aquastructures
Safety through technology

Sloshing in closed tanks

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Revision 2

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Summary:

This report is the summary of testing of internal sloshing wave in a closed tanks/ containments. The internal wave is generated according to theory explained in chapter 2.

The result of the test shows good compliance between the analytical results and the Aquasim results.

1	19.05.2019	AJB	-	Sloshing loads
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Content

1 Introduction 4
2 Theory 4
3 Validating case study 5
3.1 Sloshing table testcase 1: 6
3.2 Sloshing table testcase 2: 8
3.3 Sloshing table testcase 3: 9
4 References 10

1 Introduction

Tanks and closed containments where sloshing loads may occur can come in many forms. This document shows how a possible sloshing wave from such tanks can be introduced in AquaSim

This report follows the theory presented by (Solaas, 1995).

2 Theory

For generation of internal waves, we will use the natural periods for sway motion from (Solaas, 1995) equation 4.8:

$$\omega_n^2 = gk\tanh(kh)\, where\ k = \frac{n\pi}{2a}\ n = 1,2, \ldots.$$

Equation 1

Where ω_n is the eigenfrequency of the n^{th} internal wave = $2\pi/T_n$. k is the wave number, a is the radius of the tank h = depth of tank. Figure 1

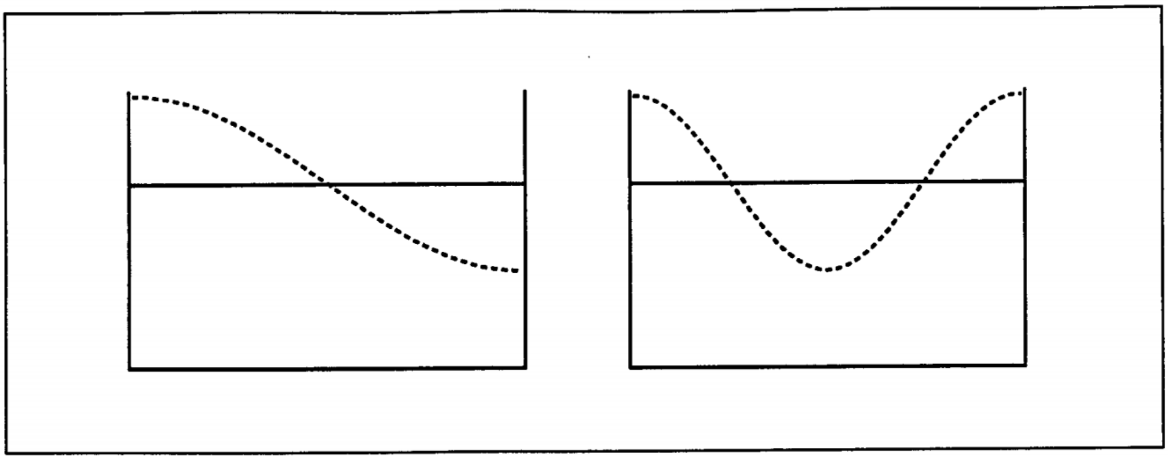


Figure 4.2 Modes of liquid motion: n=1 gives the first antisymmetrical sloshing mode (left) and n=2 the first symmetrical sloshing mode.

Figure 1 Wave motions for sloshing waves, n = 1 and n = 2. From Solaas (1995)

The internal wave is assumed to be a sinusoidal regular wave with the velocity potential according to (Faltinsen, 1990):

$$\emptyset = \frac{g\zeta_a}{\omega}\frac{\cosh k(z+h)}{\cosh kh}\cos(\omega t - kx)$$

Equation 2

Which gives the following dynamic pressure at tank wall side:

$$p_D = \rho g \zeta_a \frac{\cosh k(z+h)}{\cosh kh}\sin(\omega t - kx)$$

Equation 3

Where *x*- is the horizontal coordinate, *z*- = vertical coordinate, and ζ_a is the wave amplitude. The origin of the wave to the AquaSin input is from the tank side. Do always a check of phases of output to be certain that input is as desired.

3 Validating case study

A circular closed compartment with diameter 10 meter and depth 4 meter is modelled as shown in Figure 2.

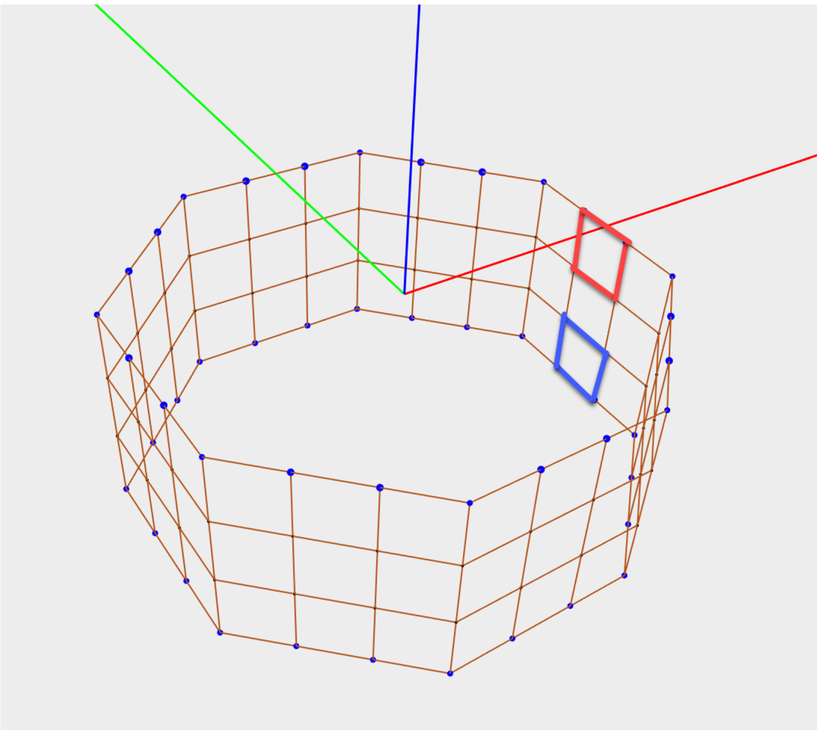


Figure 2 Analysis model. Red square is placement of panel used for check of sloshing pressure at z = 0 and blue for z = -4

The membrane elements properties as given in Figure 3.

⊟ **Properties**	
E-module	1E11 N/m^2
Thread diameter	0.01 m
☐ Area	7.854E-5 m^2
Mass density	1025.0 kg/m^3
☐ Relative density in water	0.0 kg/m^3
No compression forces	☐
⊟ **Solidity**	
Pretension Y	0.0
Pretension Z	0.0
Growth coefficient	1.5
Maskwidth Y	0.1 m
Maskwidth Z	0.1 m
Solidity	20.000023 %
Solidity incl growth	30.000035 %
☐ ☐ **Volume**	
Top open	☐
Bottom open	☐
⊟ **Advanced**	
Rayleigh damping stiffness	0.0
Rayleigh damping mass	0.0

Figure 3 Properties for membrane component

Further properties are given in Figure 4.

Impermeable net load formulation	
Drag coefficient	1.0
Lift coefficient, peak value	2.4
Density of fluid inside tank	1025.0 kg/m^3
Height of fluid level inside tank relative to sea level	0.1 m
Added mass coefficient	0.25
Hydrodynamic damping coefficient	0.25
Bottom factor, 0 if water flow through bottom	1.0
Area top that water can penetrate over	80.0 m^2
Damping coefficient	0.0
Include drift	☐
Skin friction coefficient	0.1
Height of net edge	0.0
Inner fluid mass scaling	1.0
Added mass indicator	1
Extra drag in front	0.0
Wave damping tangential to panels	0.0
Combined pressure from waves and current	0.0
Type of diffraction load	MacCamy-Fuchs
Diffraction scaling	1.0
Thickness	
Thickness Y	7.854E-4 m
Thickness Z	7.854E-4 m
Thickness	1.5708E-3 m
Advanced	
Wave amplitude reduction	0.0
Current reduction	0.0
Sloshing	
Table	Sloshing 1

Figure 4 Properties for dense net formulation

3.1 Sloshing table testcase 1:

Sloshing wave data for testcase 1 is given in Figure 5.

Name	Sloshing 1
Type	Radians

n	Amplitude	Phase	Direction	Tank width	Tank depth	Period
1	1.0	0.0	0.0	10.0	4.0	3.88
2	0.0	0.0	0.0	10.0	4.0	2.55
3	0.0	0.0	0.0	10.0	4.0	2.07

Add row | Delete row | OK | Cancel

Figure 5 Sloshing wave

Figure 6 and Figure 7 shows calculated pressure at z = 0 and z = -4 respectively compared to the analytic expression.

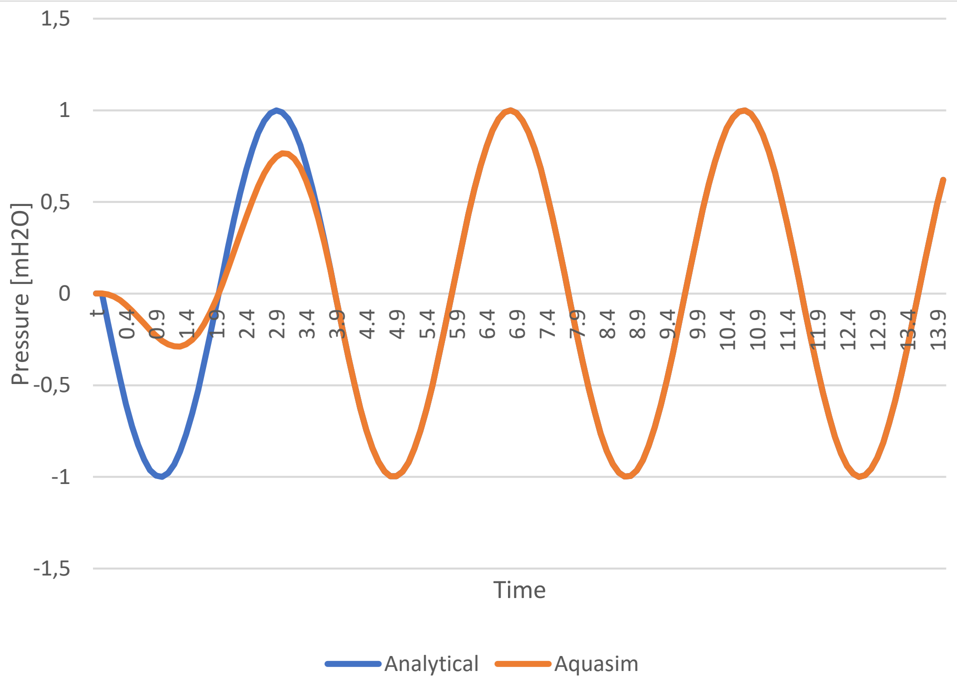


Figure 6 Sloshing pressure at z = 0

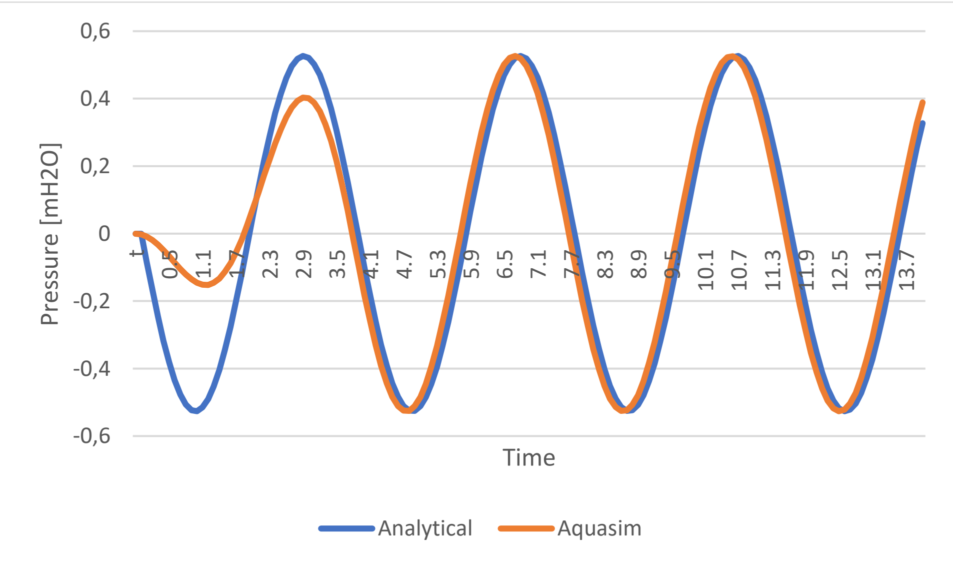


Figure 7 Sloshing pressure at z= -4

As seen from Figure 6 and Figure 7 results compare well.

3.2 Sloshing table testcase 2:

Figure 8 shows sloshing input data for testcase 2.

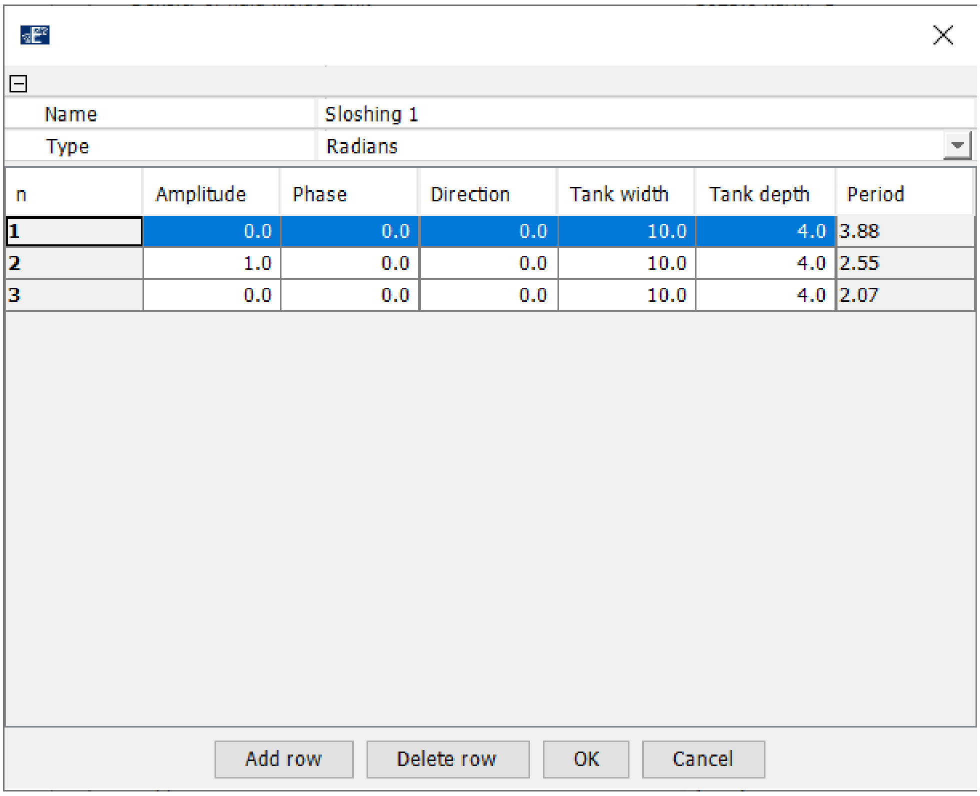


Figure 8 Sloshing wave

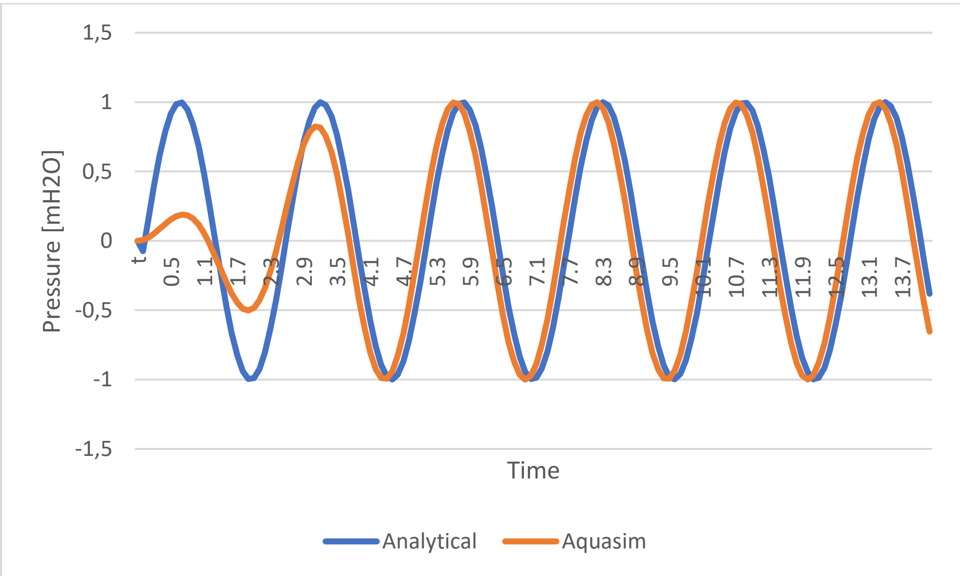
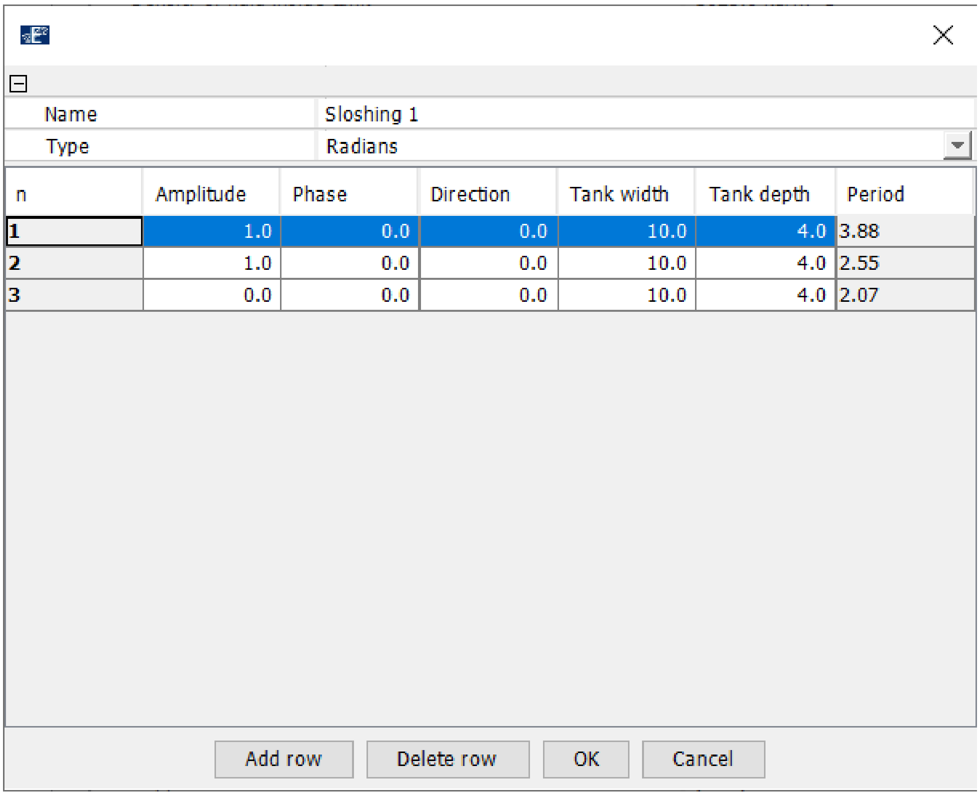


Figure 9 Sloshing pressure at z= 0

As seen from Figure 9 results compare well.

3.3 Sloshing table testcase 3:

This is a case with 2 amplitude on the two first waves as seen in Figure 10.



Name	Sloshing 1
Type	Radians

n	Amplitude	Phase	Direction	Tank width	Tank depth	Period
1	1.0	0.0	0.0	10.0	4.0	3.88
2	1.0	0.0	0.0	10.0	4.0	2.55
3	0.0	0.0	0.0	10.0	4.0	2.07

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Figure 10 Two Sloshing waves

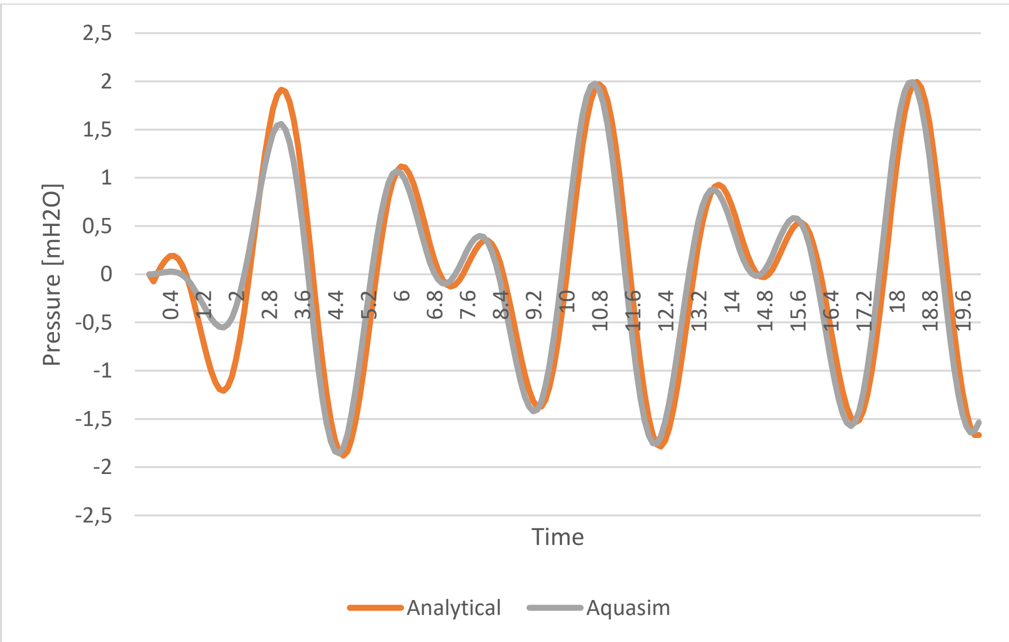

Figure 11 Sloshing pressure at z= 0

Maksimum pressure from Aquasim is approximately 2 mH2O, and results compare well.

4 References

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

Solaas, F. (1995). *Analytical and numerical studies of sloshing in tanks.* Thesis.