

Wave amplitude- and current reduction

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

TR-FOU-2328-10

Revision 1

	TR-FOU-2328-10		aquastructures Page 2 of 10
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021

Report no.:	TR-FOU-2328-10		
Date of this revision:	23.08.2021		
Number of pages:	10		
Distribution:	Open		
Author:	Ida S. Hystad	Keywords:	Wave amplitude reduction, current reduction, hydrodynamic, beam

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.

1	23.08.2021	ISH	AJB	Wave amplitude- and current reduction
Revision no.	Date	Author	Verified by	Description

Content

1	Intro	oduction	4
2	The	oretical formulation	4
	2.1	Wave amplitude reduction	4
	2.2	Current reduction	5
3	Vali	dation of Wave amplitude reduction	
	3.1	AquaSim model	7
	3.2	Results and discussion	8
4	Vali	dation of Current reduction	8
	4.1	AquaSim model	9
	4.2	Results and discussion 1	0
5	Con	clusions 1	0
6	Refe	erences 1	0

	TR-FOU-2328-10		aquastructures Page 4 of 10
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021

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.

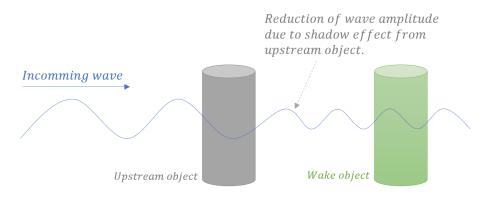


Figure 1 Wave amplitude reduction due to upstream object

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):

$$F_{i} = \underbrace{0.5\rho C_{D}LD \cdot u\sqrt{u^{2} + w^{2}}}_{Drag \ force} + \underbrace{\rho V_{S}(1 + C_{a}) \cdot a_{i}}_{Froude-Kriloff} + \underbrace{\rho C_{a}V_{S}a_{i(beam)}}_{force}_{diffraction \ force} + \underbrace{\rho C_{a}V_{S}a_{i(beam)}}_{force}$$

TR-FOU-2328-10			aquastructures
			Page 5 of 10
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021

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:

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

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.

	TR-FOU-2328-10		aquastructures Page 6 of 10
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021

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.

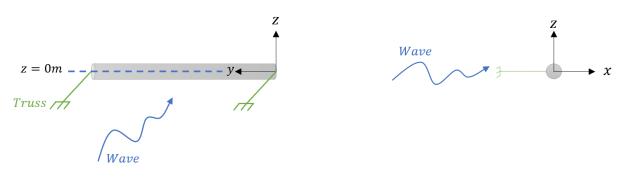


Figure 2

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	Tecnnical parameters	

T 1 1 T 1 · 1

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
	<i>R</i> 1	0.0
Reduction factor	<i>R</i> 2	0.5
	<i>R</i> 3	0.2
Wave amplitude	ζ_A	3
Wave period	T	5.1 s
No. of truss elements	# _{truss}	2 -

	TR-FOU-2328-10		aquastructures Page 7 of 10
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021

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.

🖼 Edit beam: 1 Beam Hydr	rodynamic	×	Edit beam: 1 Beam Hydro	dynamic		×
Information	Material properties		🖃 Hydrodynamic load			
Material / section properties	E-modulus	9E8 N/m^2	Material / section properties Stress calculation	Hydrodynamic length coefficient	1.0	
Stress calculation	G-modulus	3.46E8 N/m^2	Element loads	Neutral axis Z	0.0 m	
Element loads	Cross sectional properties		Advanced	Waterline Z Mass centre Z	0.0 m	
Advanced	Area	0.502655 m^2		Mass centre 2 Viscous roll damping coefficient	0.0 m	
		0.042726 m^4			0.0	
1		0.042726 m^4				
	Tt			Y	0.0	
	Weight and volume per meter le			Z	0.0	
				Diameter for drag		
1				Y (depth)	1.0 m	
				Z (width)	1.0 m	×
		orongym		Crossection		
		0.0	10	Symmetrical Asymmetric ends	A B Scale Move	
						\longleftrightarrow
1					^	1,0000
Iy 0.042226 m ⁻⁴ Iz 0.042226 m ⁻⁴ It 0.085451 m ⁻⁴ Weight and volume per meter length 7 Volume 0.785398 m ⁻³ 3/m Weight na* 0.0 kg/m ⁻³ It 0.0 Rayleigh damping (nass) 0.0 Mass radus 0.0 m Pretension 0.0 Longitudinal drag coefficient 0.0 0.02778<0.4577						
	Î					
	congressing and and coerricent	0.0			1,0000	
				0.0975 -0.4904	÷	$\mathbf{\nabla}$
				0.0000 -0.5000		
					~	-2
4				ок		
		OK Cancel]			OK Cancel

Figure 3 Beam properties in AquaSim

The truss has properties according to Figure 4.

Information	Information		^
Wind load	Name	Rope	
Damper	Description		
Advanced	Properties		
	E-modulus	1E11 N/m^2	
	Area	0.1 m^2	
	U Volume	0.1m^3	
	Mass density	0.0 kg/m^3	
	Weight in air	0.0 kg/m	
	Weight in water	0.0 kg/m	
	Drag loads		
	Diameter Y	0.0 m	
	Diameter Z	0.0 m	
	Drag coefficient Y	0.0	
	Drag coefficient Z	0.0	
	Added mass coefficient Y	0.0	
	Added mass coefficient Z	0.0	

Figure 4 Truss properties in AquaSim

Analysis is set up according to Figure 5.

Enviro	nment														×
Normal ×	Directional	× +													
		Nr		Amp[m]	T[s]		V[deg]	cX[m/s]	cY[m/s]	wX[m/s]	wY[m/s]	Comment		Gro	.p
			1	:	3	5.1	0.0	0	0	0			*Regular Wave*		01
Add	Edit	Delete	Import	Generate irreg	ular sea	Genera	te irregular wind							ОК	Cancel
🗄 Time s	erie											~	Create max out file		
Preincre	ement			1											
Max iter	rations pr step	p		1000									Export groups		
Num tot	tal steps for w	vaves		150									Automatic grouping		4 ≑
Num ste	eps for one w	ave		50									Delete AVS files after run		
Converg	gence criteria			0.1											
Change	dynamic con	wergence cr	iteria	0.0									Analyse immediately after export		
	reduction typ	pe		Deformed by curr	rent and way	/es						v	Enable low priority processes		
Infinite													Omit PEAT files from analysis		
	wave profile)			-1.0 m											
	wave factor			0.0									Verify model when exporting		
Botton													Split file by timesteps	10	00
Bottom															
Bottom				-100.0 m									Extract timestep range		
	rain as botton	n											aquasim_2_16.exe 🗸		Export
	parameter			1.0											
Bottom				0.0											
🗄 Advanc															
	volume correc	tion		None								v			
Reporte				1											
	gence acceler	rator		0.0											
	rk damping			0.5											
Analysis				Normal								+			
Type of				Lumped mass								-			
	/eigen period														
	ar density fie	ble													
	of threads			1											
	rodynamic j	properties													
	e headings			90											
	nents on hull			160											
	nents on wate	er surface		160									,		
													1		

Figure 5 Export parameters AquaSim

	TR-FOU-2328-10	TR-FOU-2328-10									
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021								

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 [%]
R1 = 0	18328	18322	0.03
R2 = 0.5	9164	9161	0.03
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.

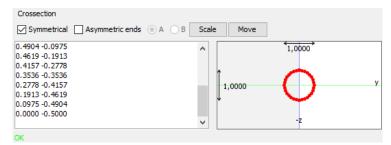


Figure 6 Nodes that constitute the beam cross section in Edit beam-window

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.

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
	<i>R</i> 1	0.0
Reduction factor	R2	0.5
	<i>R</i> 3	0.2
No. of truss elements	# _{truss}	2 -

Table 3 Technical parameters

	TR-FOU-2328-10		aquastructures Page 9 of 10
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021

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.

🖼 Edit beam: 1 Beam Hyd	rodynamic		×	Edit beam: 1 Beam Hydro	dynamic		×	
Information				Information	Hydrodynamic load			
Material / section properties	E-modulus	G-modulus 3.46E8 N/m^2		Material / section properties	Hydrodynamic length coefficient	1.0		
Stress calculation	G-modulus			Stress calculation	Neutral axis Z	0.0 m		
Element loads	Cross sectional properties			Element loads	Waterline Z	0.0 m		
Advanced	Area	0.502655 m^2		Advanced	Mass centre Z	0.0 m		
	Iy	0.042726 m^4			Viscous roll damping coefficient	0.0		
	Iz	0.042726 m^4			🖃 Drag load			
	It	0.085451 m^4			Drag coefficients			
	Weight and volume per meter le	ngth			Y	1.0		
	Volume	0.785398 m^3/m 0.0 kg/m^3			Z	1.0		
	Mass density				Diameter for drag			
	Weight in air	0.0 kg/m	0.0 kg/m		Y (depth)	0.5 m		
	Advanced				Z (width)	0.5 m	~	
	Rayleigh damping (mass)	Rayleigh damping (mass) 0.0			Crossection			
	Rayleigh damping (stiffness)	0.0	111					
	Mass radius	0.0 m			Symmetrical Asymmetric ends A B Scale Move			
	Pretension	0.0			0.0000 0.5000		1.0000	
	Longitudinal drag coefficient	0.0			0.2500 0.4330		1,0000	
					0.4330 0.2500	-		
					0.5000 0.0000 0.4330 -0.2500	1.0000		
					0.2500 -0.4330	1,0000		
					0.0000 -0.5000	۴	~	
							7	
					ок			
		ОК	Cancel]			OK Cancel	

Figure 7 Beam properties in AquaSim

The truss has properties according to Figure 8.

Information	Information							
Wind load	Name	Rope						
Damper	Description							
Advanced	Properties	Properties						
	E-modulus	1E11 N/m^2 0.1 m^2 0.1 m^3						
	Area							
	Volume							
	Mass density	0.0 kg/m^3						
	Weight in air	0.0 kg/m						
	Weight in water	0.0 kg/m						
	🖂 Drag loads	🖃 Drag loads						
	Diameter Y	0.0 m						
	Diameter Z	0.0 m						
	Drag coefficient Y	0.0						
	Drag coefficient Z	0.0						
	Added mass coefficient Y	0.0						
	Added mass coefficient Z	0.0	~					

Figure 8 Truss properties in AquaSim

The analysis is set up according to Figure 9.

Environment													×
Normal × Directional ×	+												
	Nr		Amp[m]	T[s]	V[deg]	cX[m/s]	cY[m/s]	wX[m/s]	wY[m/s]	Comment		G	roup
		1	0	1	0.0	0.5	0		0	b	"Regular Wave"		01
Add Edit D	Delete	Import	Generate irregul	lar sea Genera	ate irregular wind							OK	Cancel
🗄 Time serie			-							^	Create max out file		
Preincrement			5								Export groups		
Max iterations pr step			1000										
Num total steps for wave			0								Automatic grouping		4 🗘
Num steps for one wave			50								Delete AVS files after run		
Convergence criteria			0.1								Analyse immediately after export		
Change dynamic converg	gence crit	teria	0.0										
Current reduction type			Deformed by curre	ent and waves						Ψ	Enable low priority processes		
Infinite depth											Omit PEAT files from analysis		
Depth (wave profile)			-1.0 m								Verify model when exporting		
Cresting wave factor			0.0										
Bottom											Split file by timesteps		100
Bottom contact										Extract timestep range			
Bottom depth			-100.0 m								_		
Use terrain as bottom											aquasim_2_16.exe	~ 🔺	Export
Bottom parameter			1.0										
Bottom friction			0.0										
Advanced													
Water volume correction	1		None							¥			
Reported steps			1										
Convergence accelerato	r		0.0										
Newmark damping													
Analysis type Type of mass			Normal							* *			
Type of mass Buckling/eigen period analysis			Lumped mass										
Non linear density field			···							-			
Non linear density field Number of threads			1										
Number of threads Hydrodynamic pro			1										
Wave headings	perdes		90										
Segments on hull			40										
Segments on null Segments on water si	rfree		40										
segments on water si	urrace		24							~			

Figure 9 Export properties in AquaSim

	TR-FOU-2328-10	TR-FOU-2328-10									
Author: ISH	Verified: AJB	Revision: 1	Published: 23.08.2021								

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 [%]
R1 = 0	320.31	320.31	0%
R2 = 0.5	80.08	80.08	0%
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.