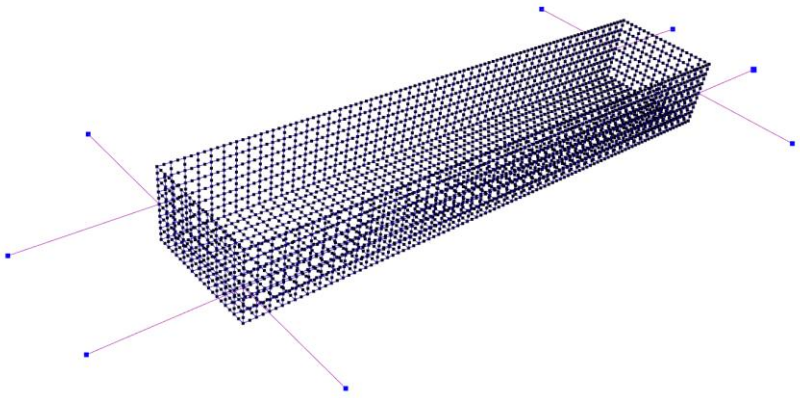
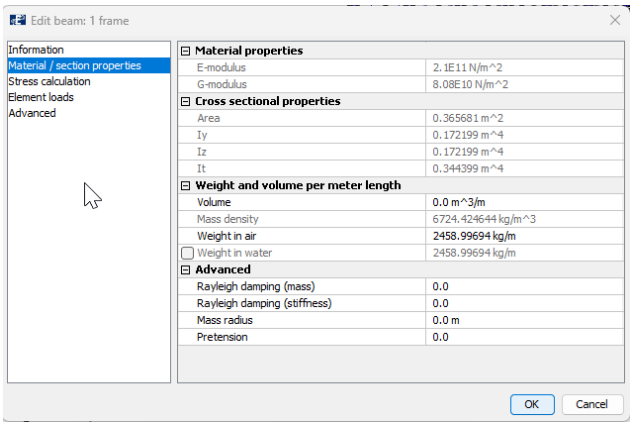


Figure 8 Frame consisting of "Beam" elements to ensure structural stiffness, hydrostatic stiffness and provide buoyancy.



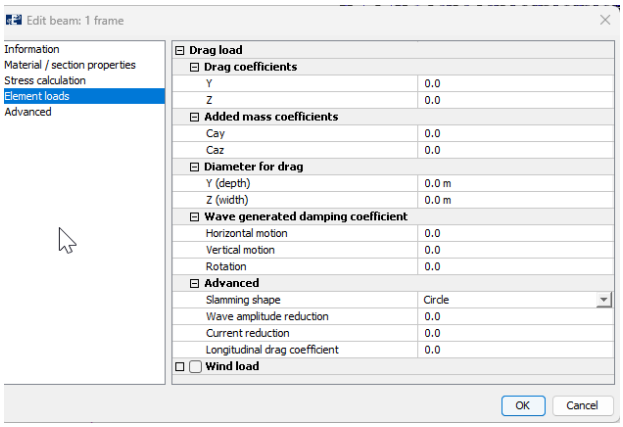
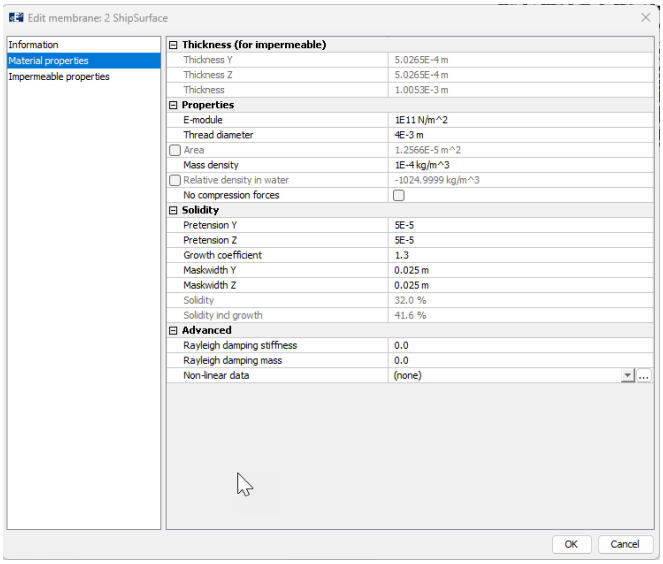


Figure 9 Properties of "Beam" elements in frame.



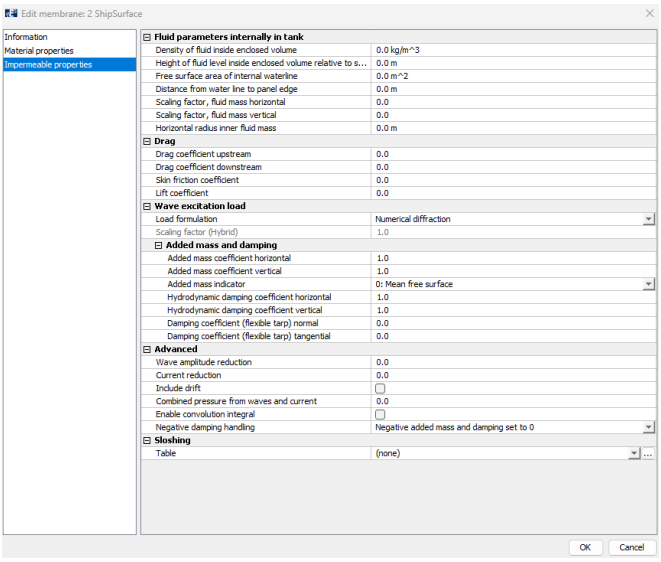


Figure 10 Properties of "Membrane X" elements corresponding to the hull surface.

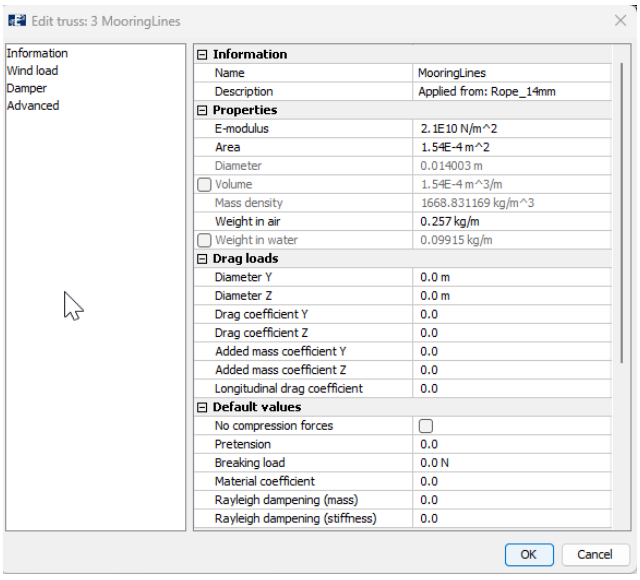


Figure 11 Properties of "Truss" elements corresponding to the mooring lines.

8 Load cases, postprocessing and analysis results

There are performed analyses with waves with amplitude of 1.0m and periods of 3.0s and 30.0s respectively, as shown in Figure 12. The waves move in the direction of the width of the barge (beam sea).

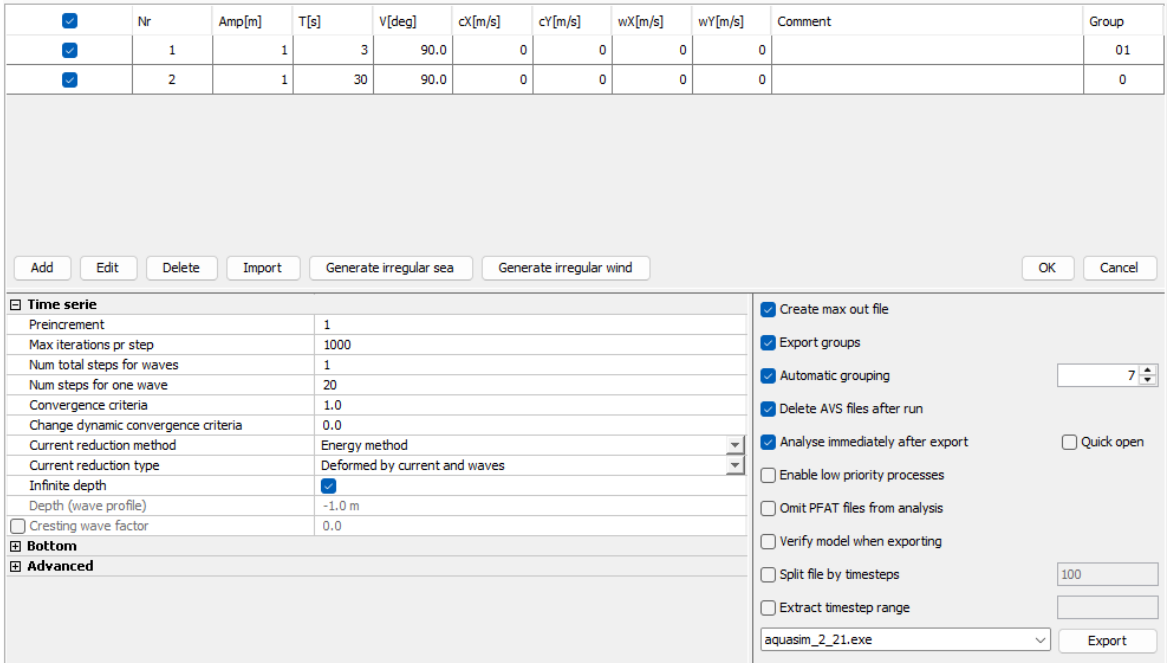


Figure 12 Environmental loads, for analyzed load cases.

8.1 Results in AquaView, "avz-file" and "PFAT-file"

In AquaView, from the "avz-file" and the "PFAT-file" you can see the distribution of added mass, hydrodynamic damping, total wave excitation pressure and more, on each individual panel on the structure, as seen from the dropdown menu for "Impermeable net" in Figure 13 and Figure 14, respectively.

The main difference between the results presented in the "avz-file" and the "PFAT-file", is that for the "avz-file" you are presented with the time-varying values that are applied in the analysis at any given analysis step, meaning you can see in-and-out of water effects and other non-linear corrections that are done to the actual instantaneous wetted surface of the structure, while the "PFAT-file" provides you with the "raw" uncorrected time-independent results for the mean wetted surface of the structure, that are calculated by the NEMOH solver.

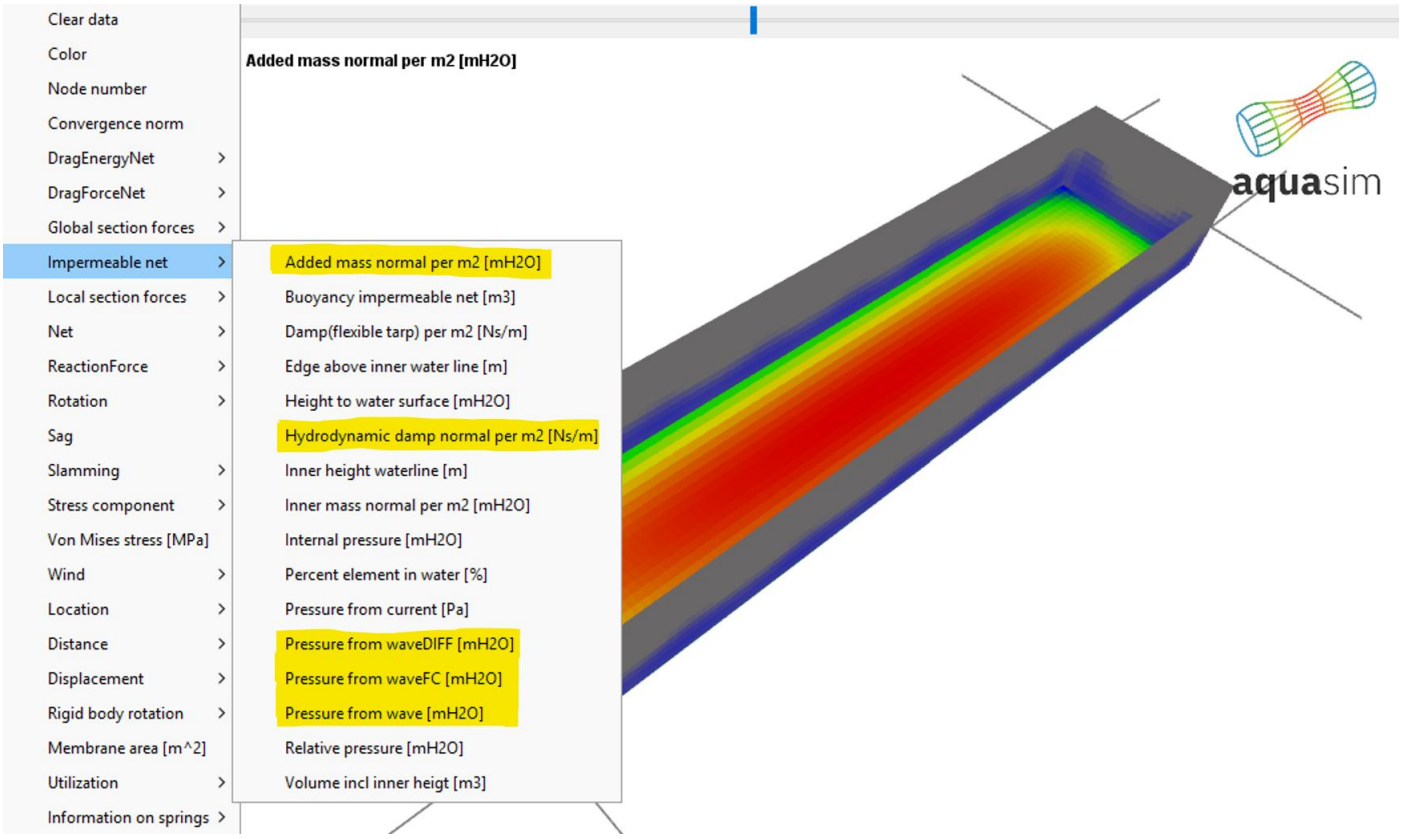


Figure 13 Analysis results and postprocessing in AquaView from "avz-file" for load case 1.

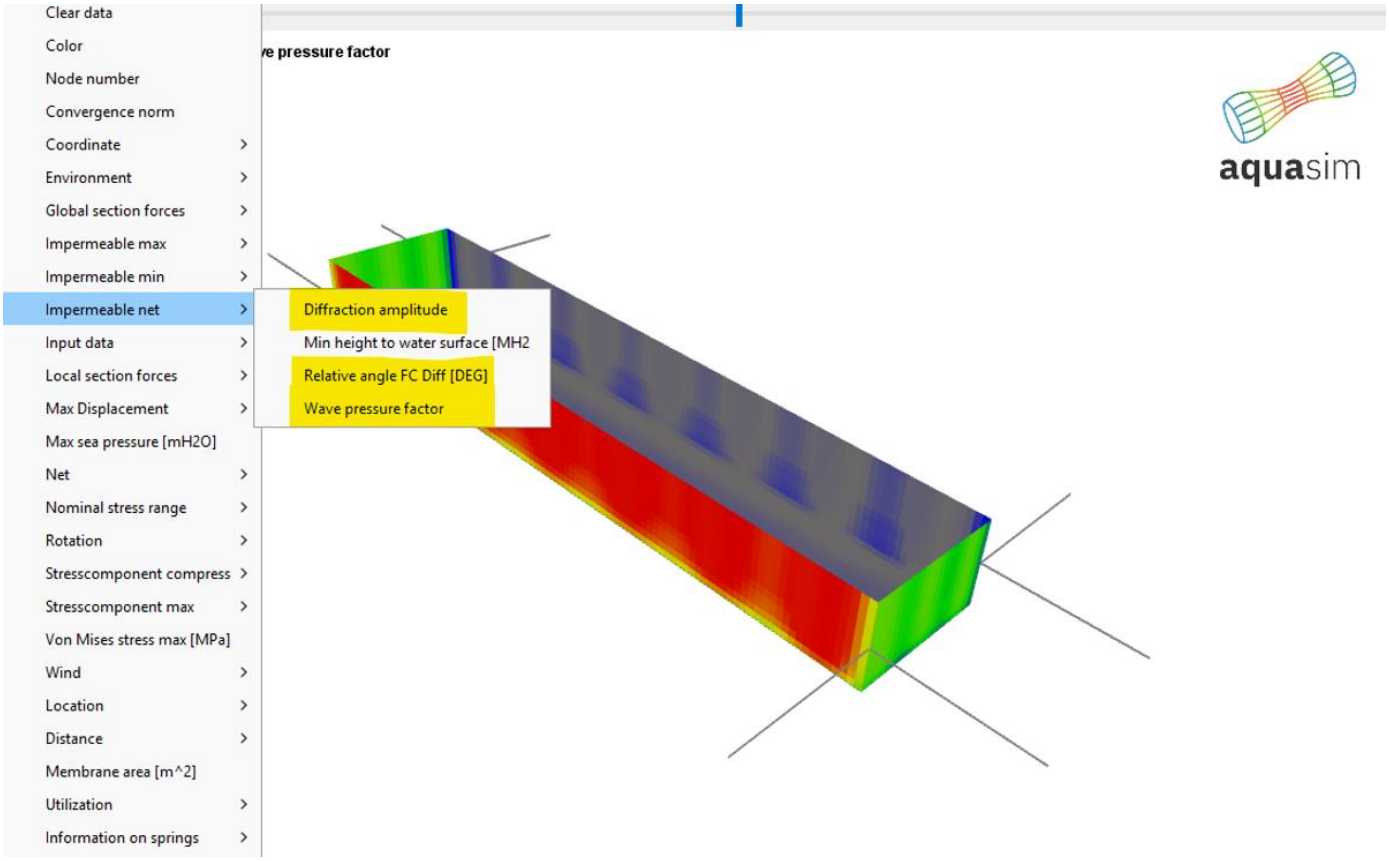


Figure 14 Analysis results and postprocessing in AquaView from "PFAT-file" for load case 1.

8.1.1 Pressure from waves and corresponding phases

Figure 15 - Figure 17 presents the total wave excitation pressure, the diffraction pressure and diffraction pressure phase distribution, respectively, for load case 1.

In AquaView the total wave excitation pressure is presented in the "PFAT-file" by the unitless parameter denoted as "Wave pressure factor", which provides the ratio between the total wave excitation pressure and the Froude-Kriloff pressure.

The diffraction pressure in the "PFAT-file" is presented in AquaView by the unitless parameter denoted as "Diffraction amplitude" which provides the ratio between the diffraction pressure amplitude and the Froude-Kriloff pressure amplitude.

The diffraction pressure phase in the "PFAT-file" is presented in AquaView by the parameter denoted as "Relative angle FC Diff" and has unit degrees. This parameter provides the relative phase angle between the diffraction pressure and the Froude-Kriloff pressure.

From Figure 15 it is possible to see that the "Wave pressure factor" is approximately 2.0, while Figure 16 and Figure 17 shows a "Diffraction amplitude" of 1.0 and a diffraction pressure phase of around 0 degrees at the side facing the waves. This corresponds to the generation of a reflected wave with equal amplitude and phase as the incoming wave, but with opposite wave propagation direction, resulting in a standing wave of amplitude twice that of the incoming wave, which is the analytical solution expected for an infinite wall, which the barge will resemble for such a short wave period, T = 3.0s.

On the opposite side of the barge (shadow side), it is possible to see that the "Wave pressure factor" is approximately 0.0, and the "Diffraction amplitude" is 1.0, with a diffraction pressure phase of around 180 degrees. This corresponds to the generation of a transmitted wave with equal amplitude and wave propagation direction as the incoming wave, but with opposite phase, resulting in a cancellation effect behind the barge, which is the analytical solution that is to be expected.

In the "avz-file" the Froude-Kriloff pressure, diffraction pressure and the total wave excitation pressure are presented in AquaView by the parameters denoted as "Pressure from waveFC", "Pressure from waveDIFF" and "Pressure from wave", respectively, as seen in Figure 13. These pressures have unit [mH2O] meaning that the pressure in pascal [Pa], is divided by the gravitational acceleration ($g = 9.81 m/s^2$) and the density of seawater ($\rho = 1025\ kg/m^3$). These parameters provide you with the time-variations of the different pressures.

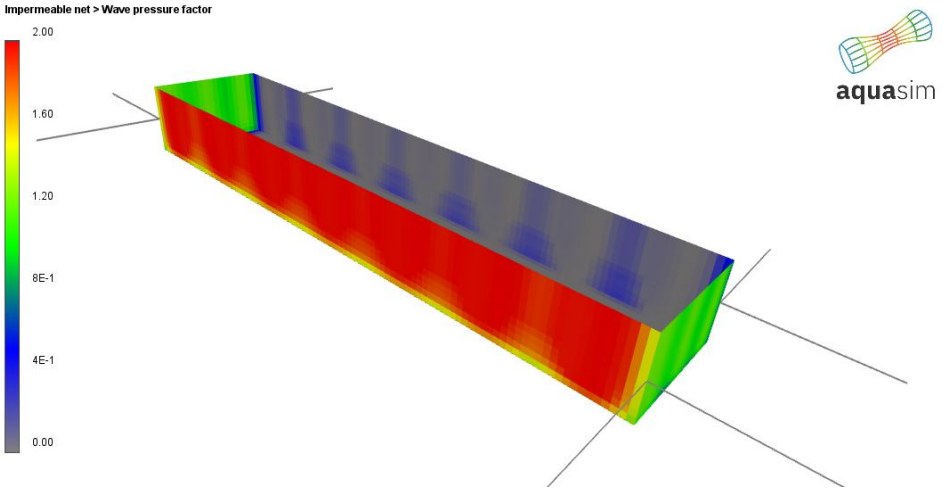


Figure 15 Wave pressure factor for load case 1 (wave amplitude 1.0m and wave period 3.0s).

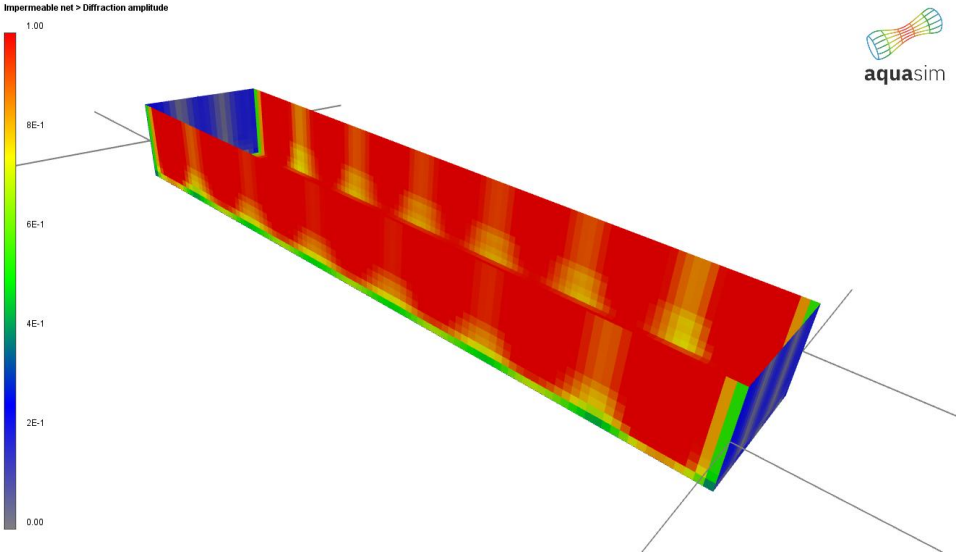


Figure 16 Diffraction amplitude for load case 1 (wave amplitude 1.0m and wave period 3.0s).

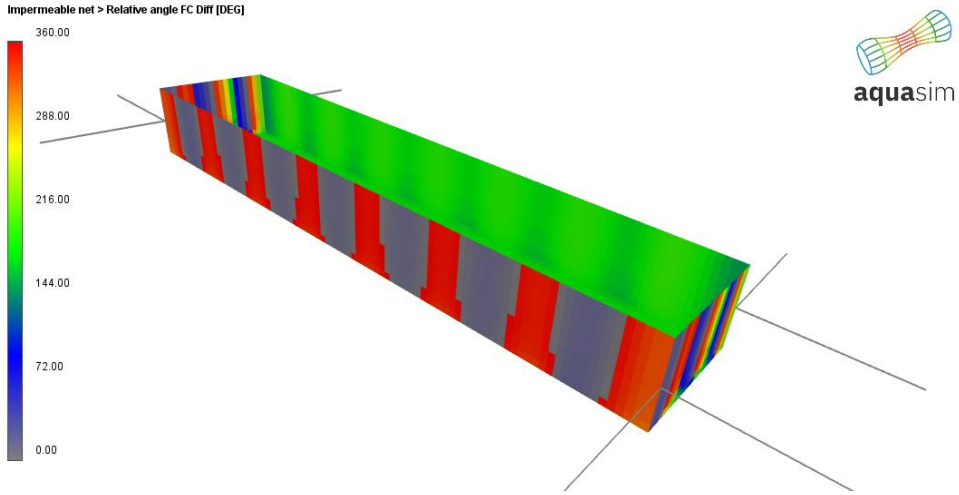


Figure 17 Diffraction pressure phase for load case 1 (wave amplitude 1.0m and wave period 3.0s).

8.1.2 Added mass and hydrodynamic damping

Figure 18 and Figure 19 presents the added mass and hydrodynamic damping distribution, respectively, for load case 2.

The added mass presented in AquaView by the parameter denoted as “Added mass normal per m2” and has unit [mH2O]. Meaning that the added mass of the panel in [kg], is divided by the area of the panel and the density of water ($\rho = 1000\ kg/m^3$). This parameter represents the amount of water that the panel accelerates per area (m^2).

The hydrodynamic damping presented in AquaView by the parameter denoted as “Hydrodynamic damp normal per m2” and has unit [(Ns/m)/m^2]. This parameter represents the hydrodynamic damping force, due to wave generation, that acts on the panel per area (m^2).

One should also note that if the scaling parameters for added mass and hydrodynamic damping in AquaEdit, highlighted in Figure 20 are set to any other value than 1.0, the horizontal and vertical contributions for the added mass and hydrodynamic damping used in the analysis, as well as the results presented in AquaView for the for the added mass and hydrodynamic damping, will be scaled in accordance with the input values provided by the user for these parameters.

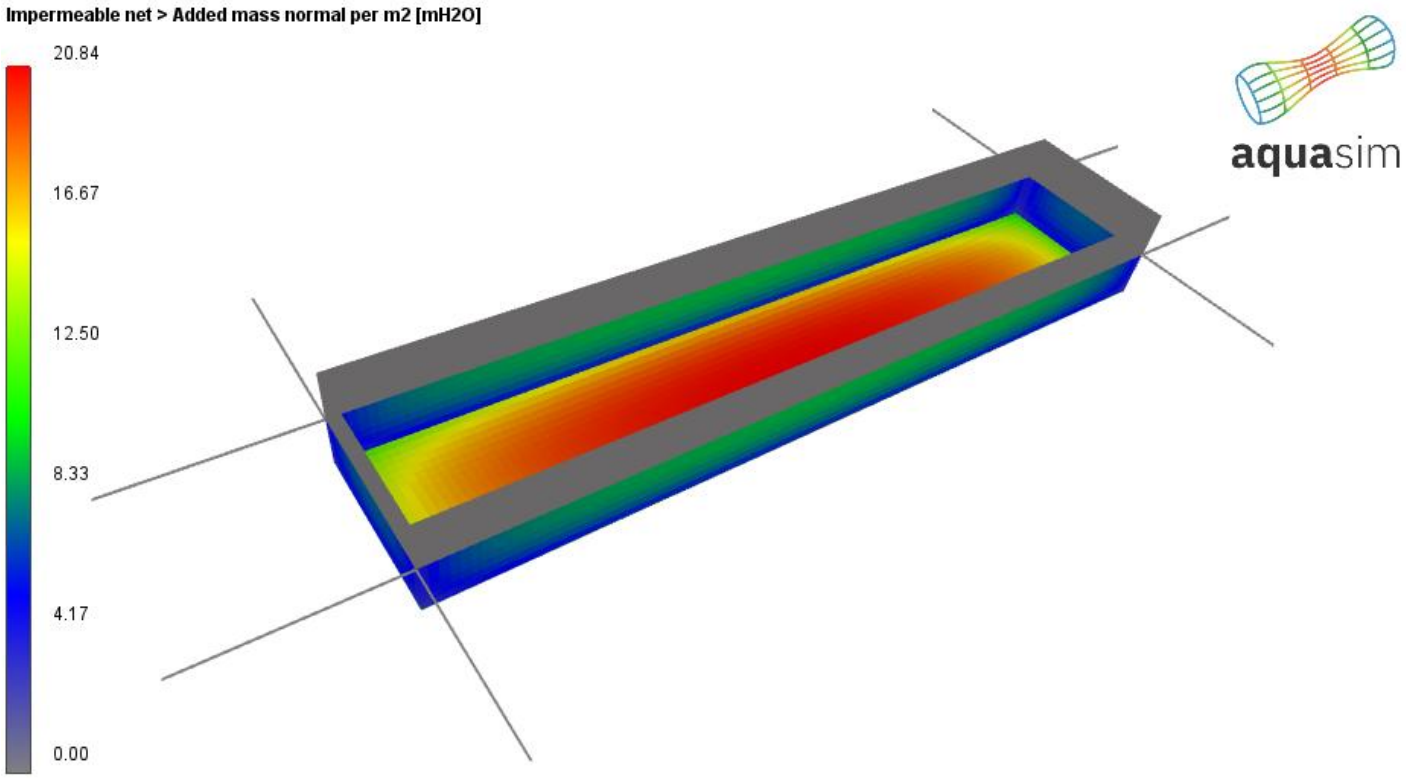


Figure 18 Added mass for load case 2 (wave amplitude 1.0m and wave period 30.0s).

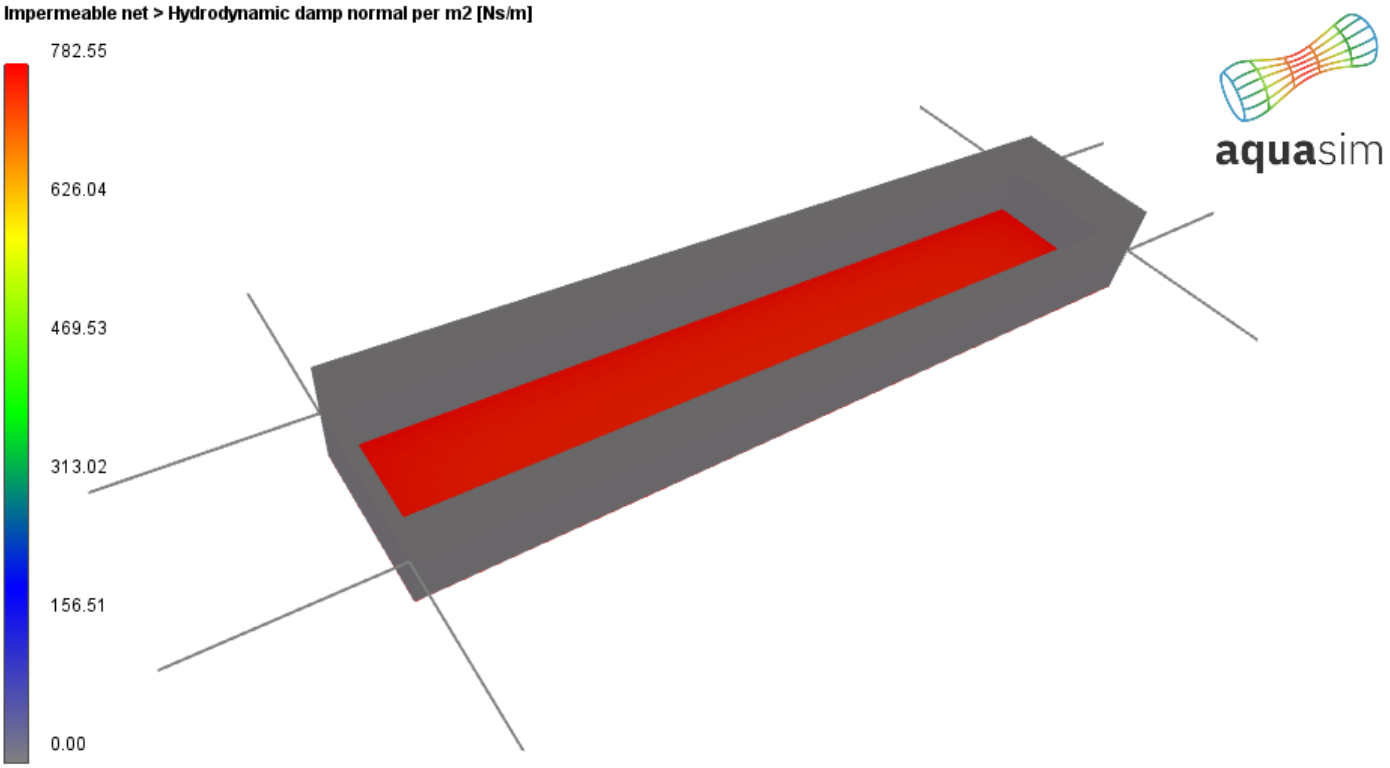


Figure 19 Hydrodynamic damping for load case 2 (wave amplitude 1.0m and wave period 30.0s).

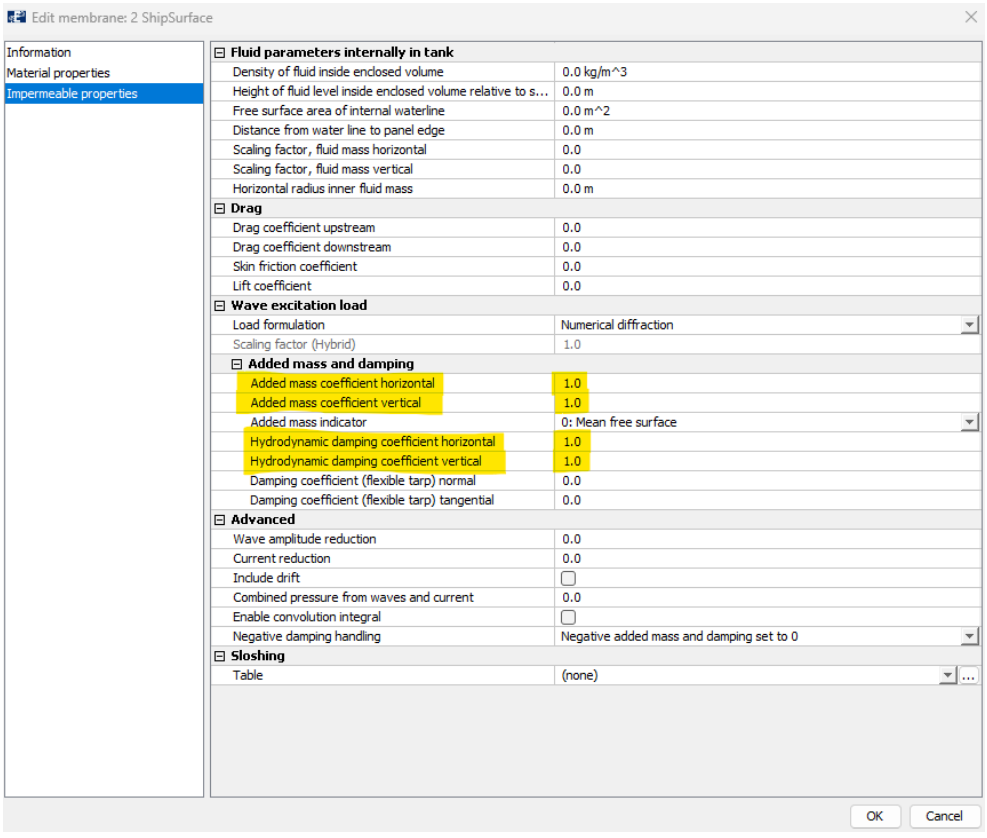


Figure 20 Scaling factors for added mass and hydrodynamic damping in AquaEdit.

8.2 Results in "Hydro-file"

If you are interested in the total added mass, total hydrodynamic damping and/or total wave excitation force, Froude-Kriloff force, diffraction force and the phases of these forces, you will find these results provided in the text file appended with the name "hydro", as shown in Figure 21. This file is in this tutorial referred to as the "Hydro-file".

From Figure 22 you can see how added mass, hydrodynamic damping, hydrodynamic forces and their phases are presented in the "Hydro-file" for load condition 2.

Furthermore, when analysing with several steps you will also be provided with the total instantaneous hydrodynamic forces acting on the structure at any given step, as shown in Figure 23, where load condition 1 has been analysed with 20 steps per wave and a total of 40 dynamic steps.

One should also be aware that the total instantaneous hydrodynamic drift force acting on the structure is calculated and presented in the "Hydro-file" as well, when analysing at least two full wave cycles. Meaning that at least one entire wave cycle with full wave amplitude is required for calculating the drift force.

The drift force is calculated based on the total instantaneous hydrodynamic forces averaged over the last number of steps corresponding to one wave cycle, which in this case means the last 20 steps. This is done for each step from the second wave cycle and onwards. Since in this case there is only analysed a total of exactly two wave cycles, there is only calculated drift forces for the one step, namely the very last analysis step, as seen in Figure 23.

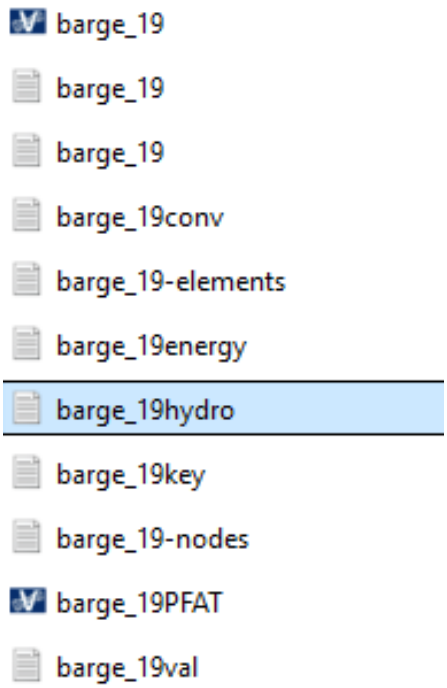


Figure 21 "Hydro-file".

```
Values in global coordinate system
STEP           2
Inner water mass [Tonne]
                        X,                      Y,                      Z,
Component      2        0.00000000E+00          0.00000000E+00          0.00000000E+00

Added mass [Tonne]
                        X,                      Y,                      Z,
Component      2        0.15153013E+04          0.91044396E+04          0.35614368E+05

Hydrodynamic damping [Nm/s]
                        X,                      Y,                      Z,
Component      2        0.61626211E+04          0.73586184E+04          0.15228690E+07

Damping flexible tarp [nm/s]
                        X,                      Y,                      Z,
Component      2        0.00000000E+00          0.00000000E+00          0.00000000E+00


Total areas of all element with features stated

Surface area
                        Total area [m2]         Wetted area [m2]
Component      2        0.48900991E+04          0.34400000E+04

Projected areas [m2]
(Sum of dot products areas with normal vectors)
                        X,                      Y,                      Z,
Component      2        0.22867316E-07         -0.58177188E-01         -0.20006175E+04


Projected areas absolute [m2]
(Sum of dot products areas with the absolute of normal vectors)
                        X,                      Y,                      Z,
Component      2        0.60285414E+03          0.24920062E+04          0.20467104E+04

Hydrodynamic wave force RAO [N] (per m wave amplitude)
(Froude Kriloff + diffraction)
Component      2 Wave      1       0.67881810E-01       0.91811361E+06       0.18015685E+08

Hydrodynamic wave force RAO phase [DEG]
(Froude Kriloff + diffraction)
Component      2 Wave      1      20.76     -89.97      -1.02

Froude Kriloff wave force RAO [N]  (per m wave amplitude)
(Froude Kriloff only)
Component      2 Wave      1       0.22731781E-01       0.53218728E+06       0.19571628E+08

Froude Kriloff wave force RAO phase [DEG]
(Froude Kriloff only)
Component      2 Wave      1      90.00     -90.00       0.00

Diffraction wave force RAO [N]  (per m wave amplitude)
(Diffraction only)
Component      2 Wave      1       0.58880132E-01       0.38592646E+06       0.15916127E+07

Diffraction wave force RAO phase [DEG]
(Diffraction only)
Component      2 Wave      1       1.14     -89.94    -168.35
```

Figure 22 Example of results in "Hydro-file" for load condition 2.

Hydrodynamic forces [N]

Component,		Step,		X,	Y,	Z,
Component	2	Step	2	0.68290820E-02	-0.20998785E+06	0.12056916E+09
Component	2	Step	3	0.13942412E-01	-0.38186013E+06	0.12056074E+09
Component	2	Step	4	0.18674267E-01	-0.45323818E+06	0.12055741E+09
Component	2	Step	5	0.17518918E-01	-0.41521045E+06	0.12056113E+09
Component	2	Step	6	0.10008754E-01	-0.23209233E+06	0.12057296E+09
Component	2	Step	7	-0.20215392E-03	0.11348684E+06	0.12059282E+09
Component	2	Step	8	-0.13559122E-01	0.60257236E+06	0.12061859E+09
Component	2	Step	9	-0.25729653E-01	0.12333861E+07	0.12064676E+09
Component	2	Step	10	-0.38045575E-01	0.18848716E+07	0.12067308E+09
Component	2	Step	11	-0.51316794E-01	0.24789700E+07	0.12068865E+09
Component	2	Step	12	-0.64973474E-01	0.28562037E+07	0.12069436E+09
Component	2	Step	13	-0.80835005E-01	0.29034861E+07	0.12068805E+09
Component	2	Step	14	-0.89637170E-01	0.25633633E+07	0.12066844E+09
Component	2	Step	15	-0.90445236E-01	0.18462741E+07	0.12063505E+09
Component	2	Step	16	-0.81385061E-01	0.89266431E+06	0.12058576E+09
Component	2	Step	17	-0.53612089E-01	-0.14992817E+06	0.12052686E+09
Component	2	Step	18	-0.95478196E-02	-0.10694929E+07	0.12046778E+09
Component	2	Step	19	0.50666811E-01	-0.19015404E+07	0.12041371E+09
Component	2	Step	20	0.11302355E+00	-0.25272447E+07	0.12036940E+09
Component	2	Step	21	0.15665133E+00	-0.29693075E+07	0.12033860E+09
Component	2	Step	22	0.16643708E+00	-0.30539539E+07	0.12033763E+09
Component	2	Step	23	0.15175131E+00	-0.29118368E+07	0.12035829E+09
Component	2	Step	24	0.11773979E+00	-0.25209041E+07	0.12039789E+09
Component	2	Step	25	0.73905231E-01	-0.19112308E+07	0.12045270E+09
Component	2	Step	26	0.27373970E-01	-0.10129762E+07	0.12052190E+09
Component	2	Step	27	-0.13650227E-01	0.12490088E+06	0.12059902E+09
Component	2	Step	28	-0.45473129E-01	0.16253558E+07	0.12067833E+09
Component	2	Step	29	-0.66276426E-01	0.32503928E+07	0.12074145E+09
Component	2	Step	30	-0.77725556E-01	0.47408589E+07	0.12078616E+09
Component	2	Step	31	-0.90425749E-01	0.57382895E+07	0.12081358E+09
Component	2	Step	32	-0.11059796E+00	0.60876577E+07	0.12082075E+09
Component	2	Step	33	-0.13044348E+00	0.56806430E+07	0.12080574E+09
Component	2	Step	34	-0.14425022E+00	0.46680041E+07	0.12077339E+09
Component	2	Step	35	-0.14035341E+00	0.32190662E+07	0.12072888E+09
Component	2	Step	36	-0.12681816E+00	0.16515776E+07	0.12067364E+09
Component	2	Step	37	-0.89970154E-01	0.20636969E+06	0.12060606E+09
Component	2	Step	38	-0.31357153E-01	-0.92459128E+06	0.12054059E+09
Component	2	Step	39	0.37661077E-01	-0.18190659E+07	0.12048490E+09
Component	2	Step	40	0.10377748E+00	-0.24458936E+07	0.12044141E+09
Component	2	Step	41	0.15215823E+00	-0.28598726E+07	0.12041190E+09

Drift forces [N]

Component,		Step,		X,	Y,
Component	2	Step	41	-0.11826873E-01	0.87663956E+06

Figure 23 Example of results in "Hydro-file" for load condition 1.

8.3 Comparison with WADAM/HydroD

Table 1 provides a comparison of the total vertical added mass and total vertical hydrodynamic damping for load case 2, obtained from AquaSim using the analysis model shown in Figure 7 and from WADAM/HydroD using a corresponding analysis model shown in Figure 24. Very similar results are obtained, with AquaSim calculating a slightly larger added mass and hydrodynamic damping. However, some numerical differences are to be expected since AquaSim is based on the source-formulation, while WADAM/HydroD is based on the potential-formulation, when solving the hydrodynamic problem.

Table 1 Comparison of total vertical added mass and total vertical hydrodynamic damping for load case 2.

	AquaSim	WADAM/HydroD	Difference [-]
A33 [tonne]	35614.4	34146.3	1.04
B33 [Ns/m]	1522869.0	1440000.0	1.06

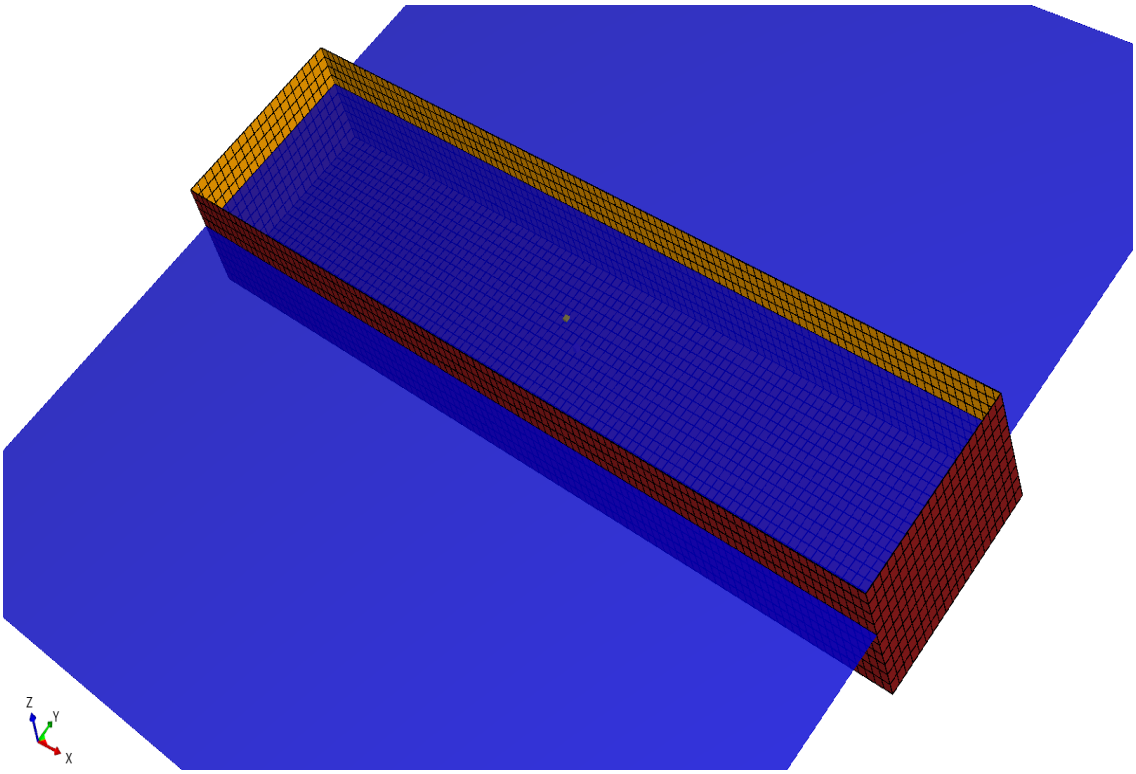


Figure 24 Analysis model from WADAM/HydroD used for comparison with AquaSim.

9 Notes on additional aspects

9.1 Accounting for finite water depth

In AquaSim you can account for finite water depth in the hydrodynamic analysis done in NEMOH by un-toggling the parameter “Infinite depth” and specifying your desired water depth in the parameter “Depth (wave profile)” in the Export-window, as shown in Figure 25.

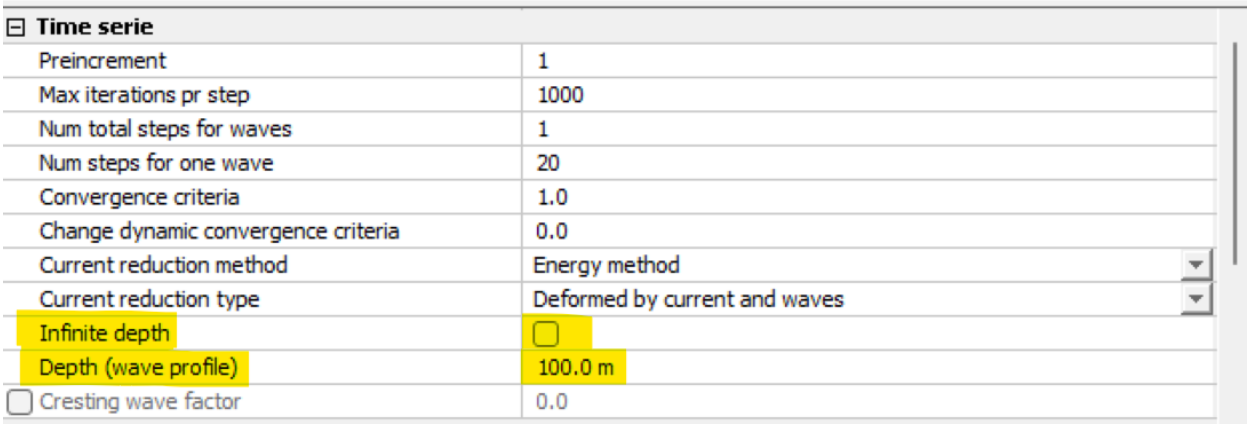


Figure 25 Accounting for finite water depth in the hydrodynamic analysis in AquaSim.

9.2 Current-wave interaction

There are mainly two different effects with respect to current wave-interaction that is accounted for in AquaSim.

The first effect is the Doppler effect and corresponding correction according to the frequency of encounter (Aquastructures AS, 2025a). When a wave propagates in a medium with a current of velocity U, the observed (encounter) angular frequency ω_e differs from the intrinsic frequency ω_0. For deep-water waves, the Doppler-shifted encounter frequency is approximated as:

$$\omega_e = \omega_0 + \frac{\omega_0^2 U}{g}$$

where:

- $\omega_e = \frac{2\pi}{T_e}$: Encounter angular frequency (rad/s).
- $\omega_0 = \frac{2\pi}{T}$: Intrinsic angular frequency (rad/s).
- U: Current velocity (m/s), positive if in the same direction as wave propagation, negative if opposing.

In practice this means that a wave traveling in a current field acting in the same direction as the waves, will result in the wave becoming longer, and vice versa when the current and waves act in opposite directions.

AquaSim assumes that the wave period given as input is a wave period for an observer following the current velocity, this means that when waves and current rides in the same direction and the period of encounter is kept constant, the period given to AquaSim should be increased appropriately.

As an example, the environmental conditions in Figure 26 results to the same period of encounter (4.2s), which is the period that will remain constant for a wave entering a current field.

It is important to note that for all these environmental conditions, the periods in the column "T[s]" (i.e. 4.2s, 4.75s and 4.9s) are used to describe the wave that is used in the simulation in AquaSim and are also the periods that are evaluated in the "diffraction module" in NEMOH, when calculating the Froude-Kriloff force, diffraction force, total wave excitation force and the phases of these forces.

On the other hand, the period of encounter (4.2s) is applied in the calculations of added mass and hydrodynamic damping by the "radiation module" in NEMOH for all these environmental conditions, since this is the period experienced by the structure.

	Nr	Amp[m]	T[s]	V[deg]	cX[m/s]	cY[m/s]	wX[m/s]	wY[m/s]
☑	1	0.4	4.2	0.0	0	0	0	0
☑	2	0.4	4.75	0.0	1	0	0	0
☑	3	0.4	4.9	0.0	1.3	0	0	0

Figure 26 Periods in analysis giving the same (4.2s) period of encounter.

The second effect is the correction of the combined water particle velocity (current velocity + undisturbed water particle velocity from waves) that is used when calculating the pressure from drag acting on the membrane panels (Aquastructures AS, 2024a).

The pressure from drag is can either be calculated based on an uncorrected velocity on each panel or based on the average velocity for all elements at the same depth, as shown in Figure 27. This is done by setting the parameter "Combined pressure from waves and current", shown in Figure 28, to either 0.0 or 1.0. If this parameter is set to a value between 0.0 and 1.0, the two methods are weighted in accordance with the input provided by the user, i.e. a value of 0.4 results in 40% of the uncorrected velocity being used and 60% of the averaged velocity being used.

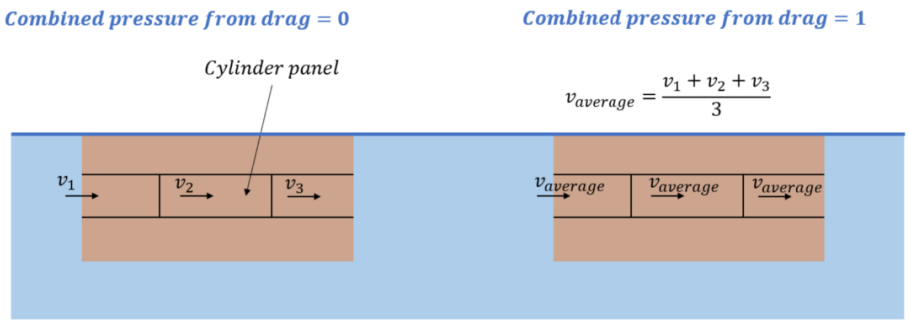


Figure 27 Combined pressure from waves and current.

Advanced	
Wave amplitude reduction	0.0
Current reduction	0.0
Include drift	☐
Combined pressure from waves and current	0.0
Enable convolution integral	☐
Negative damping handling	Negative added mass and damping set to 0
Sloshing	
Table	(none)

Figure 28 Parameter for adjusting the combined pressure form waves and current.

9.3 Irregular waves

In AquaSim, when analysing with irregular waves, the total wave excitation force is calculated for the "diffraction problem" using NEMOH and accounting for all wave components (and their different amplitudes, periods and phases) in the irregular wave spectrum.

For the "radiation problem" on the other hand you have the option of either using a fixed value for the wave period that is evaluated by NEMOH for the calculation of added mass and hydrodynamic damping, or alternatively enabling convolution, by toggling the parameter "Enable convolution integral" shown in Figure 29, thus accounting for the frequency-dependency of the added mass and hydrodynamic damping by evaluating all periods in the irregular wave spectrum. For details see (Aquastructures AS, 2025b).

By default, AquaSim uses a fixed value for the calculation of added mass and hydrodynamic damping with irregular waves, which is set equal to the mean zero crossing period of the wave spectrum, Tz (Aquastructures AS, 2025c).

However, in AquaSim, it is also possible to use a wave period that differs from the mean zero crossing period of the wave spectrum (Tz), as described in (Aquastructures AS, 2025d). Thus, enabling the use of for example the wave spectrum's peak period, Tp, or alternatively a natural period Tn (corresponding to a certain degree of freedom or eigenmode of the system), depending on whether the system response is force-driven or resonance-driven. Additionally, for double-peaked wave spectra (with both wind-generated waves and swell), this allows selecting which of the peaks' Tp to use in the calculations.

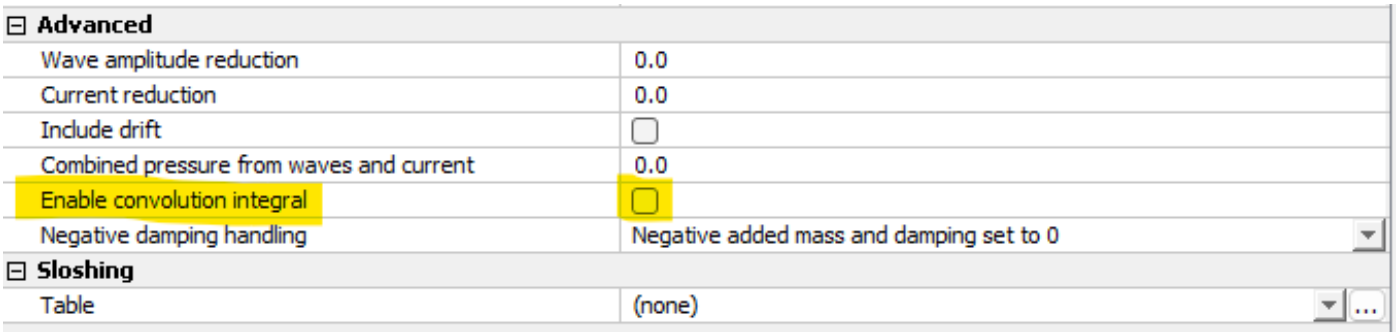


Figure 29 How to enable forces caused by convolution for hydrodynamic response.

9.4 Drift

In AquaSim the total pressure from waves acting on the membrane panels, when using a diffraction load formulation, are always calculated to the instantaneous wetted surface as described in (Faltinsen, 1990) and as shown in Figure 30. Meaning that second order drift forces are always accounted for, by default.

When activating the parameter "Include drift", shown in Figure 31, the quadratic term in Bernoulli's equation ($\frac{1}{2}\rho v^2$) is included in the evaluation of the total pressure from waves and is calculated to the instantaneous wetted surface. Meaning that this represents the inclusion of a third order drift force.

The velocity (v) in this term, does in this case represent the water particle velocity stemming from the incoming and diffracted waves (Note: contributions from radiated waves are not included), acting on each panel. For a stationary structure, the velocity (v) will then act tangentially on each panel, since the boundary condition on the structure requires the total normal fluid flow velocity on each panel to be zero, ensuring no fluid flow through the structure, as mentioned previously.

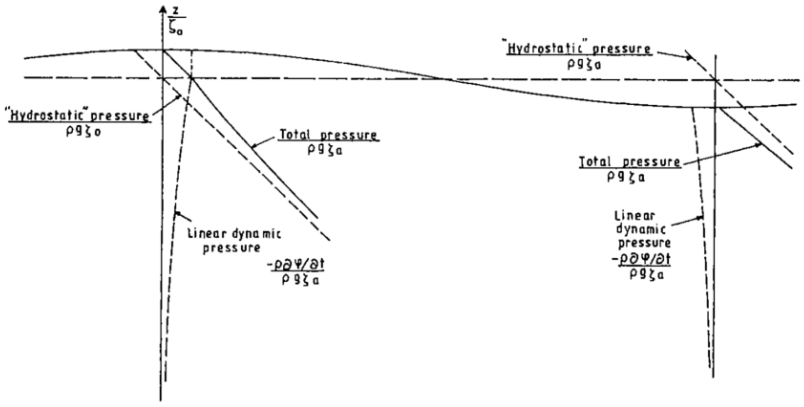


Fig. 2.3. Pressure variation under a wave crest and a wave trough according to linear wave theory.

Figure 30 Pressure variation under a wave, as presented in (Faltinsen, 1990).

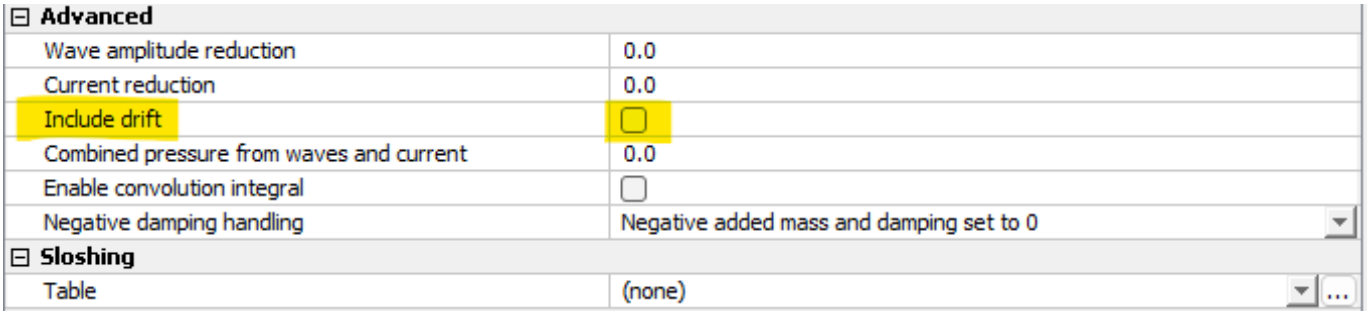


Figure 31 Option for enabling the quadratic term in Bernoulli's equation for calculations of drift forces.

9.5 Added mass waterline corrections

In AquaSim, it is possible to adjust how the added mass on the membrane panels should behave with respect to in-and-out of water effects, by choosing different options for the parameter "Added mass indicator" as shown in Figure 32 (Aquastructures AS, 2024a).

The different options are:

- **0: Mean free surface:** The added mass is distributed to the mean free surface, and the mass is distributed to the nodes based on the principle of "consistent mass" (Note: no mass is included in rotational DOF's). The mean free surface is the surface at the steady state condition where approximate 2/3 of the current velocity has been added to the system. This option is suitable for flexible membrane panels where water underneath the panel will tend to follow the panel with the wave.
- **1: Mean free surface, lumped mass:** Same as "0", but the mass is distributed to the nodes based on the principle of "lumped mass".
- **2: Actual waterline:** The added mass is distributed to the actual wetted surface (actual waterline) during the analysis, meaning that elements that have moved out of water will experience no added mass, as well as added mass will be included when elements initially above the waterline gets submerged. The mass is distributed to the nodes based on the principle of "consistent mass" (Note: no mass is included in rotational DOF's). This option can be suitable for a stiff cylinder going in and out of water in a rather wall-sided manner. It is combined with consistent mass.
- **3: Actual waterline, lumped mass:** Same as "2", but the mass is distributed to the nodes based on the principle of "lumped mass".

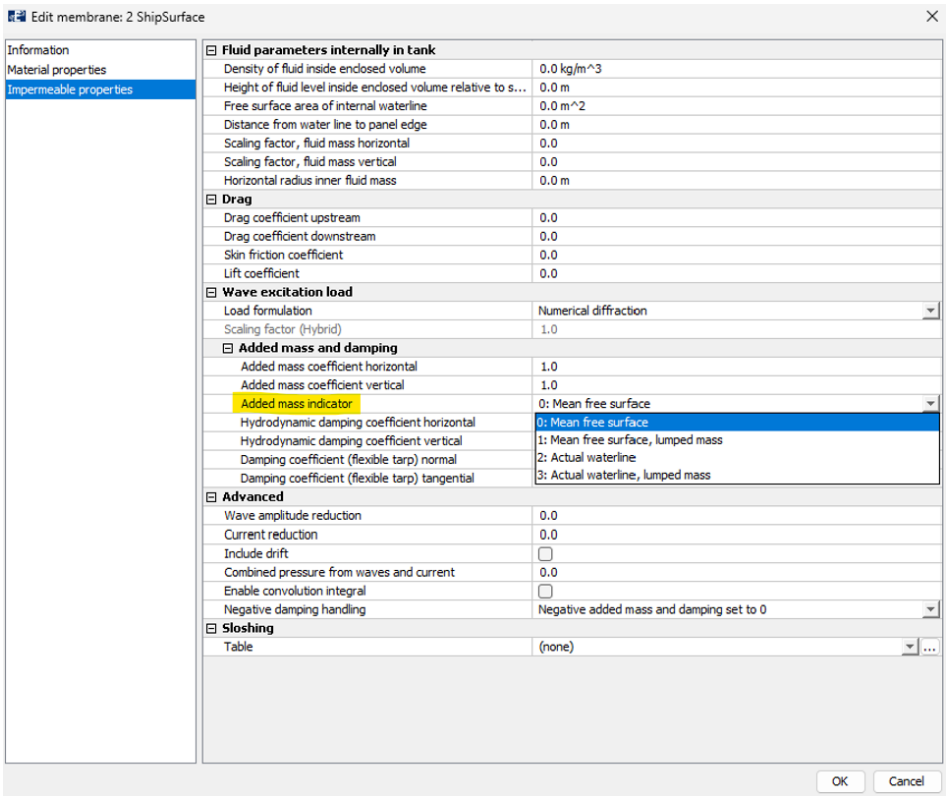


Figure 32 Option for waterline corrections for added mass.

9.6 Arbitrary motions and hydroelasticity

In the calculations of added mass and hydrodynamic damping, pure translatory rigid body motions are assumed, when solving the "radiation problem" in NEMOH. This means that for rigid body rotations (i.e. roll, pitch, yaw) and arbitrary deformations (i.e. hydroelasticity) only the contribution from the "cross-terms" stemming from the pure translatory rigid body motions (i.e. surge, sway, heave) are considered for the added mass and hydrodynamic damping (Aquastructures AS, 2025c).

9.7 Negative added mass and hydrodynamic damping

In AquaSim, you have the option of how to handle numerically calculated added mass and hydrodynamic damping, that are negative, as seen in Figure 33.

You can either use the numerically calculated added mass and hydrodynamic damping "as is" on every panel, by setting the parameter "Negative damping handling" to "Negative added mass and damping allowed".

Alternatively, you can ensure that the added mass and hydrodynamic damping are set to 0 for panels where the numerically calculated added mass and hydrodynamic damping are negative. This might be desirable, in cases where negative added mass and/or negative hydrodynamic damping, results in problems with respect to convergence.

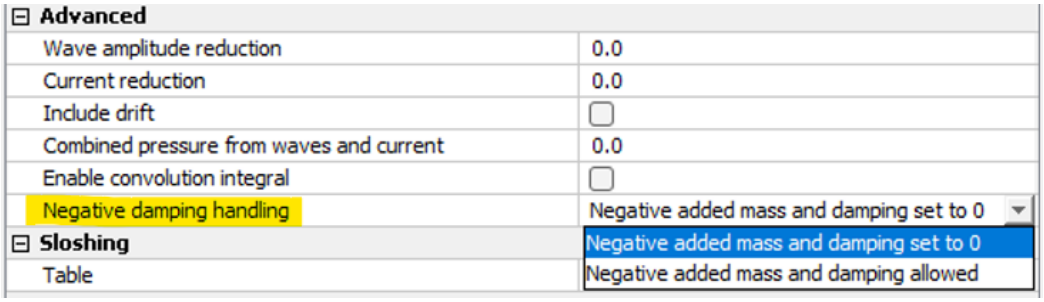


Figure 33 Options for handling negative added mass and hydrodynamic damping.

9.8 Other considerations

It is important to be aware of the limitations of linear potential theory solvers and especially with respect to parametric singularities (e.g. irregular frequencies), as well as geometrical singularities such as horizontally oriented panels close to the free-surface or close to the seabed (for finite water depth), panels very close to each other (especially parallel panels such as narrow gaps), and sharp corners (especially convex corners with small internal angles), since this might result in numerical instabilities and non-realistic results. It is therefore recommended to consider all these aspects when evaluating the results that are obtained, especially if the results seem unphysical.

10 Summary

In this tutorial we have seen how we can use the linear potential flow theory solver NEMOH in AquaSim to perform hydrodynamic analysis, exemplified by the analysis of a simple rectangular barge. Themes such as the theoretical background, preprocessing (panel orientation, meshing, structural aspects etc.), postprocessing and verification of results has been covered, as well as details concerning finite water depth, current-wave interaction, irregular waves, drift and different corrections e.g. around the free surface. Furthermore, different types of singularities relevant for linear potential flow theory BEM solvers have been discussed.

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R. Kurnia, G. D.-C. (2022, 06). Second Order Dfference- and Sum-Frequency Wave Loads in the Open-Source Potential Flow Solver NEMOH. *In International Conference on Offshore Mechanics and Arctic Engineering, volume 5A: Ocean Engineering*.

12 Revision comments

Revision no.	Date	Comment
1.0	20.10.2025	First publication

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