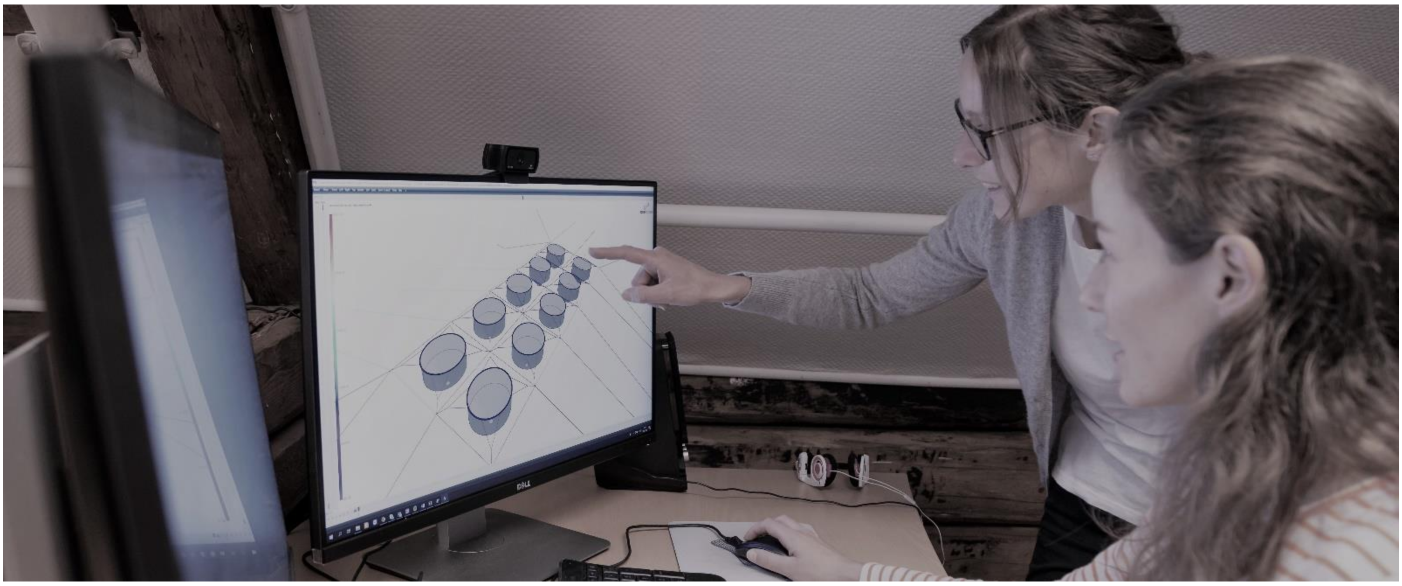
AquaSim training courses

- **Eigen periods**



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Content

1 Prerequisites

This tutorial presents some simple case studies with the purpose of demonstrating functionality in AquaSim.

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

2 Introduction

This tutorial presents the variety of possibilities to investigate resonant motions caused by eigen periods in AquaSim. You will be introduced to how these periods can be calculated explicitly, and how they can be investigated in broader sense. Eigen periods are also commonly referred to as natural periods, or eigen frequencies. In this tutorial, we apply the term ‘eigen period’.

These types of periods are important in the sense of understanding the response of structures. It is determined by the distribution of mass and stiffness. Resonant motions can cause significant response in the structure, and in worst case failure of structural integrity.

Construction standards often require eigen periods to be investigated. As an example, the Norwegian standard NS 9415 section 9.2 states that “*In order to determine dynamic amplification factors, it is necessary to know the natural frequency of the structure and variations in loads in both time and space*.” Further, section 9.4.5.2 states “*The risk of natural modes of vibrations in the structure shall be assessed and documented.”* Similar requirements are common in other standards as well.

3 Principles of eigen period analysis in AquaSim

In AquaSim, one has the possibility to apply eigen period analyses through the option **Buckling /eigen period analysis** found in the **Export** menu. This is illustrated in the figure below.

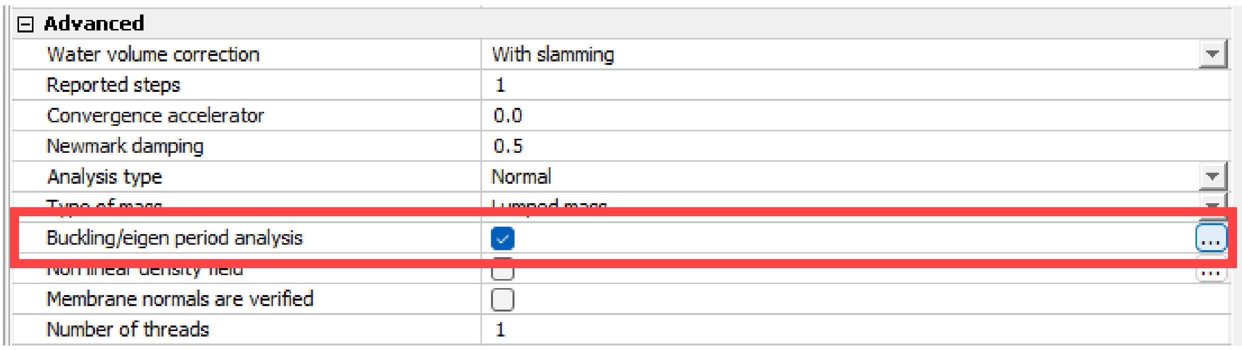

Figure 1

By selecting the three dots **[…]** to the right (see the figure above), one enters the control window for eigen period settings.

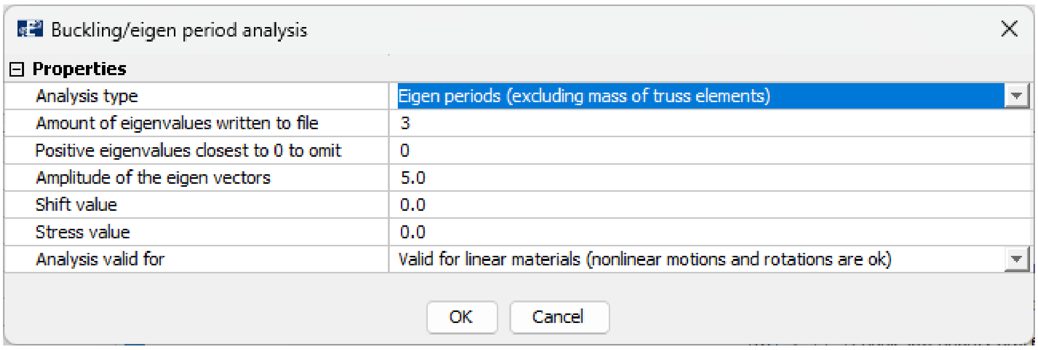

Figure 2

The parameters in the figure above should be defined prior to the analysis and are described in the succeeding sections.

3.1 Analysis type

Eigen period analysis solves the equation:

$$K - \omega^2 M = 0$$

where K is the stiffness for the structural configuration at the given analysis timestep, M is the mass of the structural configuration at the same timestep. The result that is found is the eigen value $\lambda = \omega^2$, which is the eigen frequency, and $T = 2\pi/\omega$ is then the eigen period.

Please note that in the AquaSim-eigen-period-analysis mass of water inside any modelled container is accounted for. Mass of Membranes are not included, except from Shell where this is accounted for.

Analysis type provides four different options:

- Buckling: calculation of buckling modes (not a topic of this tutorial).

- Eigen periods (excluding mass of truss elements): this analysis type exclude the effect of mass in truss elements. Then M, in the formula above, will equal to zero for truss elements. Due to the nature of truss elements (which normally are slim and not very stiff), AquaSim may find numerous of eigen periods. All these periods can be perceived as “noise”. If your model includes truss elements, but they are not an essential part of your eigen period investigation, you may choose this analysis type. One example could be eigen period study of a moored barge or ship, where the mooring lines are modelled as truss elements.

- Eigen periods (including mass of truss elements): this analysis type includes the effect of mass in truss elements. Then M, in the formula above, will not equal to zero. This analysis type can be useful to apply if you have a model where truss elements are a part of your eigen period study, e.g. framework construction such as masts or bridges.

- Eigen periods (excluding mass of truss elements and mass caused by nodal loads): if your model includes component type truss and Pointloads, this analysis type will not include the effect of mass in trusses and mass from Pointloads. If you have a model with Pointload that is for example applied as a bottom weight on mooring lines, one may risk ending up with numerous of eigen periods. As for the first analysis type, this one is useful to apply if your model contain both truss elements and Pointloads, but they are not essential for your eigen period study.

3.2 Amount of eigenvalues written to file

AquaSim may report up to six positive eigen periods to the result files. Amount of eigen values written to file must be a number that is higher than 0 and lower than 7.

If this parameter is equal to 3, then the three eigen periods that is closes to the **Shift value** is calculated.

3.3 Positive eigenvalues closest to 0 to omit

How many positive eigen values closest to 0 that shall be omitted in the results written to file.

3.4 Amplitude of the eigen vectors

The amplitude of the eigen vectors. The eigen vector indicates the direction of motion for the calculated eigen period. This parameter is unitless and can be interpreted as an amplification factor for the eigen vector. It makes is easier to identify the direction of the eigen value and evaluate the results. An example is illustrated below: a beam with two different values for the eigen vectors.

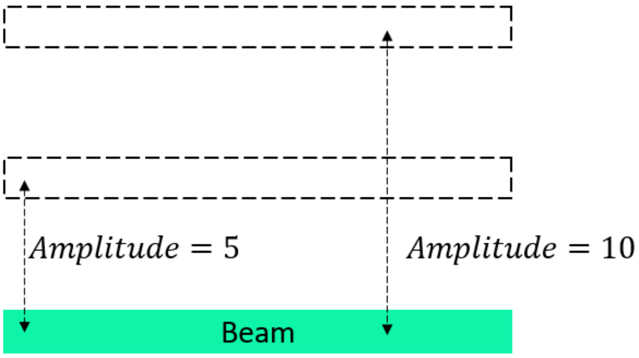

Figure 3

3.5 Shift value

Shift value is where calculated eigen values are centered around. The lowest frequencies (i.e. the highest periods) of the structure is aimed for if this parameter is 0. It pinpoints the area in which one wish to find eigen periods.

3.6 Stress value

This option is not currently available to use in AquaSim.

3.7 Analysis valid for

What type of materials the analysis should be conducted for. Two options are available:

- Valid for linear materials (nonlinear motions and rotations are ok): only material data from *Material/ section properties* are considered in the analysis. Potential nonlinear relation from NLD-tables is not considered when calculating eigen values.
- General, but noiser buckling response: materials with both linear and nonlinear relations are included in the eigen value analysis. Please note that AquaSim may find numerous of eigen values when this is selected, and can be perceived as “noise”.

3.8 Calculations and results

To include eigen period study when conducting an AquaSim-analysis, the user should select the checkbox for **Buckling /eigen period analysis**. The user then exports the model and run an analysis as for ordinary analyses, see figure below.

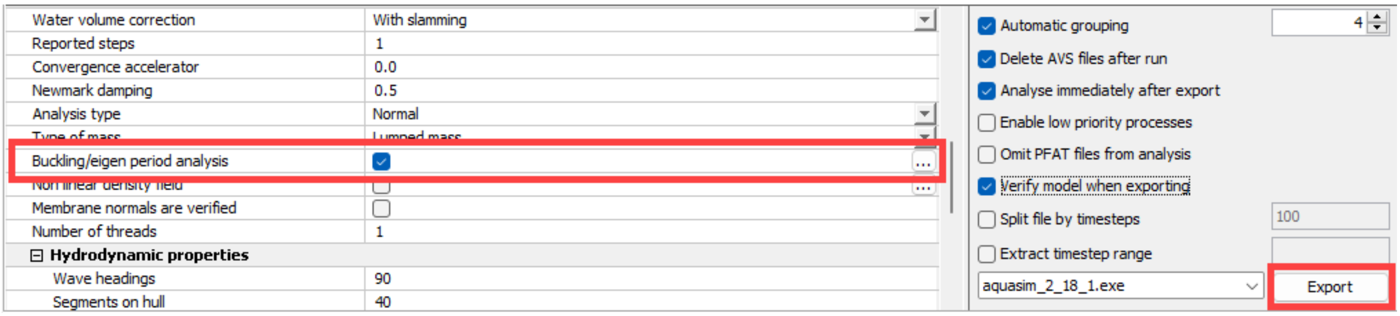

Figure 4

Eigen period studies can be run for static as well as dynamic problems. Meaning that the effect of current, wind and waves can be included in your eigen period study.

Having carried out the analysis, some additional result files will be generated, they are presented in the figure below.

0_01eigen1.avz	08.01.2024 06:32	Compressed Aquasim result file	81 kB
0_01eigen2.avz	08.01.2024 06:32	Compressed Aquasim result file	80 kB
0_01eigen3.avz	08.01.2024 06:32	Compressed Aquasim result file	80 kB
0_01eigen4.avz	08.01.2024 06:32	Compressed Aquasim result file	76 kB
0_01eigen5.avz	08.01.2024 06:32	Compressed Aquasim result file	79 kB
0_01eigen6.avz	08.01.2024 06:32	Compressed Aquasim result file	81 kB

Figure 5

The *<filename>eigen1.avz* will include the results for the eigen value closest to **Shift value**. Please note that each step in the analysis is considered separately, such that each step must be evaluated by the user. The *<filename>eigen2.avz* contain results for the eigen value second closest to **Shift value**, and so on.

4 Case study - Barge

4.1 Learning objectives

In this case study you will be presented to eigen period study of a moored barge from three different perspectives:

1. Eigen period found from stiffness and mass.
2. Eigen period found from direct calculations, applying the AquaSim built-in eigen period analysis tool.
3. Eigen period found from dynamic analysis, where the dynamic response is found, and the natural period is extracted.

4.2 Introduction

In this case study, you may apply the AquaSim model *Barge.amodel* that is associated with this tutorial. Load this in AquaEdit by double-click on the file.

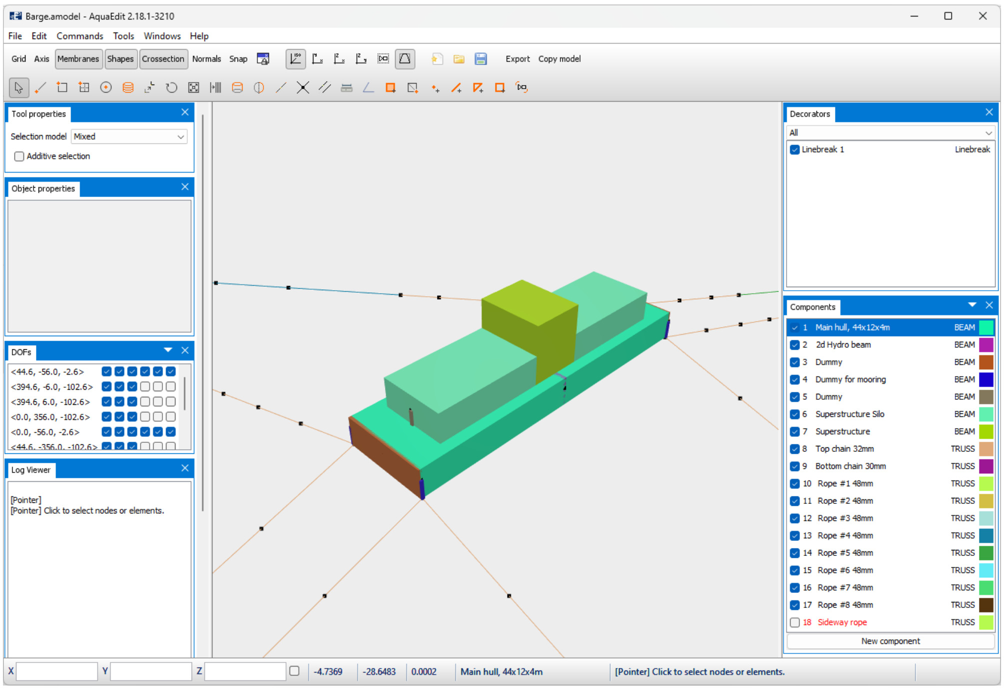

Figure 6

You may notice in the **Components** window that *18 Sideway rope* is deactivated, this should be so until you are notified to activate it.

The main particular of this barge is given in the table below. Both the mass of the barge if self and its associated added mass will contribute to the eigen period.

Length [m]	44.6
Width [m]	12
Draft [m]	2.61
Mass [kg]	1431.21E+03
Added mass sideways (y-direction) [kg]	858.58E+03

4.3 Eigen periods found from stiffness and mass

In this section, the eigen periods are found based on resulting stiffness and mass for the AquaSim analysis. To do so, one has to introduce displacement to the barge. This is done by apply wind on the broad side of the barge (along global y-direction).

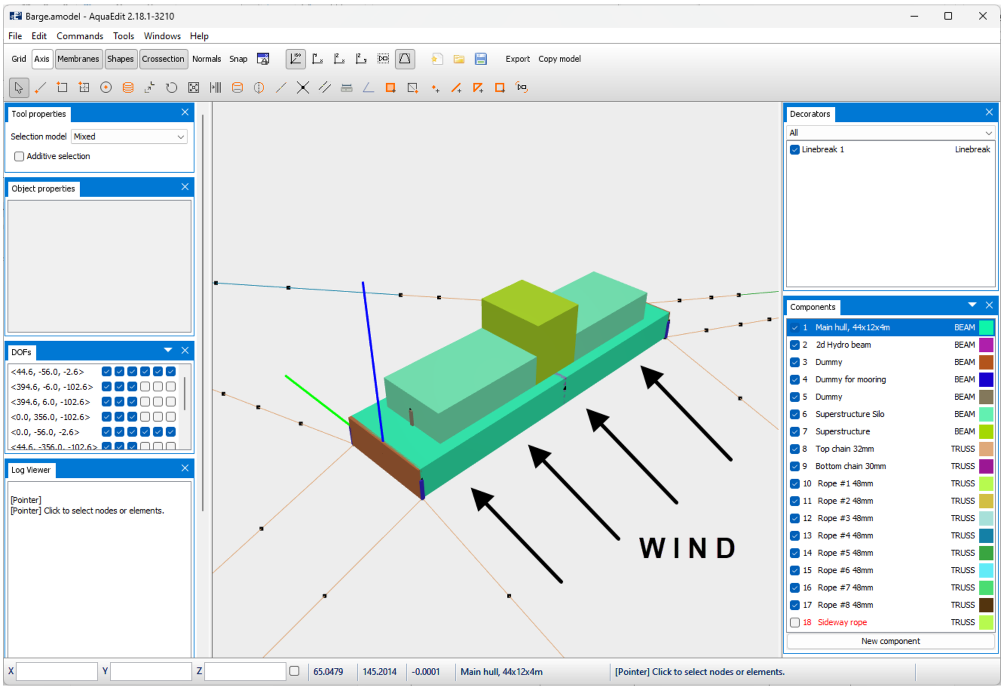

Figure 7

The wind will also induce forces in the mooring line. The eigen period is then found based on the barge displacement and the total horizontal force in the mooring line.

In AquaEdit, select **Export** and the tab **Sidewind**. The added mass is dependent on the wave period. The added mass is calculated from T[s] in the input. For this case, this is 50s. As eigen periods vary with both barge mass + added mass, one should be aware of this.

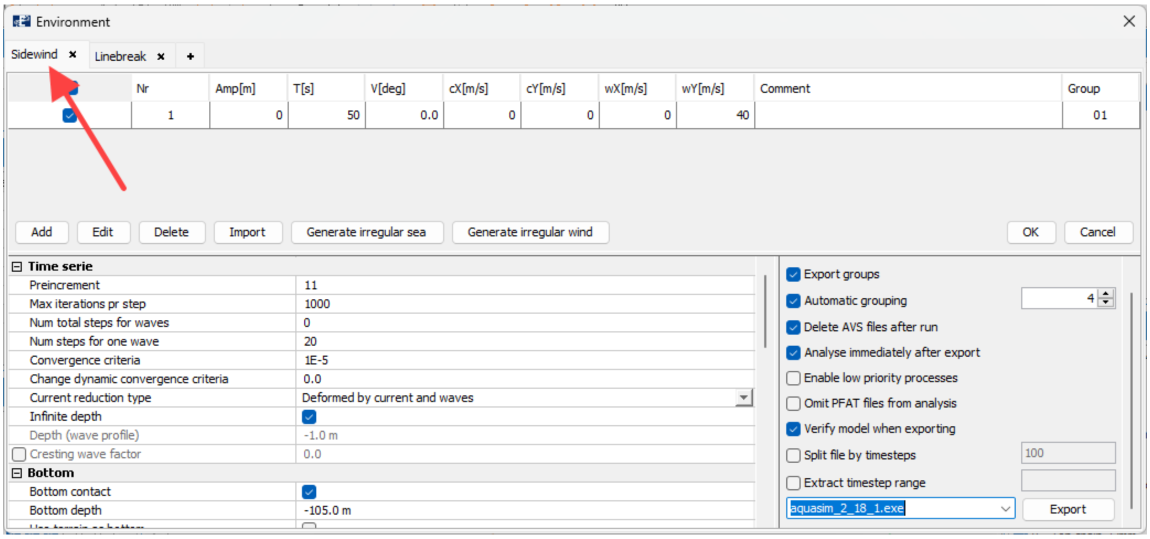

Figure 8

Select **Export** and start the analysis. Alternatively, you can open the equivalent analysis from the folder *Analysis > Barge-Mass-and-Stiffness* following this tutorial. Note that if you conduct your own analyses, you will have more files generated than the one following this tutorial. Other files, that is not relevant has been deleted.

MassStiffness_01.avz	08.01.2024 10:51	Compressed Aqua...	265 kB
MassStiffness_01key.txt	08.01.2024 10:51	Tekstdokument	11 kB
MassStiffness_01val.txt	08.01.2024 10:51	Tekstdokument	10 kB

Figure 9

Open the file *MassStiffness_01.avz*, and plot displacement of the barge in y-direction: **Result** > **Displacement** > **Displacement Y [m]**, then click on an element on the barge as shown in the figure below. In AquaSim, wind is applied in incremental steps, meaning that it is linearly increased from 0 to fully developed through the initial static steps in the analysis. This is reflected by an increased displacement of the barge. The displacements from step 1 to 11 are taken out and copied to a table (you may use the attached document *Tutorial-Eigenperiods-calculations.xlsx*).

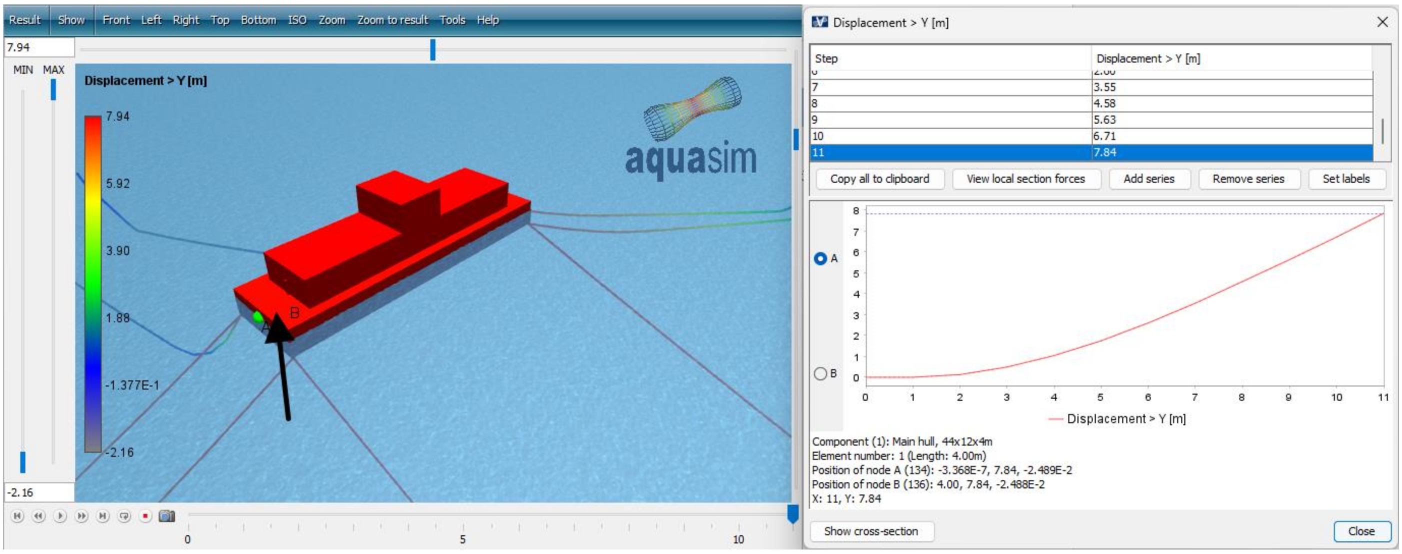

Figure 10

Global section force > **Force Y [m]** is taken out for each mooring line and copied to a table, and the net horizontal force is calculated.

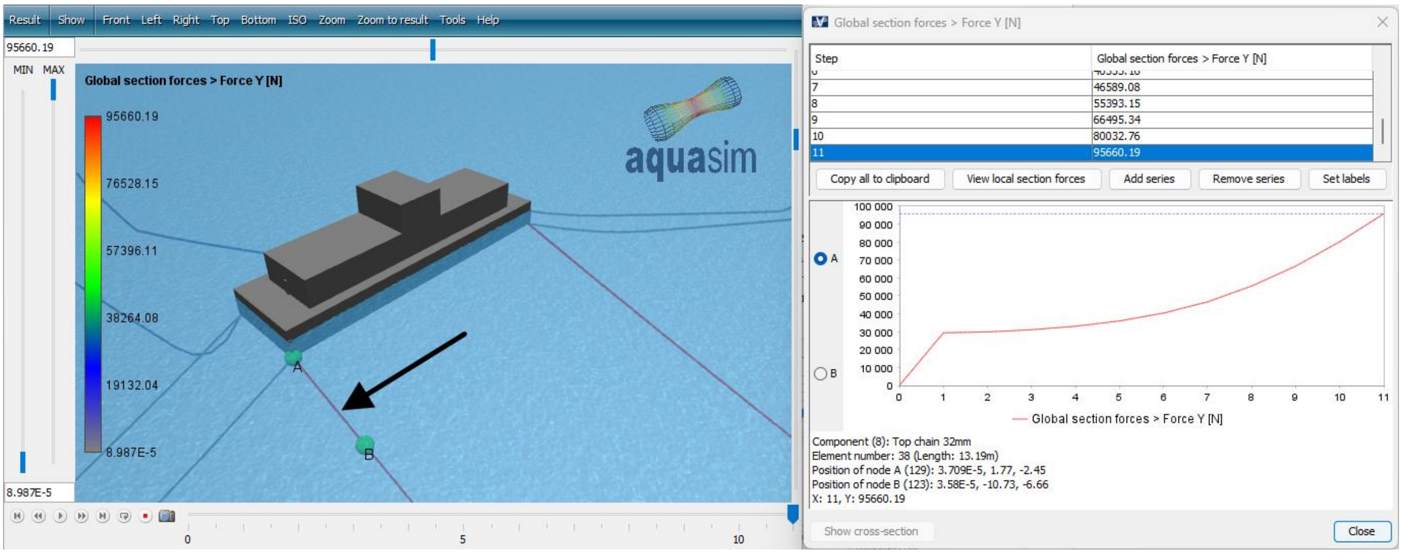

Figure 11

Then tangential stiffness K is found from Hooke's law (assuming linear relation between force and stiffness):

$$K = \frac{F_y}{r_y}$$

where F_y is the net horizontal force, and r_y is the displacement of the barge. The eigen period T is calculated based on:

$$K - \omega^2 M = 0 \;\rightarrow\; \omega = \sqrt{\frac{K}{M}} \;\rightarrow\; T = 2\pi\sqrt{\frac{M}{K}}$$

where M is the sum of the barge mass and added mass in y-direction.

The resulting eigen periods for each analysis step are presented in the table below.

F_y (horizontal force y-dir.) [N]	r_y (displacement y-dir.) [m]	K (stiffness) [N/m]	T (eigen period) [s]
2105	0.13	16591	73.8
8242	0.49	17012	72.9
18208	1.03	18300	70.3
31852	1.74	19398	68.3
49052	2.58	20334	66.7
69703	3.52	22032	64.1
93714	4.54	23421	62.1
121004	5.58	26357	58.6
151495	6.65	28397	56.4
185118	7.77	30146	54.8

4.4 Eigen periods found from direct calculations

The eigen periods of the barge should now be calculated explicitly from the eigen period analysis tool. The results are then compared with the ones found from mass and stiffness.

In the AquaEdit model, go to the **Export** menu and select the tab Sidewind. From the **Advanced** section, select the checkbox **Buckling /eigen period analysis**.

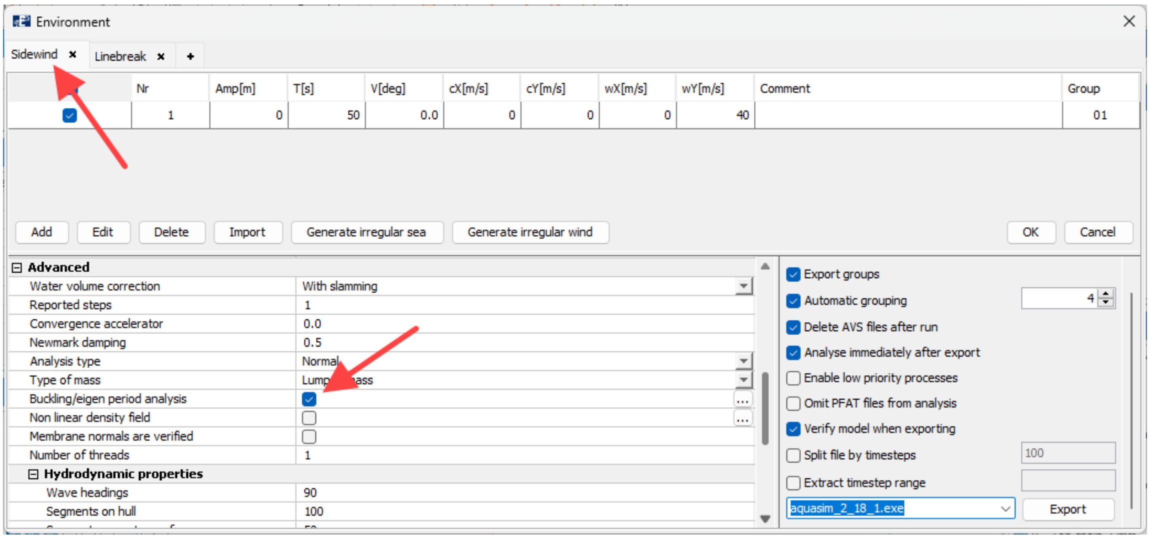

Figure 12

Then select the three dots to the right to enter the control window for eigen period settings. Select input as given in the figure below.

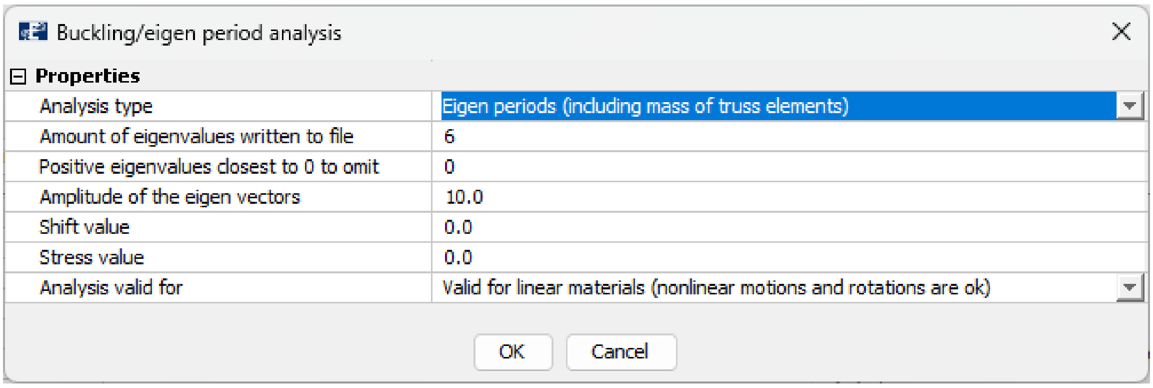

Figure 13

Select **OK**. **Export** the model and **run the analysis**. In this case study, we have named the analysis *Direct_*. In the analysis-folder, 6 additional files have been generated. The *Direct_01eigen1 -6* contain the resulting eigen periods found from the analysis.

Direct_01eigen1.avz	08.01.2024 11:23	Compressed Aquasim result file	168 kB
Direct_01eigen2.avz	08.01.2024 11:23	Compressed Aquasim result file	169 kB
Direct_01eigen3.avz	08.01.2024 11:23	Compressed Aquasim result file	175 kB
Direct_01eigen4.avz	08.01.2024 11:23	Compressed Aquasim result file	167 kB
Direct_01eigen5.avz	08.01.2024 11:23	Compressed Aquasim result file	175 kB
Direct_01eigen6.avz	08.01.2024 11:23	Compressed Aquasim result file	171 kB

Figure 14

The two succeeding figures (*Direct_01eigen1* and *Direct_01eigen2* respectively) contain the first and second eigen period of the system. The resulting eigen period is found in **Result** > **Results** > **Eigenperiod [s]**.

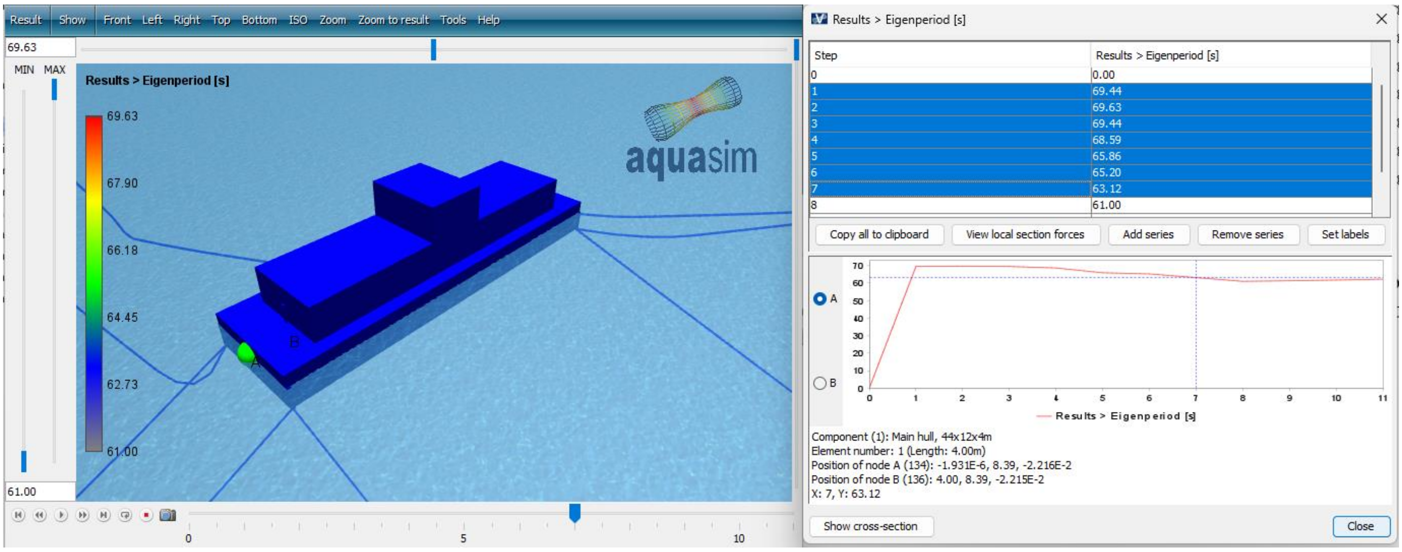

Figure 15

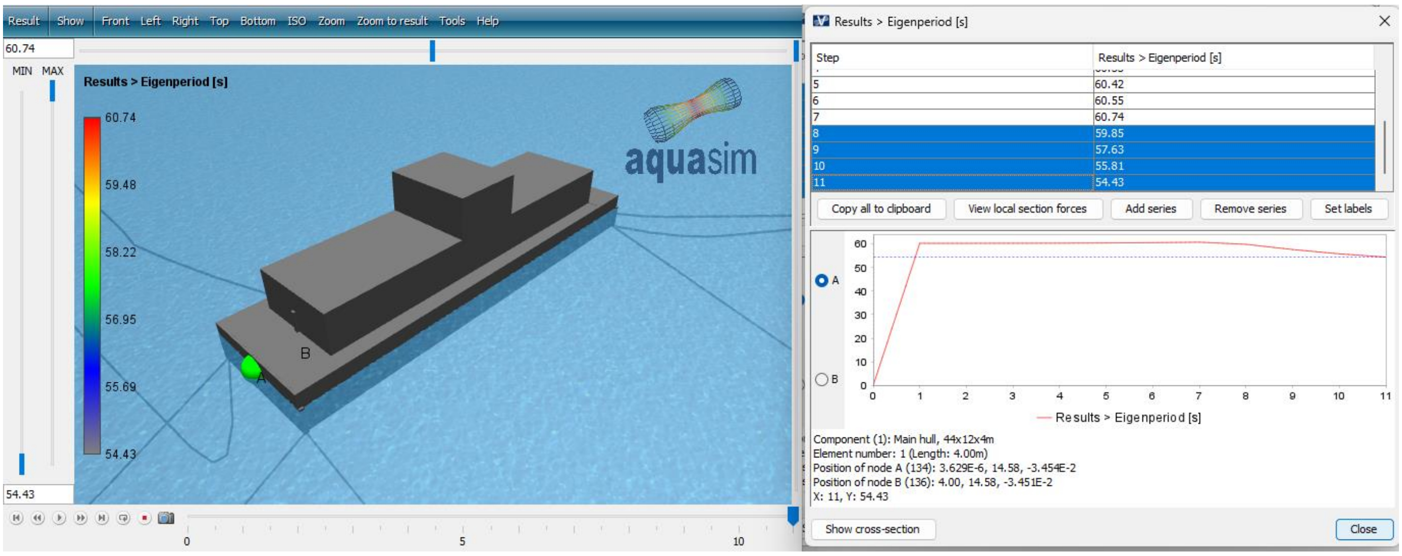

Figure 16

The 7 first steps (out of 11) in *Direct_01eigen1* correspond to the first eigen vector for translation along y-axis. Then step no. 8 to 11 in *Direct_01eigen2* is the second vector for translation along y-direction. This means that you must consider both files when evaluating eigen periods along y-direction.

Resulting eigen periods from the direct calculations in step no. 1-7 and 8-11 are then compared with the results calculated based on mass and stiffness.

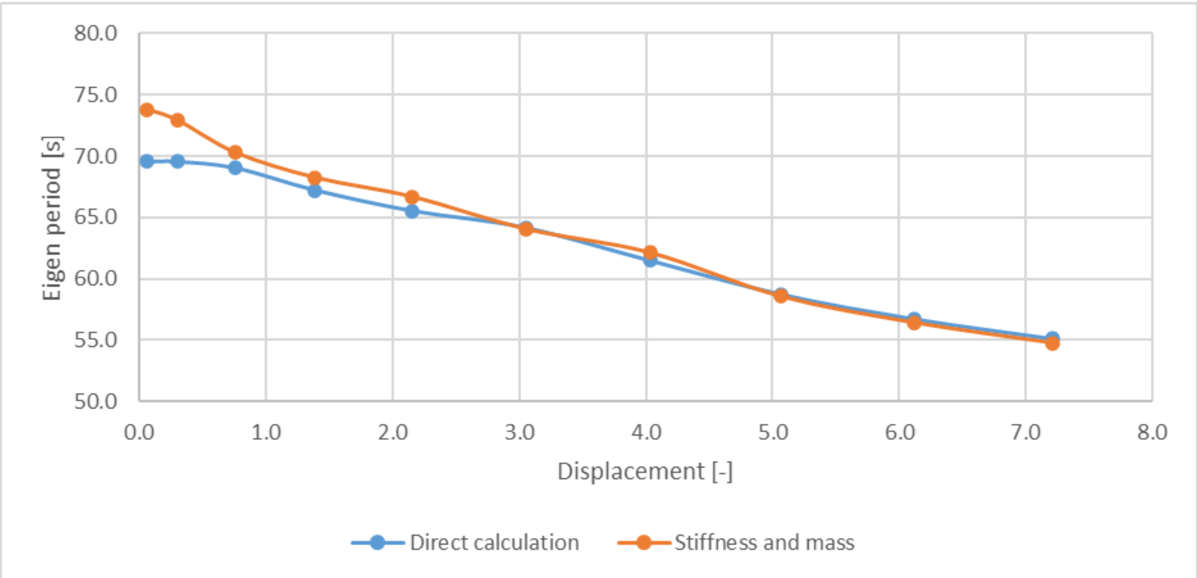

Figure 17

As seen from the graph, results compare well except from in the start. It appears this is due to the stiffness in the direct calculations becomes a bit smaller than the one based on mass and stiffness.

4.5 Eigen periods found from dynamic analysis

In this last barge-case-study, an alternative method of studying eigen periods of systems for dynamic problems is presented. Depending on the problem investigated, trusses can be introduced to induce motions to the model.

Return to the AquaEdit model and navigate to the Components window. The last component *18 Sideway rope* are two trusses attached to the barge. Activate this component by **right click** > **Deactivate**, this will activate the component and the text will go from red to black.

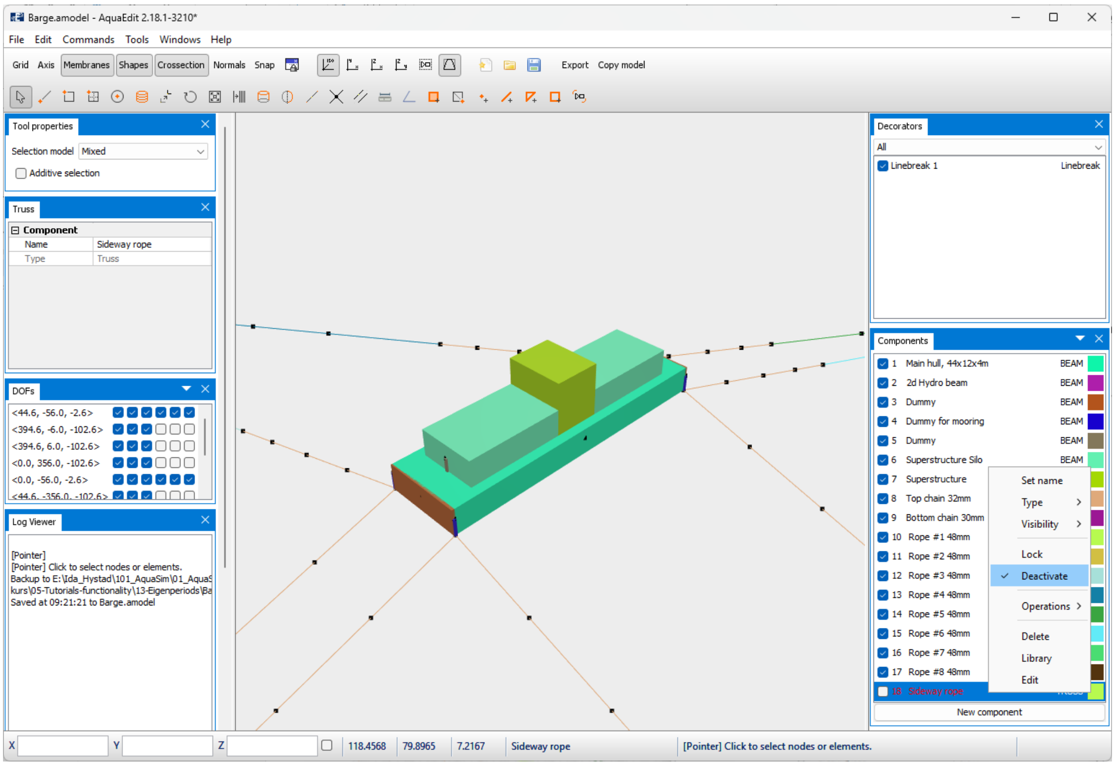

Figure 18

The side ropes are assigned pretension.

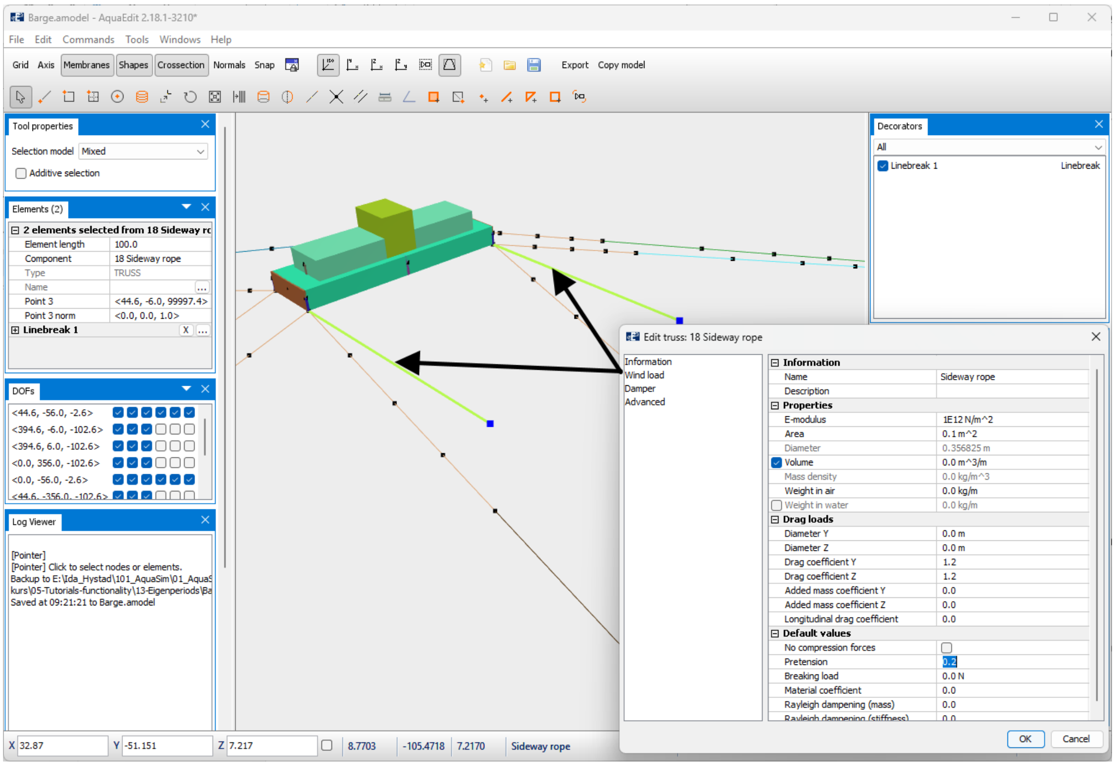

Figure 19

Both side ropes are in addition assigned Linebreak.

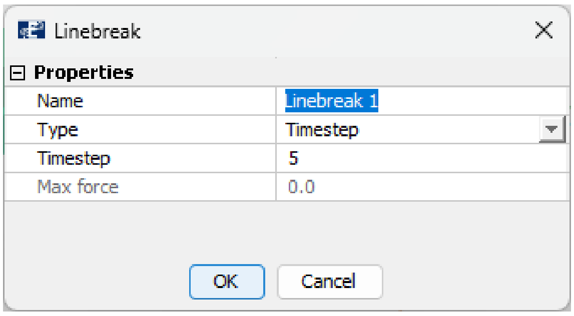

Figure 20

The pretension will cause the barge to be pushed to the side. This is equivalent as being conducted in model basin tests. This means that this is a good analysis to carry out for cases where model basin testing is compared with analyses.

Return to the **Export** menu and select the tab Linebreak. **Export** the model and **run** an analysis.

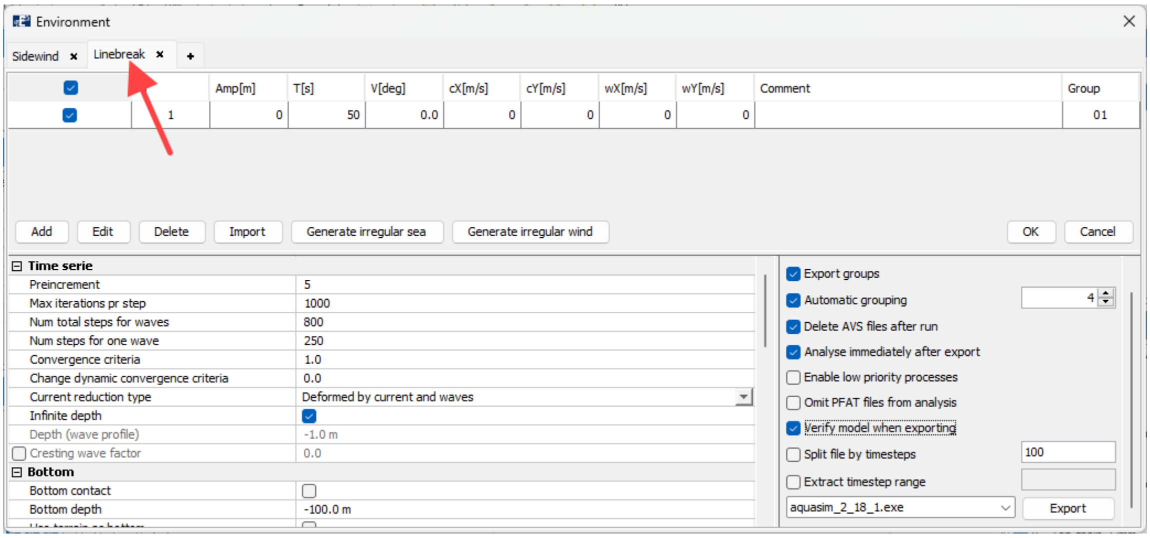

Figure 21

We named the analysis *Dynamic_*. Load the associated avz-file in AquaView and plot displacement in y-direction: **Result** > **Displacement** > **Displacement Y [m]**.

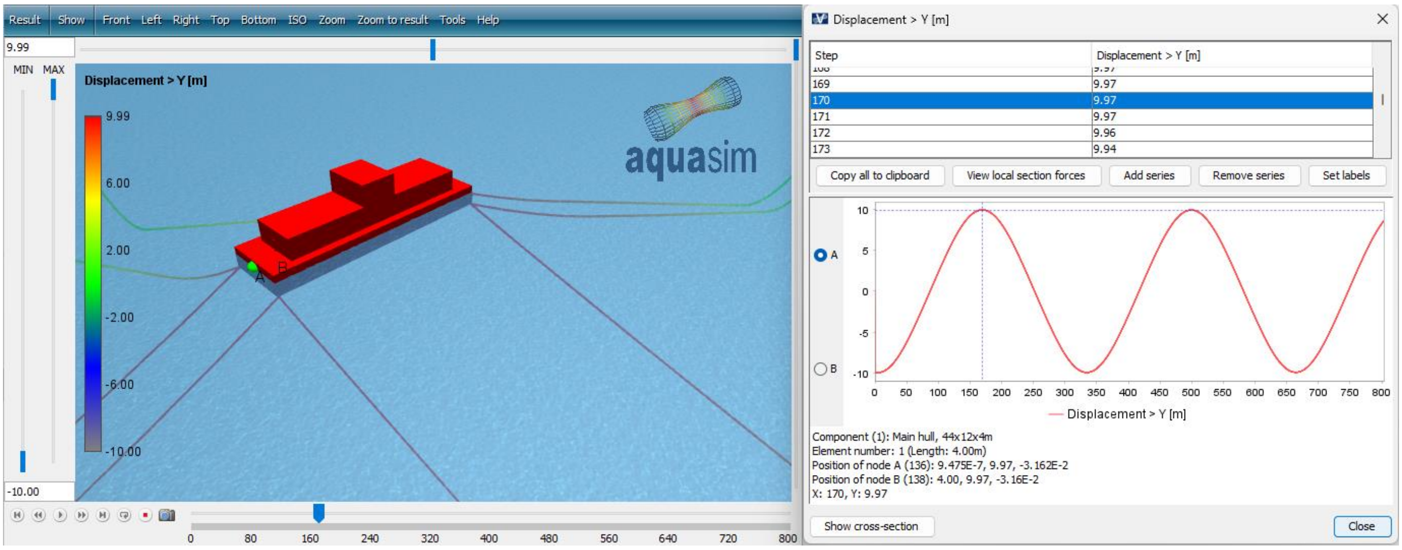

Figure 22

By measuring the time difference between the peaks, one finds that the period of this resonant response is approximate 66 seconds. This compares fairly well with the explicit analysis.

5 Case study – Wind turbines

5.1 Learning objectives

In this case study you will be presented to how eigen period study can be conducted on offshore wind turbines. Upon completion of this case study, you will know:

- basics of how to run eigen period study on a wind turbine,
- basics of how structural parts affects the eigen period of wind turbine system,

5.2 Introduction

Three cases are presented:

1. Turbine only attached to a fixed point.
2. Turbine and tower only, where tower is fixed.
3. Turbine on fixed jacket.

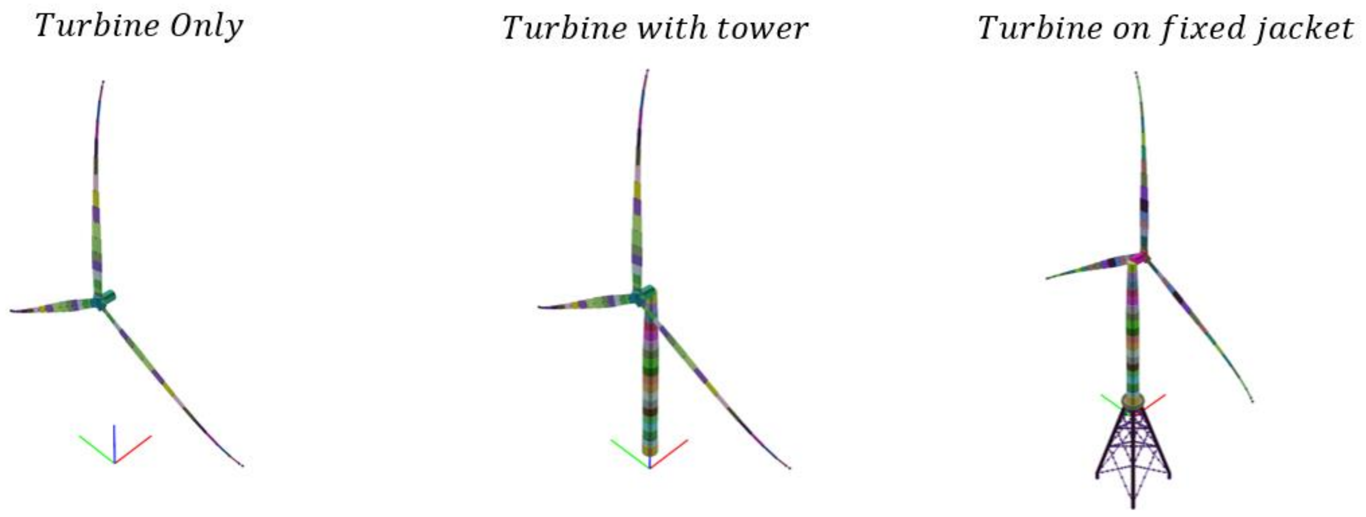

Figure 23

The eigen period analysis is arranged such that the first 5 steps the blades are static (not rotating), then in the 10 last steps the system is dynamic (blades are rotating). Eigen periods are considered for both these parts. The aim is to show that eigen periods changes depending on static or dynamic conditions. Analyses are conducted with a wind velocity of 7 m/s.

5.3 Turbine only

In this case, only the turbine itself is considered. Result files are found in the folder *Analysis* > *Turbine.*

The turbine is fixed at the back end of the shaft. The figure below shows the eigen period and -shape where the upper blade is bending backwards (*turbine-only_01eigen2.avz*). Eigen period for static part is 2.8 s, and about 2.6 s for dynamic.

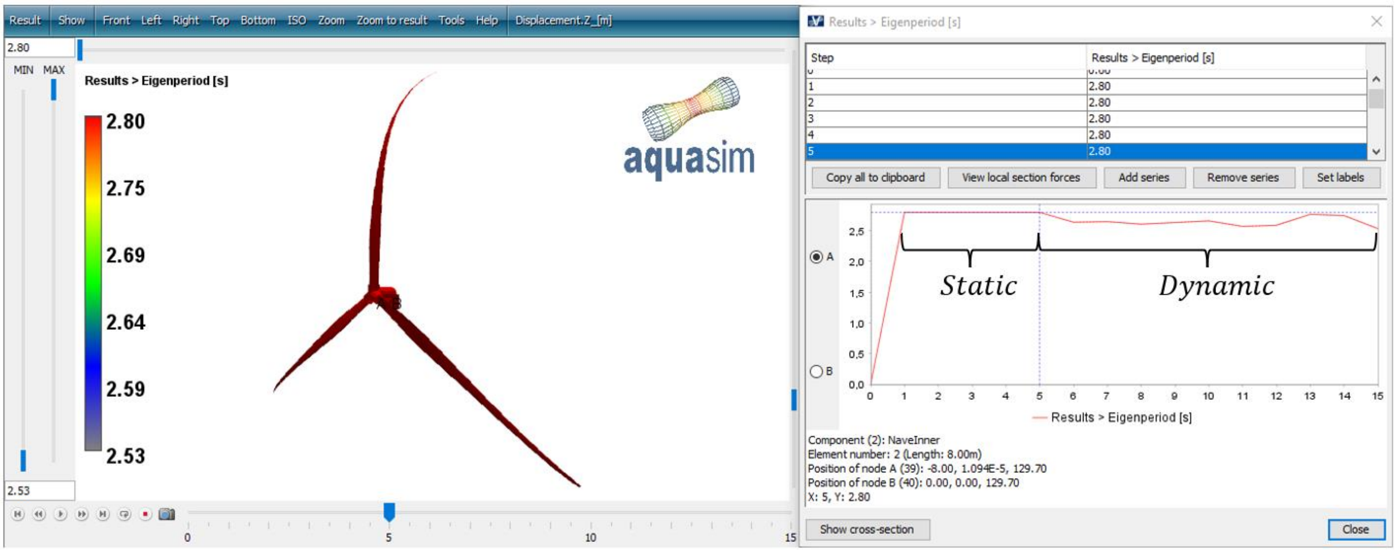

Figure 24

5.4 Turbine with tower

The same analysis is conducted on the same turbine when the tower is included. Result files are found in the folder *Analysis > Turbine*.

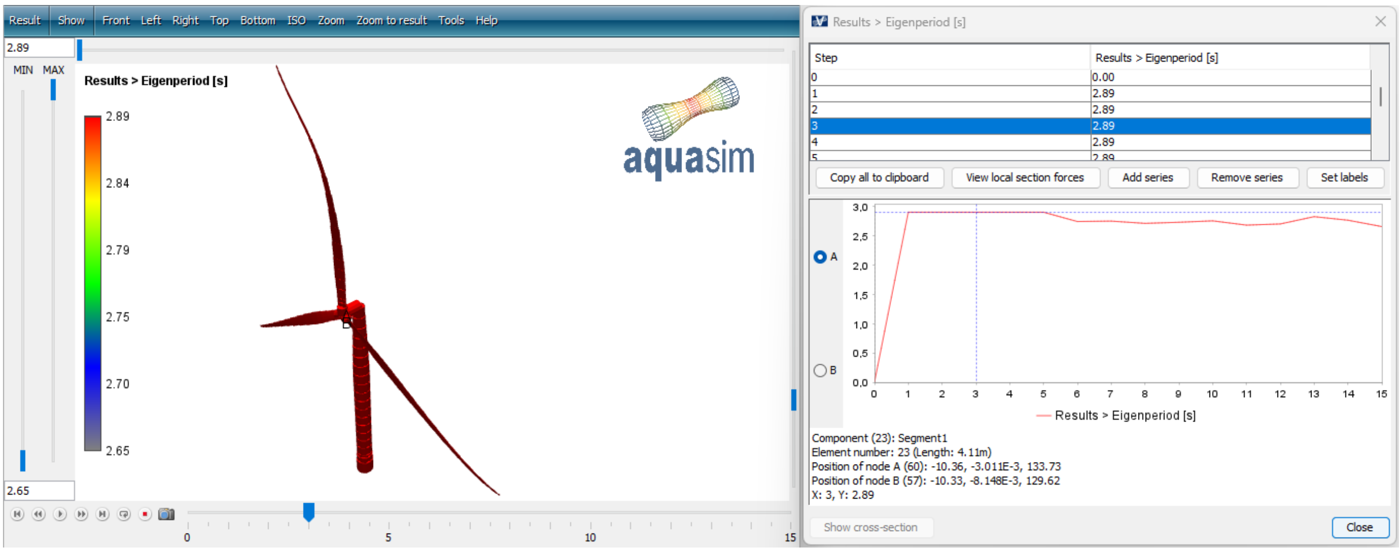

Figure 25

The figure above shows the eigen period and -shape where the upper blade is bending backwards (*turbine-tower_01eigen2.avz*). Eigen period for static part is 2.89 s, and about 2.7 s for dynamic.

5.5 Turbine on fixed jacket

A jacket, fixed to the seabed, is placed beneath the tower. Results are found in the folder *Analysis* > *Turbine*.

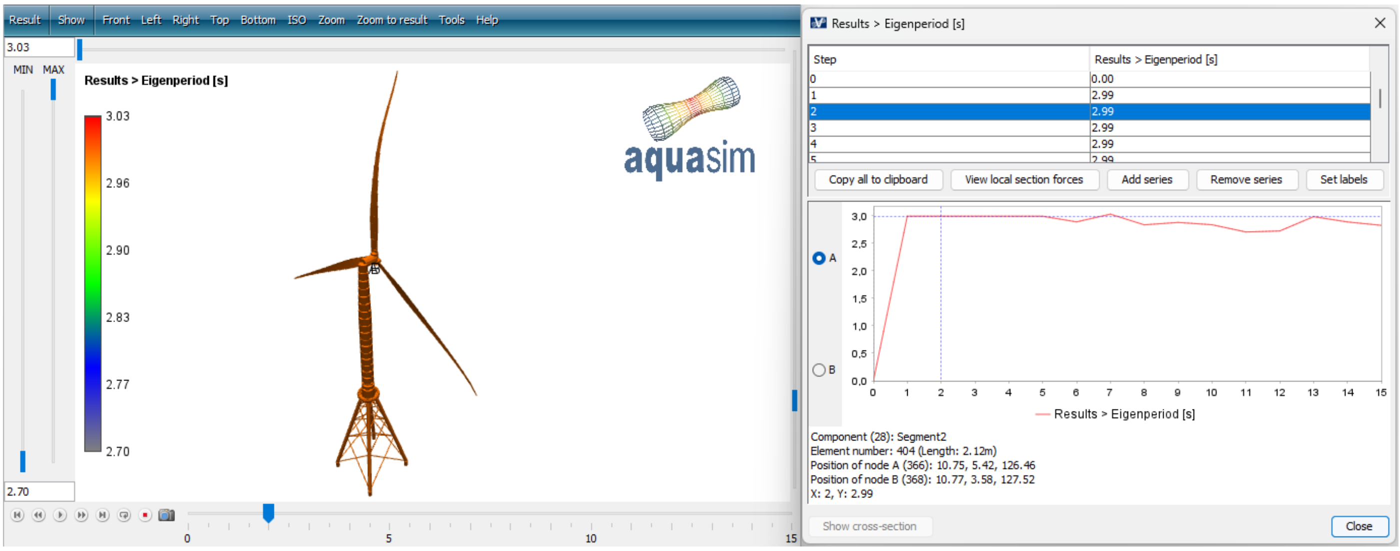

Figure 26

The figure above shows the eigen period and -shape where the upper blade is bending backwards (*turbine-jacket_01eigen2.avz*). Eigen period for static part is 2.99 s, and about 2.9 s for dynamic.

5.6 Result summary

The eigen periods for the different wind turbine configurations are presented in the figure below.

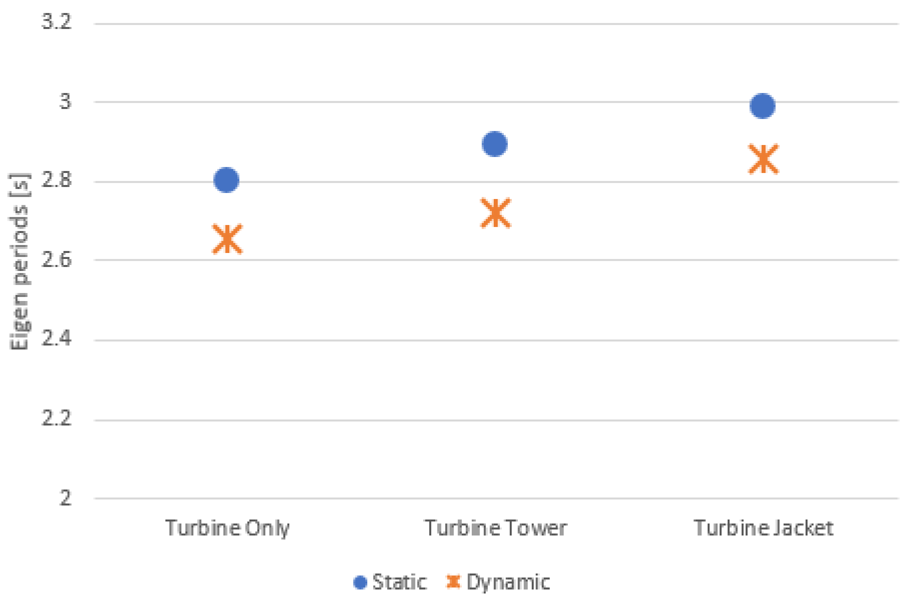

Figure 27

Comparing the three cases one can see the eigen period is sensitive to stiffness of the system. From the first case with only the turbine, to the one with jacket, the eigen period is increasing.

6 Summary

In this tutorial, you have been introduced to different methods for eigen period- and resonant motion studies in AquaSim. In addition to calculate directly by the built-in eigen period analysis tool, one can also set up a model case with trusses and pretension to induce resonant motions.

7 Revision comments

Revision no.	Comment
1.0	First publication

--- End of document ---