Shock loads from masses connected to ropes in AquaSim

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Summary:
This report summarizes verification study of snap loads in AquaSim. Numerical calculations have been compared to analytical formulae.

The presented results in AquaSim, show good correspondence with the analytical results.

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Content

1 Introduction

In earlier papers, e.g. Berstad et al 2017, simplified expressions for calculation of response to masses attached to ropes going from slack to bearing load in the rope has been compared to AquaSim analysis. An example of this is illustrated in Figure 1.

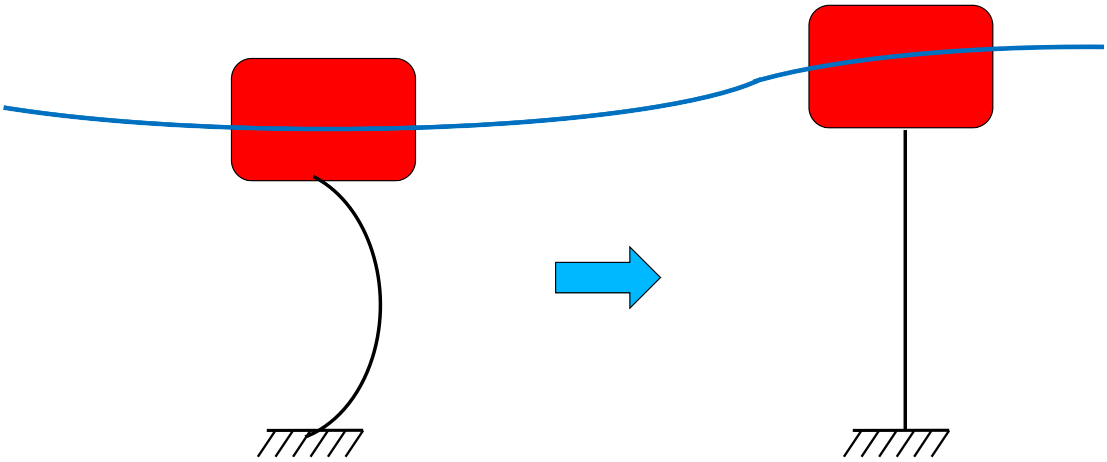

Figure 1 Floating mass going from slack in rope to snapping

This report is an extension of the case in Figure 1 to the case seen in Figure 2.

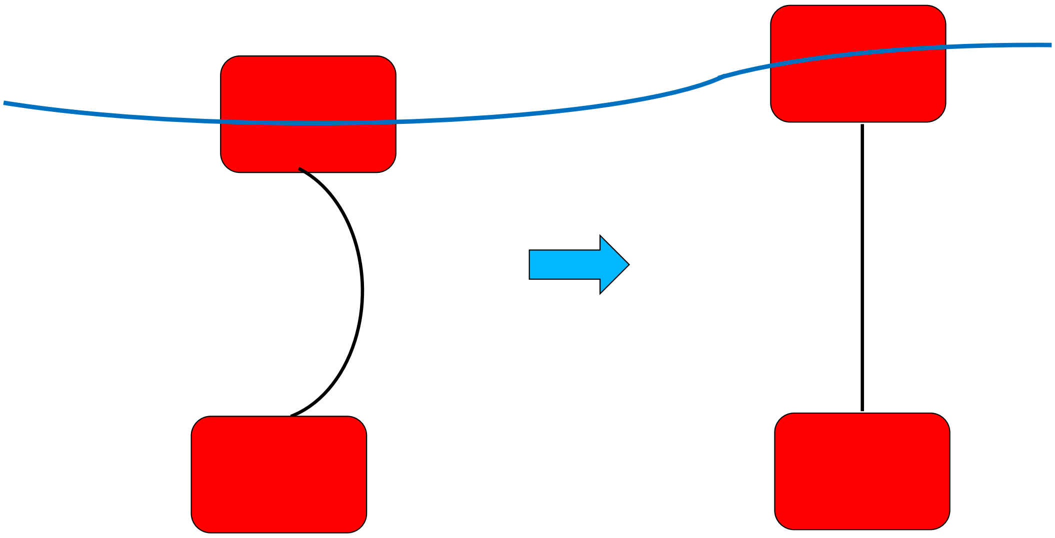

Figure 2 Case with top mass and bottom mass

The case in Figure 2 is placed in a coordinate system where v_1 is the relative velocity between the upper and the lower mass. The *z*- axis points upward through the lower and the upper mass. Denote the upper mass m_1 and the lower mass m_2. Make an energy consideration where the system will have a kinetic energy of:

$$k_e = \frac{1}{2} m {v_1}^2$$

As M2 have zero velocity it also have zero kinetic energy. When the rope snaps, there will be an instant when the velocity of the two masses are the same. Denote this velocity v_f. The rule of keeping momentum then gives:

$$m_1 v_1 = m_1 v_f + m_2 v_f$$

Or rewritten:

$$m_1 v_1 = (m_1 + m_2) v_f$$

Meaning, the velocity at this time is:

$$v_f = v_1 \frac{(m_1)}{(m_1 + m_2)}$$

Kinetic energy combined for the two masses in then:

$$\frac{1}{2} m_f v_f^{\ 2} = \frac{1}{2}(m_1 + m_2) v_1^{\ 2} \frac{(m_1)^2}{(m_1 + m_2)^2}$$

As the analysis are elastic, the missing kinetic energy needs to be stored in the rope acting like an elastic spring:

$$\frac{1}{2} m_1 v_1^{\ 2} = \frac{1}{2}(m_1 + m_2) v_1^{\ 2} \frac{(m_1)^2}{(m_1 + m_2)^2} + \frac{1}{2} k x^2$$

Simplify the above equation:

$$m_1 v_1^{\ 2} = (m_1 + m_2) v_1^{\ 2} \frac{(m_1)^2}{(m_1 + m_2)^2} + k x^2$$

Rearrange such that spring stiffness terms is on one side of the equation and velocity terms on the other side:

$$k x^2 = m_1 v_1^{\ 2} - (m_1 + m_2) v_1^{\ 2} \frac{(m_1)^2}{(m_1 + m_2)^2}$$

Simplifying yields:

$$k x^2 = m_1 v_1^{\ 2} - v_1^{\ 2} \frac{(m_1)^2}{(m_1 + m_2)}$$

And then rearranging to:

$$kx^2 = m_1 {v_1}^2 \left(1 - \frac{m_1}{(m_1 + m_2)}\right)$$

Or:

$$kx^2 = m_1 {v_1}^2 \left(\frac{m_2}{(m_1 + m_2)}\right)$$

Then displacement x is found as:

$$x = v_1 \sqrt{\frac{m_1}{k}\left(\frac{m_2}{(m_1 + m_2)}\right)}$$

Or:

$$x = v_1 \sqrt{\frac{1}{k}\left(\frac{m_1 m_2}{(m_1 + m_2)}\right)}$$

Then the corresponding force is found as:

$$F = kx = v_1 \sqrt{\frac{k m_1 m_2}{(m_1 + m_2)}}$$

Noting that velocity v_1 is the relative velocity between the two masses. As it snaps it is seen that this expression corresponds to the expression for snap load to a rope fixed at the other end as m2 >> m1, which is logical:

$$m2 \gg m1 : F = kx \approx v_1 \sqrt{k m_1}$$

If m2 approach 0, there will be no snap load, which is logical.

2 Comparison with analysis

A simplified analysis case has been established as shown in Figure 3.

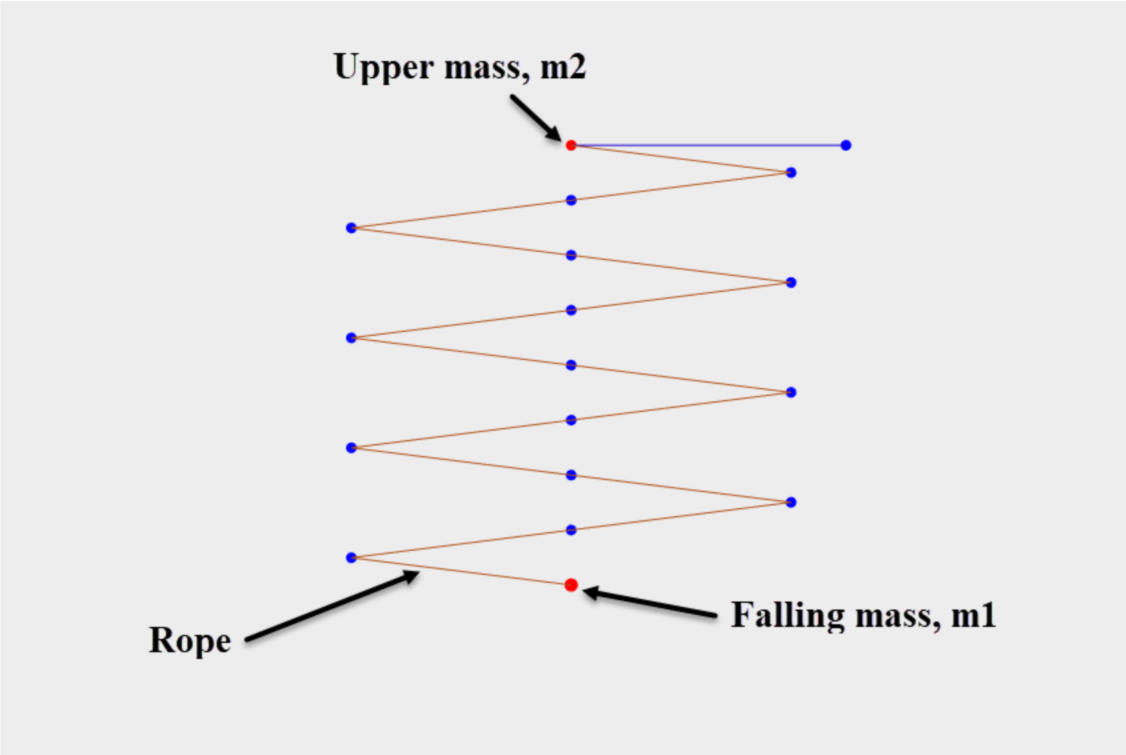

Figure 3 Truss elements in a zig-zag pattern in AquaSim

Masses are put on without corresponding gravity to them. At the beginning of the analysis a force is applied to the lower node, accelerating the lower node to the velocity at impact. Then this load is removed. Then, also the upper supporting truss is taken off such that the system is ideal to compare to analytic results. The properties in the system is given in Table 1.

Table 1 Properties for comparison case study

Model properties	Abbreviation	Value
Upper mass	m_2 [Tonn]	10
Elastic modulus rope	E [N/m2]	2.00E+10
Cross sectional area rope	A [m2]	0.01
Total length rope	l [m]	8.062
Stiffness, EA/l	k [N/m]	2.48E+07
Velocity, m1 at impact	v_1 [m/s]	2.72
Falling mass	m_1 [Tonn]	1-320

Figure 4 shows the location of the rope and support at a time instant where the downward force to the system is taken off (time load RAO).

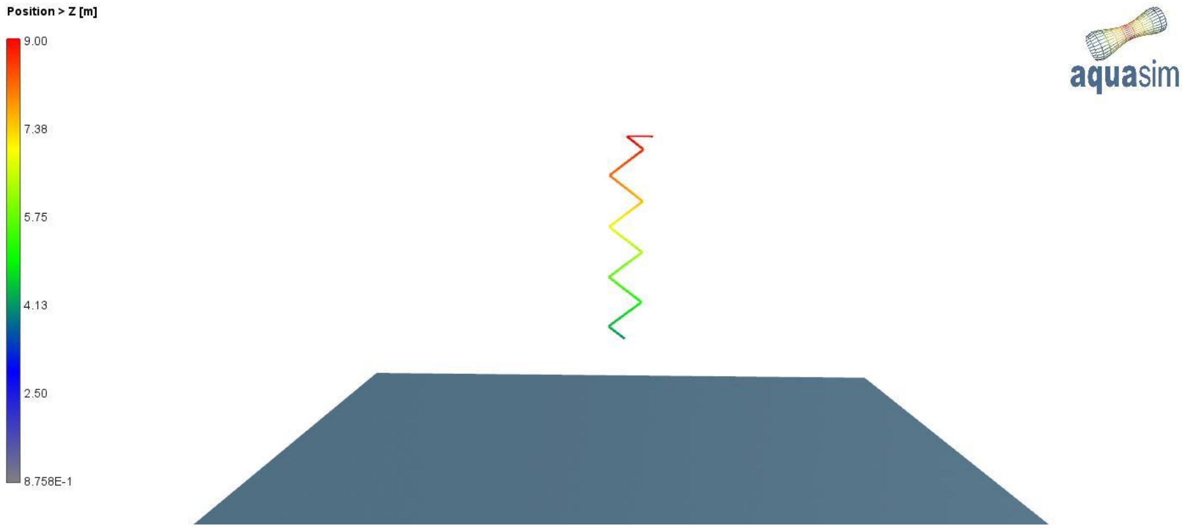

Figure 4 Vertical loaction before snapping

Figure 5 shows the velocity at a time instant before snap occurs.

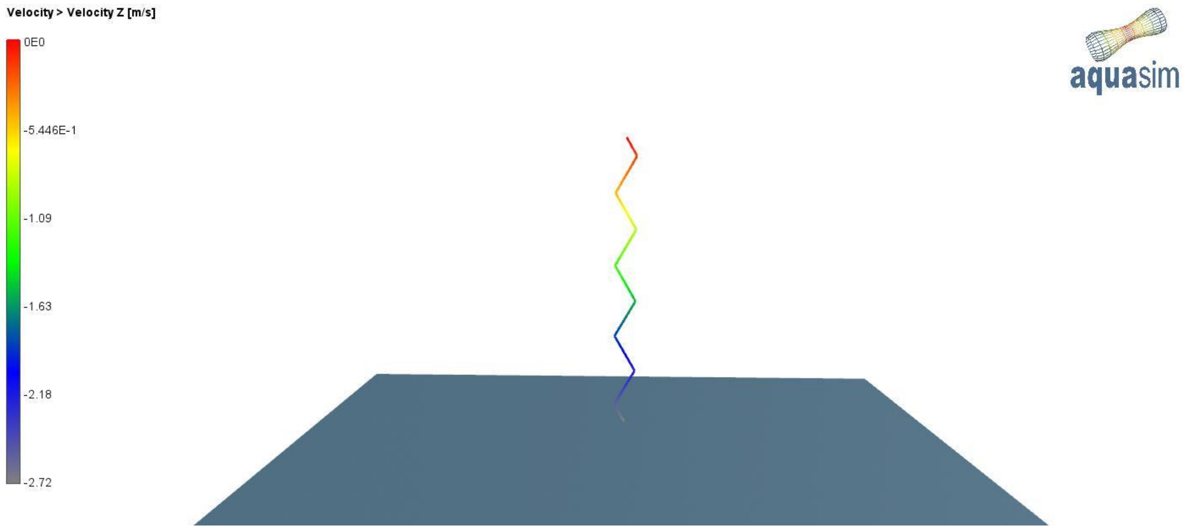

Figure 5 Velocity before impact

Figure 6 show that axial force in the rope is zero before impact.

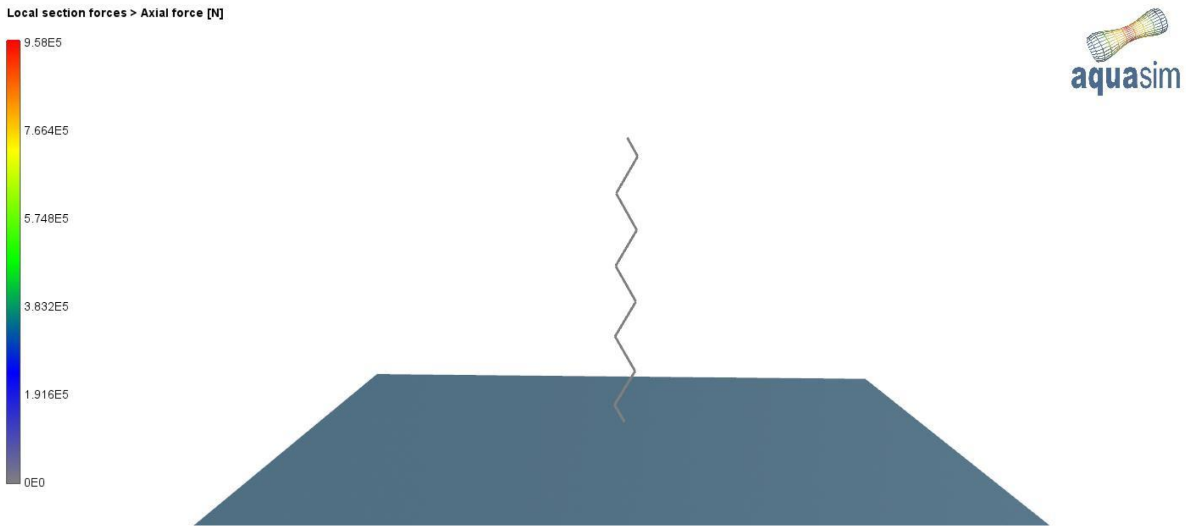

Figure 6 Axial force in rope is zero before impact

Figure 7 shows maximum force at impact for the case with 10ton load at both rope ends.

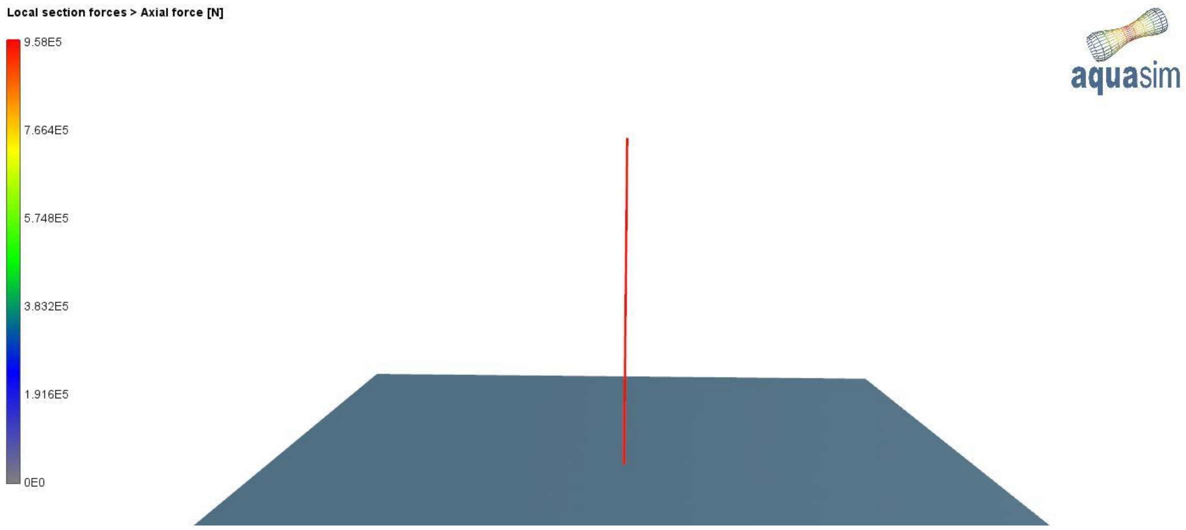

Figure 7 Axial force at snap

Figure 8 shows a comparison of force in the rope between analysis and analytical formulae. As seen from the figure, there results correspond well.

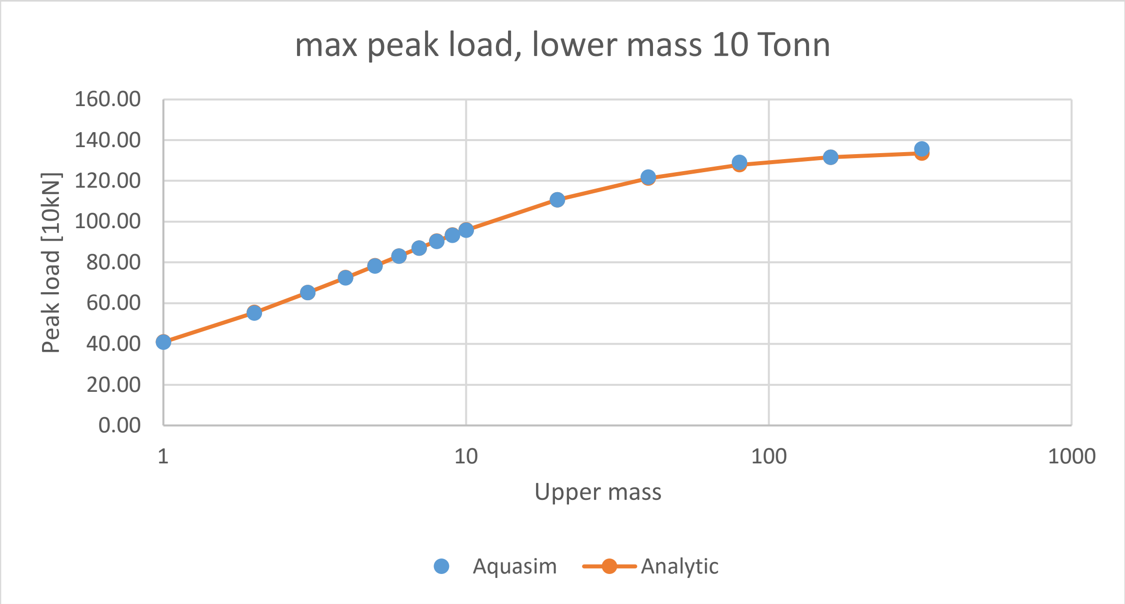

Figure 8 Comparison of analysis results to analytical formulae

3 Conclusions

A case study of snap loads has been carried out. Analysis results from AquaSim have been compared to analytical formulae. Results are presented in Figure 8, and show good correspondence.

4 References

1. Berstad, A. J. and L. F. Heimstad (2017) "Experience from introduction of the design code NS 9415 to the aquaculture industry in Norway and Expanding the scope to also cover operations" OMAE2017-62426 Proceedings of the 36th International Conference on Ocean, Offshore & Arctic Engineering OMAE 2017 June 25-30, 2017, Trondheim, Norway