Wave amplitude- and current reduction

Reduction of wave amplitude and current on hydrodynamic beam elements in AquaSim

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Summary:
This report summarizes implementation and validation of the feature Wave amplitude reduction and Current reduction on beam elements with the load formulation Hydrodynamic. Numerical analysis has been compared to analytical calculations.

Beam elements with load formulation Hydrodynamic has been applied in this study. Comparison of results show good correspondence, and validation is regarded successful.

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Content

1 Introduction

Reduction of waves and current can occur due to shadow effects. Objects may be situated behind other elements causing reduction of environmental loads, as illustrated in Figure 1.

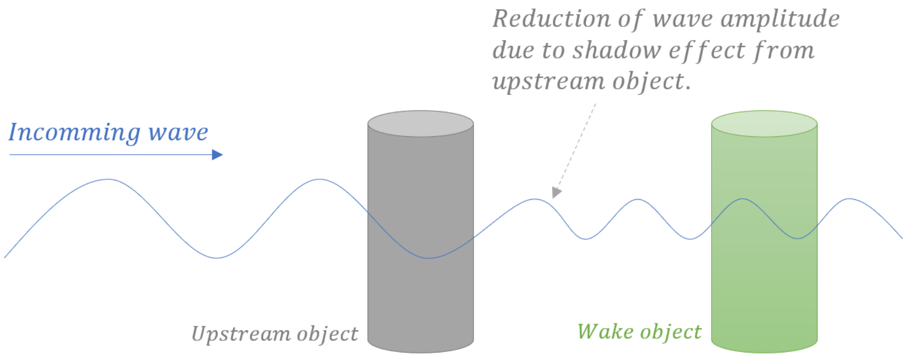

Figure 1 Wave amplitude reduction due to upstream object

The *Upstream object* causes the amplitude of the incoming wave to be reduced in the wake. The *Wake object* is then exposed to a wave with a lower amplitude. In these cases, factors for reduction of wave amplitude and current can be applied in AquaSim.

2 Theoretical formulation

Wave amplitude reduction and *Current reduction* is found in the Edit-beam window Element loads > Advanced in AquaEdit.

2.1 Wave amplitude reduction

The input is a number between 0.0 and 1.0 and corresponds to a percentage of reduction of the wave amplitude. The number 0.0 correspond to 0% reduction, 0.5 is 50% reduction, 0.2 is 20% reduction, and 1.0 is 100% reduction. In the calculation of wave forces, the reduction factor is applied only to the wave amplitude. The reduced wave amplitude is expressed as:

$$\zeta_{AR} = \zeta_A \cdot R$$

Equation 1

where

- ζ_A is the wave amplitude,
- R is the wave amplitude reduction factor (which is the input parameter to AquaSim = 1-wave amplitude reduction),
- ζ_{AR} is the wave amplitude including the reduction factor.

Applying the load formulation Hydrodynamic, the wave forces are calculated according to Morison equation in combination with strip theory. A generalized expression for the wave force in horizontal and vertical direction is ((Faltinsen, 1990) pp.225):

$$F_i = \underbrace{0.5\rho C_D L D \cdot u\sqrt{u^2 + w^2}}_{\text{Drag force}} + \underbrace{\rho V_S(1 + C_a) \cdot a_i}_{\text{Froude-Kriloff \& diffraction force}} + \underbrace{\rho C_a V_S a_{i(beam)}}_{\text{Added mass \& damping force}}$$

Equation 2

where

- F_i is the wave force in i=[x, y, z]-direction,
- C_D is the drag coefficient,
- $u = u_c + u_w$ is the horizontal fluid particle velocity due to current (u_c) and wave (u_w),
- $w = w_c + w_w$ is the vertical fluid particle velocity due to current (u_c) and wave (u_w),
- $V_S = \pi D^2 L/4$ is the wetted volume of the beam,
- D is beam diameter,
- L is beam length,
- C_a is the added mass coefficient,
- a_i is the fluid particle acceleration due to waves,
- $a_{i(beam)}$ is the acceleration of the beam.

The F-K & diff. term and Added mass & damping terms are calculated by strip theory. This means, the resulting wave forces are affected by the number of strips the beam is divided into (See Export > Hydrodynamic properties > Segments on hull in AquaEdit). In addition, the hydrostatic properties are calculated based on the input parameters, as well as beam location in the water line, from AquaEdit.

The fluid particle velocity and -acceleration is calculated based on linear wave theory ((Faltinsen, 1990) pp.16). Fluid particle acceleration due to waves is presented as example:

$$a_1 = \omega^2 \zeta_{AR} e^{kz} \cos(\omega t - kx)$$

Equation 3

where ζ_{AR} is calculated according to Equation 1.

2.2 Current reduction

As for *Wave amplitude reduction*, the input for *Current reduction* is based on a number between 0.0 and 1.0. In AquaSim, the drag coefficient and the drag diameter are scaled according to the Current reduction input value. The drag load, inclusive the reduction, is calculated based on Morison equation:

$$F_i = 0.5 \rho C_{DR} (L D_R) u_c |u_c|$$

Equation 4

where

- F_i is the drag force due to current, in i=[x, y, z]-direction,
- ρ is fluid density,
- $C_{DR} = C_D \cdot R$ is the drag coefficient, inclusive the Current reduction factor R,
- L is length of the object,
- $D_R = D \cdot R$ is the submergence of the object ("Diameter for drag" in AquaEdit), inclusive the Current reduction factor R,
- u_c is current velocity.

A *Current reduction factor* of 0.0 correspond to 0% reduction, 0.5 is 50% reduction and 1.0 is 100% reduction.

3 Validation of Wave amplitude reduction

The aim of this case study is to validate the *Wave amplitude reduction* factor. This is done by consider the axial force in a truss element attached to a beam. Consider a horizontal beam element 50% submerged in the mean water line, see Figure 2. The beam is restrained with two truss elements, only to be allowed to move in x-direction. The beam is assumed static, meaning that velocities and acceleration of the beam will equal to zero. Further, the beam and truss elements are exposed to linear sinusoidal waves.

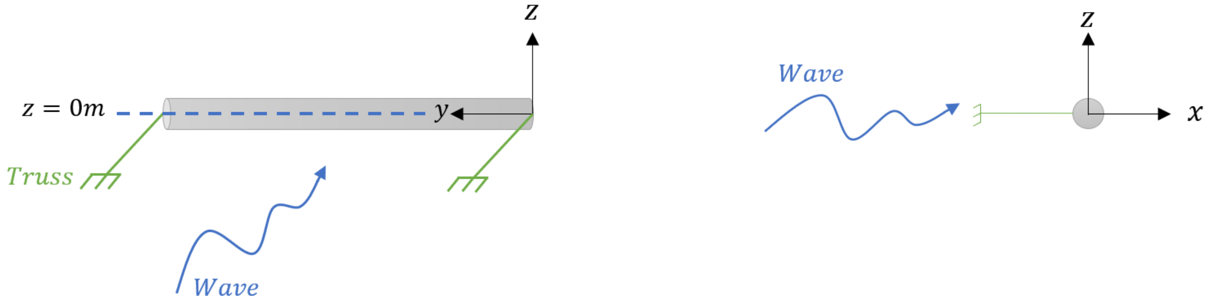

Figure 2

The force in one truss element is found by calculating the horizontal wave force on the beam based on Equation 2. Since the beam is assumed static, the added mass and damping term in Equation 2 will equal zero. To further simplify the case study, the drag coefficient C_D is defined equal to zero, leading the drag-term to be zero. The force in the truss may then be expressed:

$$F_1 = \frac{\rho V_S (1 + C_a) \cdot a_1}{\#_{truss}}$$

where the acceleration a_1 is calculated according to Equation 3. Technical input is presented in Table 1.

Table 1 Technical parameters

Parameter	Abbreviation	Value
Length, beam	L	10 m
Diameter, beam	D	0.5 m
Submergence, beam	S	0.5
Wetted volume, beam	$V_S = (\pi D^2 L/4) \cdot S$	3.93 m3
Drag coefficient	C_D	0 -
Added mass coefficient	C_a	1 -
Fluid density	ρ	1025 kg/m3
Gravitation	g	9.81 m/s2
Reduction factor	$R1$	0.0
	$R2$	0.5
	$R3$	0.2
Wave amplitude	ζ_A	3
Wave period	T	5.1 s
No. of truss elements	$\#_{truss}$	2 -

3.1 AquaSim model

The numerical model is established in AquaSim beta-version 2.16.2-2729 and solver dated 20.08.2021. The beam has properties according to Figure 3.

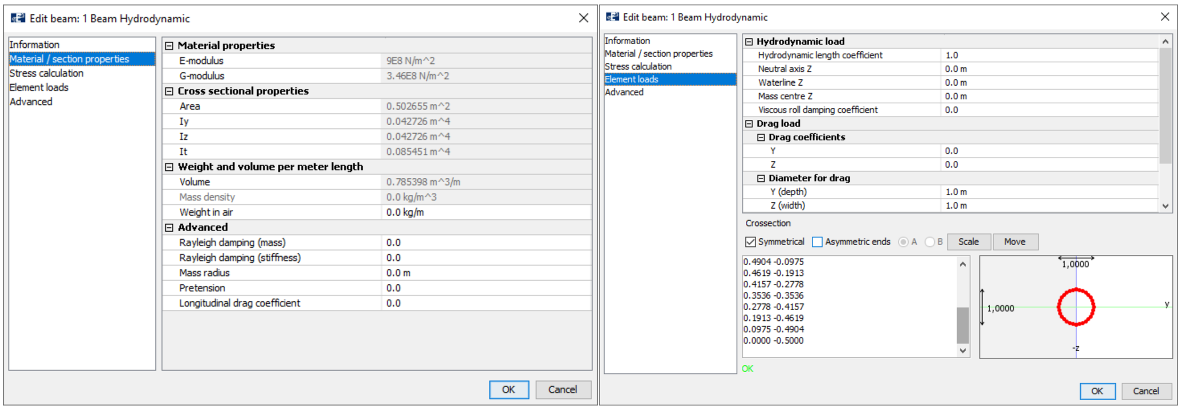

Figure 3 Beam properties in AquaSim

The truss has properties according to Figure 4.

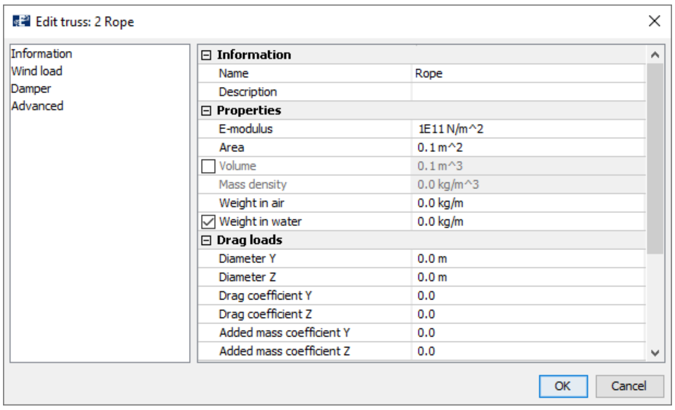

Figure 4 Truss properties in AquaSim

Analysis is set up according to Figure 5.

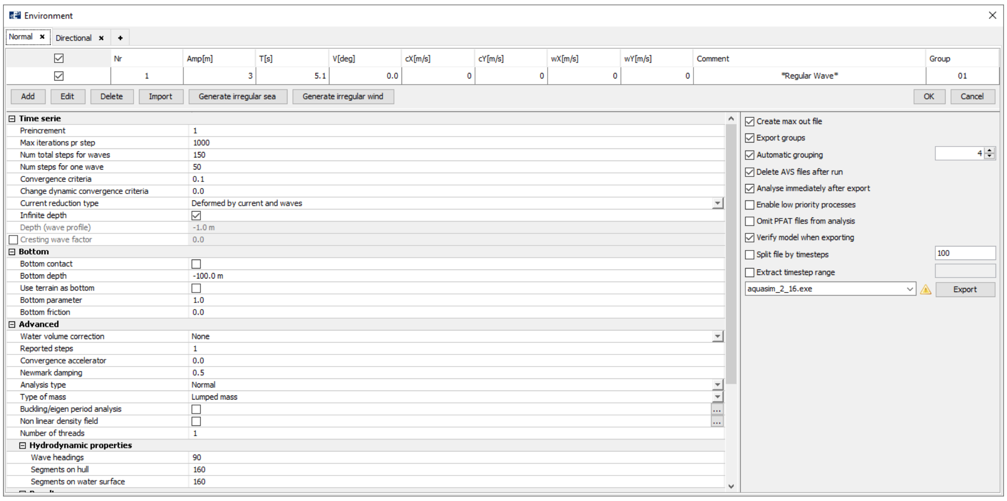

Figure 5 Export parameters AquaSim

3.2 Results and discussion

Comparison between analytic solution and AquaSim results are presented in Table 2.

Table 2 Comparison analytic solution vs AquaSim results

Reduction factor	Analytic (axial force truss) [N]	AquaSim (axial force truss) [N]	Difference [%]
$\boldsymbol{R1 = 0}$	18328	18322	0.03
$\boldsymbol{R2 = 0.5}$	9164	9161	0.03
$\boldsymbol{R2 = 0.2}$	14663	14658	0.03

The results compare well. The deviations are primary due to difference in how the submerged volume of the beam is calculated. The deviations are accepted. Note: AquaSim calculates the submerged volume based on the nodes that constitute the cross section, see Figure 6. In the cross section builder, 12 nodes are default for tubes. To increase accuracy in volume calculation, add more nodes. In this validation case, 32 nodes have been applied.

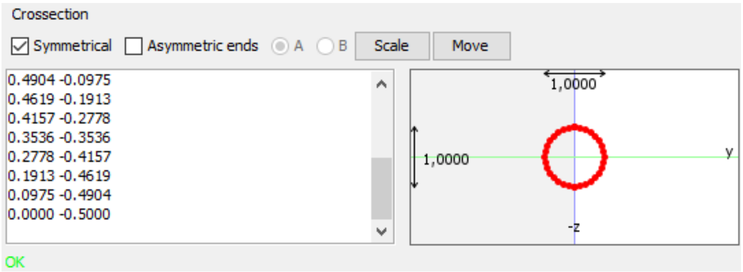

Figure 6 Nodes that constitute the beam cross section in Edit beam-window

4 Validation of Current reduction

The aim of this case study is to validate the *Current reduction* factor. The same case as in chapter 3. is considered. The difference is that the beam is not exposed to waves, but current u_c and the drag coefficient is $C_D = 1.0$. The force in the truss is found by consider the drag load, due to current, on the beam. By consider Equation 4, the axial force in one truss may be expressed as:

$$F_1 = 0.5\rho C_{DR}(LD_R)u_c|u_c|/\#_{truss}$$

where $C_{DR} = C_D \cdot R$ and $D_R = D \cdot R$, R being the reduction factor. Technical input is according to Table 3.

Table 3 Technical parameters

Parameter	Abbreviation	Value
Length, beam	L	10 m
Diameter, beam	D	0.5 m
Submergence, beam	S	0.5
Wetted volume, beam	$V_S = (\pi D^2 L/4) \cdot S$	3.93 m3
Drag coefficient	C_D	0 -
Fluid density	ρ	1025 kg/m3
Reduction factor	$R1$	0.0
	$R2$	0.5
	$R3$	0.2
No. of truss elements	$\#_{truss}$	2 -

4.1 AquaSim model

The numerical model is established in AquaSim beta-version 2.16.2-2729 and solver dated 20.08.2021. The beam has properties according to Figure 7.

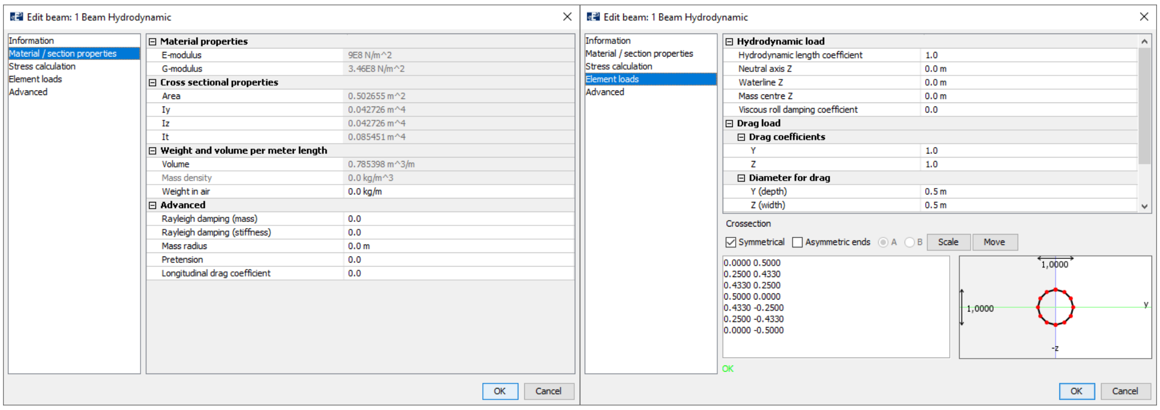

Figure 7 Beam properties in AquaSim

The truss has properties according to Figure 8.

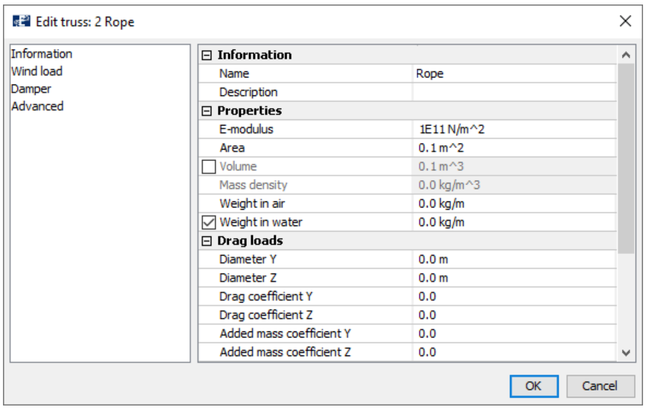

Figure 8 Truss properties in AquaSim

The analysis is set up according to Figure 9.

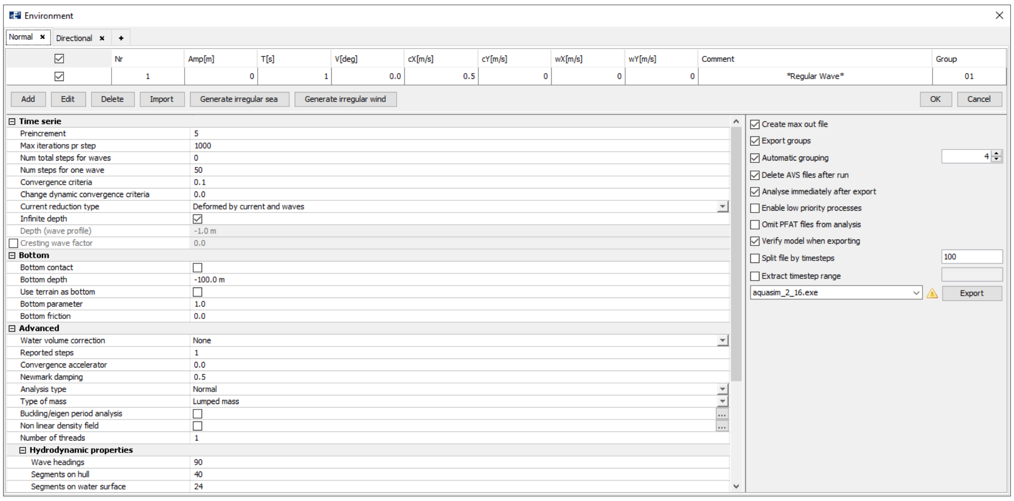

Figure 9 Export properties in AquaSim

4.2 Results and discussion

Comparison between analytic solution and AquaSim results are presented in Table 4.

Table 4 Comparison analytic solution vs AquaSim results

Reduction factor	Analytic (axial force truss) [N]	AquaSim (axial force truss) [N]	Difference [%]
$\boldsymbol{R1 = 0}$	320.31	320.31	0%
$\boldsymbol{R2 = 0.5}$	80.08	80.08	0%
$\boldsymbol{R2 = 0.2}$	205.0	205.0	0%

The results compare well, and no deviations are found. The results are accepted.

5 Conclusions

The Wave amplitude reduction and Current reduction are regarded as successfully implemented. Some deviations between analytical solution and AquaSim results are found for Wave amplitude reduction. But this is explained by the differences in calculated submerged volume. No deviations are found for Current reduction.

6 References

Faltinsen, O. (1990). *Sea Loads on Ships and Offshore Structures.* Cambridge University Press. ISBN 0-521-37285-2.