Beam Buckling and Eigenperiods in AquaSim

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Revision 3

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Summary:
This report summarizes the theory of Buckling eigenperiods in AquaSim.

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Content

1 Structural resonance

On the input line shown in Figure 1 , type of mass calculation and possible calculation of buckling and/or resonance is given as input. In this line from left to right Parameter #2 to #8 is about Eigenvalues to find:

#2-#8: Eigen value parameters.
#9-#11: Dummies.

Explicit calculation of beam buckling is a plugin to AquaSim. Although it is not included in the AquaSim basic package it is described herein. The resonance plugin to AquaSim solves the linearised eigenvalue problem

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

Equation 1

at each timestep in the analysis where:

> *K* is the stifness for the structural configuration at the timestep including both geometrical and element stiffness.

> *M* is the mass of the structural configuration at the timestep. This includes both structural mass and added mass. Note that mass of truss element is not included

The result found is the eigenvalue, λ which is the factor the load distributions should linearly be increased to to obtain linearised buckling. The corresponding eigenvector is the buckling shape for this. The inputparameters on the file input line is as follows: Negative λ are disregarded meaning the reversing load distributions are not considered.

#2: Indicator to if buckling and/or eigen period analysis should be carried out. 1 means buckling analysis 2 means eigen period analysis is carried out in addition to buckling analysis based on the same input parameters for the other values and only accounting for mass of beams node mass points and node loads with mass to avoid internal eigenforms in moorings (mass of truss elements is not includ). -1 means is the same as 2 for eigenperiods but no buckling shapes are calculated. -2 means the same as -1 but in this case also mass of truss elements is accounted for.

#3: Indicator to how many of the positive eigenvalues one wish to write to file. (max 4)

#4: How many positive eigenvalues closest to 0 shall be omitted in the eigenvalues written to file.

#5: The amplitude of the eigen vectors.

#6: Shift value. Value where fond eigenvalues are centered around.

#7: Target stress value. Presently this value is not used, but all stress values are reported, for later this can be used to skip or allert values below (the un interesting values).

#8: Eigen value analysis valid for linear material relation (nonlinear motions and rotations are ok) = 0. General but more noicy bukcling respons = 1.

If more eigenvalues are desired written to file than existing, results for extra eigenvalues are put to 0. This may vary for different timesteps in the analysis. Figure 1 shows typical input values for buckling.

```
4    1236     0.0 0.0 15000.0 0.0 0.0 0.0 1    0    0    0    #Buoy
0    1   3    0    5.0 0.0 0    0    0    0    0    0    0    ## Extra
0.0 1.0 180.0    0.5 0.0 0.0 -0.0    0.0 0.0  ## Seastate/Curr
```

Figure 1 Typical input values for buckling

2 Validation

Consider the Sevan platform 650 catcher. This has been modeled with parameters shown in

Buckling of columns and beams

$$P_1 = \frac{\pi^2 EI}{L^2} \quad P_2 = \frac{4\pi^2 EI}{L^2} \quad P_3 = \frac{9\pi^2 EI}{L^2}$$
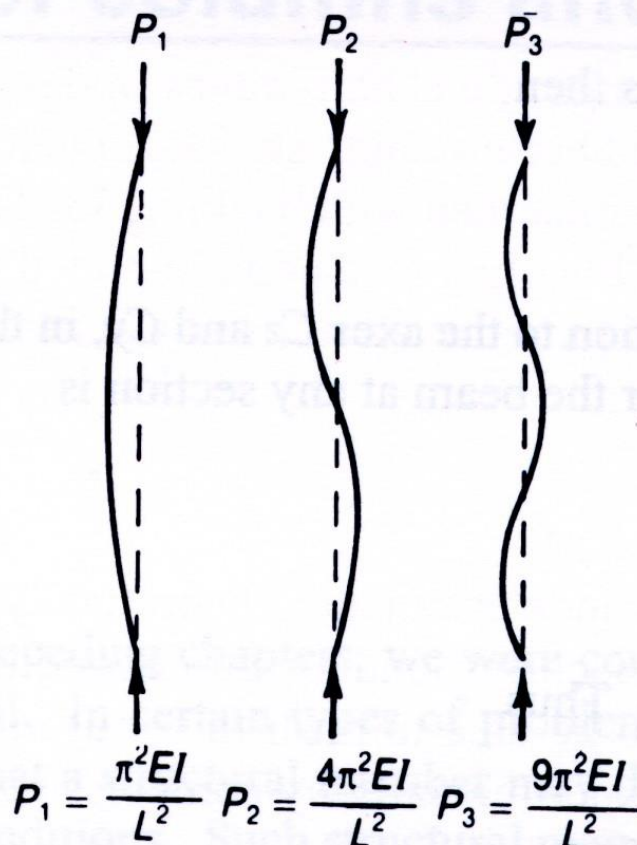
Figure 18.2   Modes of buckling of a pin-ended strut.

Figure 2 The analytically calculated buckling loads for the 3 first buckling modes for a beam with pinned connections at top and bottom. Only buckling in one plane is considered. From http://jim-quinn.blogspot.no/2012/03/wheelchair-drilling.html

Introduce a case to AquaSim with data as given in Table 1.

Table 1 Beam data

E [Gpa]	100
I [m4]	1.00E-04
L [m]	10

Figure 3, Figure 4 and Figure 5 gives the buckling shapes 1,2 and 3 respectively for the case considered. The labels shows corresponding buckling force. This is the applied force multiplied with eigenvalue. For a case where the load distribution is not constant this is the load buckling load given the load distribution analysed.

Results > Compressive buckling force[N]

9.87E5

7.896E5

5.922E5

3.948E5

1.974E5

0

Figure 3 Buckling shape 1

Results > Compressive buckling force[N]

3.948E6

3.158E6

2.369E6

1.579E6

7.896E5

0

Figure 4 Buckling shape 2

Results > Compressive buckling force[N]

8.883E6

7.106E6

5.33E6

3.553E6

1.777E6

0

Figure 5 Buckling shape 3

Table 2 shows difference between calculated and analytical buckling loads. As seen results correspond very well.

Table 2 Comparison of numerically calculated buckling loads to analytical value

Buckling force kN	1	2	3
Analytic	987.0	3947.8	8882.6
Aquasim 1 element	1200.0		
Aquasim 10 elements	987.0	3948.7	8892.0
Aquasim 100 elements	987.0	3947.8	8882.6
Difference			
Difference 1 elements	21.59%		
Difference 10 elements	0.00%	0.02%	0.10%
Difference 100 elements	0.00%	0.00%	0.00%

From Table 2 note that using 1 element only overestimates the buckling load. This is because the beam in this case is forces to follow the buckling pattern described by the buckling stiffness for a beam. This gives a higher buckling load. Using one beam one can neither find the higher order buckling modes.

2.1 Example fish farm

Figure 6 and Figure 7 shows a fish farm case where the relations between actual compressive load on the bottom ring and the theoretical buckling length is 1.2 at 0.5 m/s current. This means in fact the bottom ring is unstable and is in the "buckling zone".
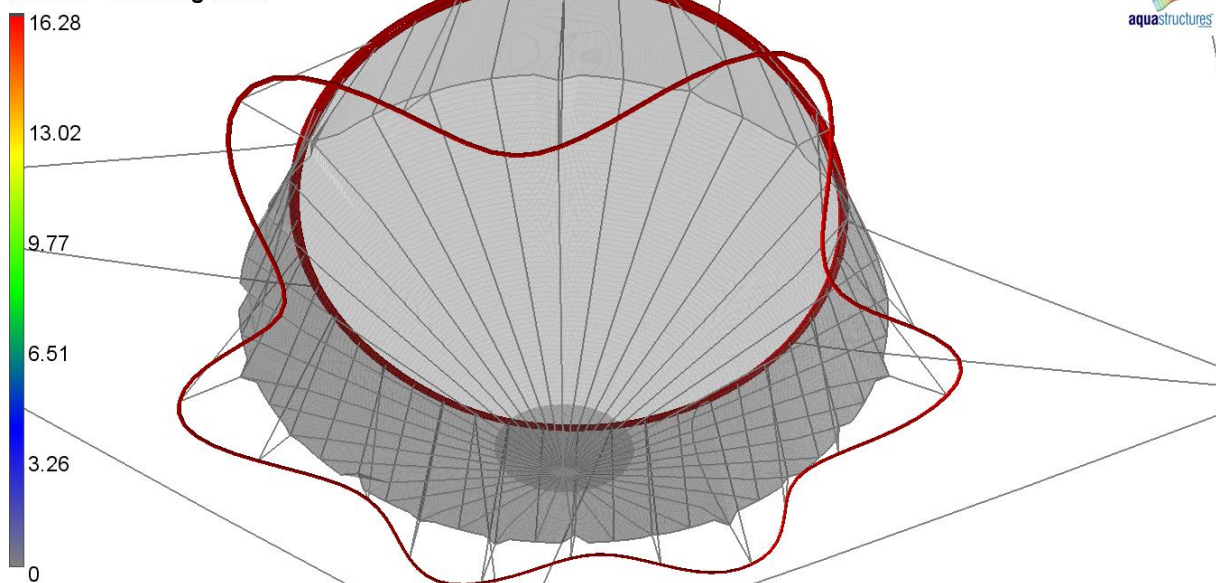
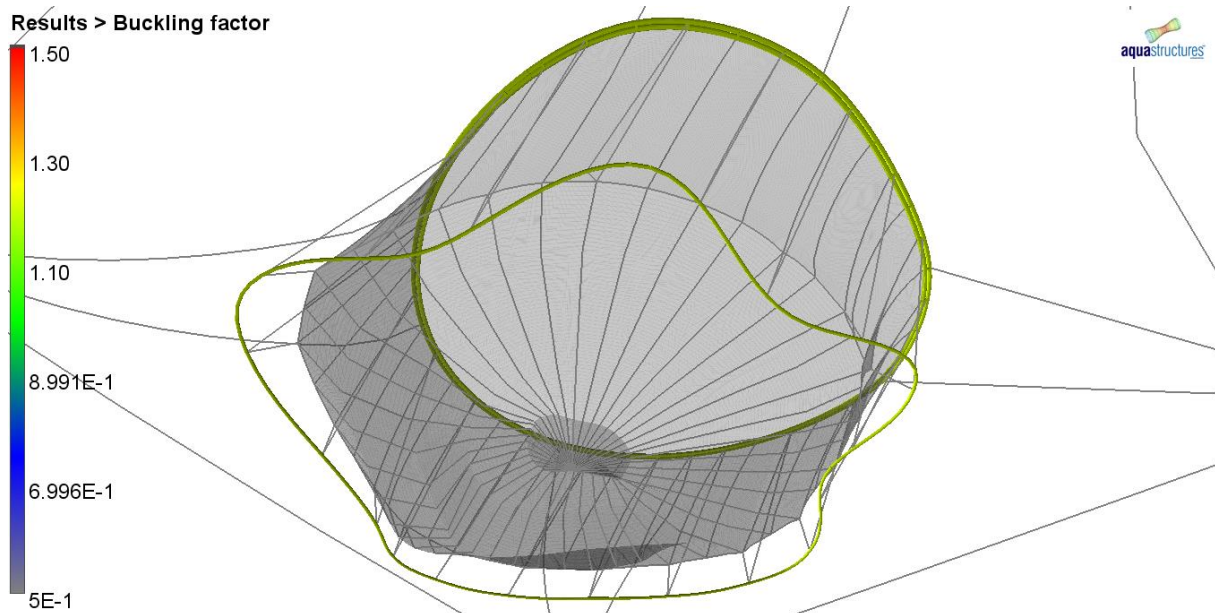*Figure 6 Bottom ring in fish farm at static equilibrium. Buckling factor is range from applied load to buckling load*

Figure 7 Bottom ring in fish farm at 0.5 m/s current. Buckling factor is range from applied load to buckling load. The buckling factor is at 1.2

2.2 Example lifting operation

Figure 8 and Figure 9 shows a lifting operation. This configuration have several eigenvalues connected to stiff transformation of the system. These are not reported. The reported ones are the ones which involves stiff transformation of the system. The buckling value found in these cases are the relation between the actual load and the load needed for buckling. One may call it a safety factor on buckling.

Displacement > X mm
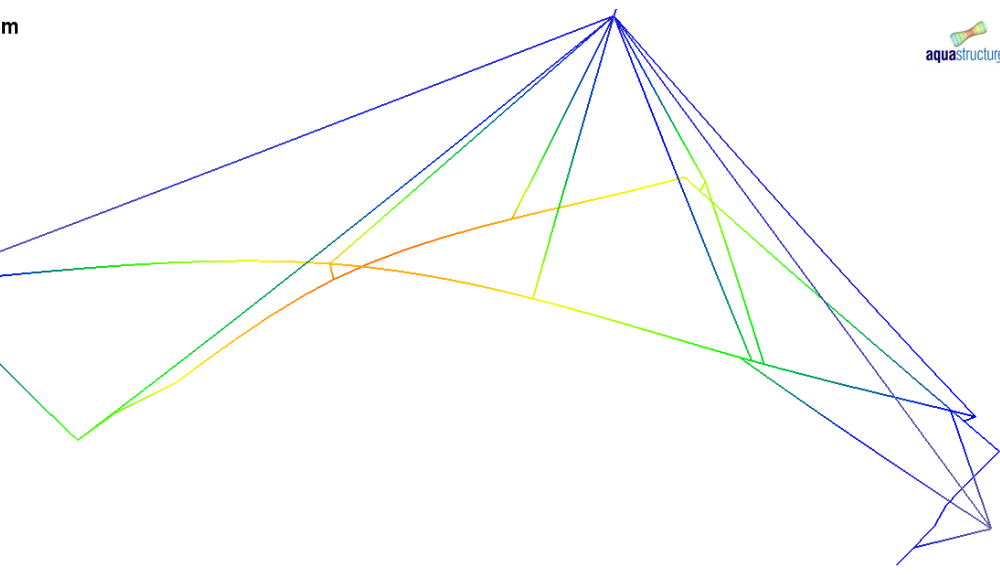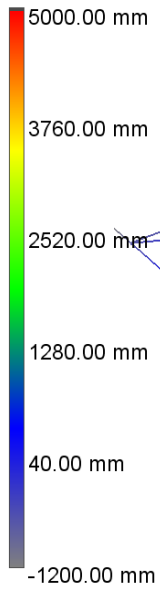
Figure 8 1st buckling mode involving deformations. Buckling load is 7.9 times the applied load
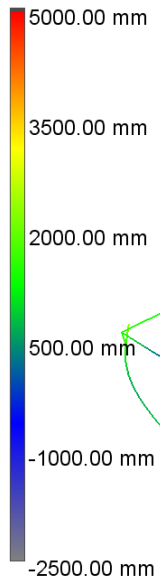
Displacement > X mm
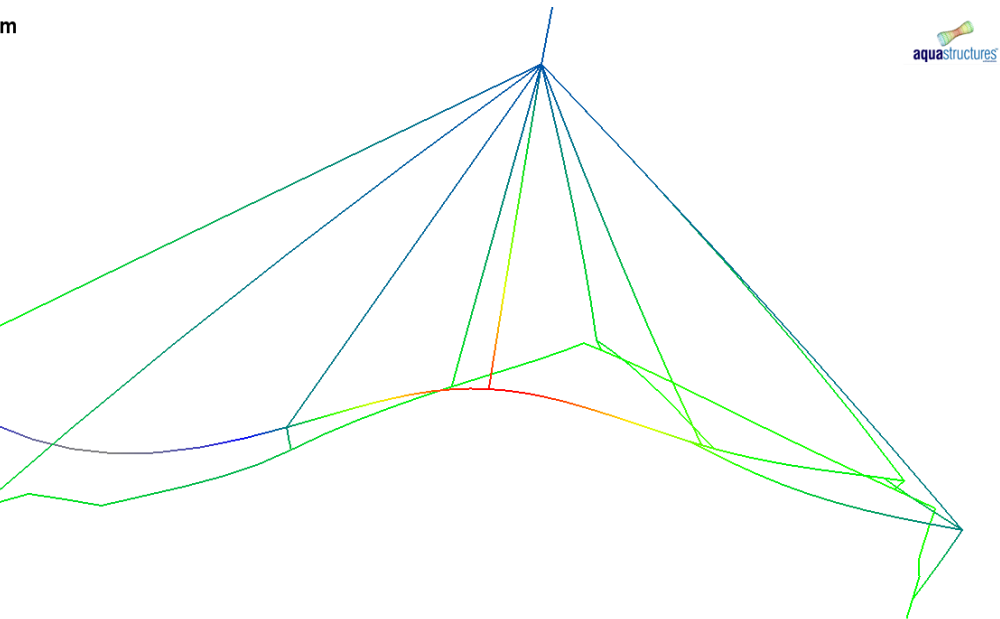
Figure 9 2nd buckling shape not involving "stiff element" rotations. Buckling factor is 35

3 Results and results interpretation

The results in the buckling output files in the "local section forces" tab as seen in Figure 10 are forces in the structure at the time instant the buckling analysis is taking place. Under the flap "Results" as seen in Figure 10 results from the buckling analysis is shown.
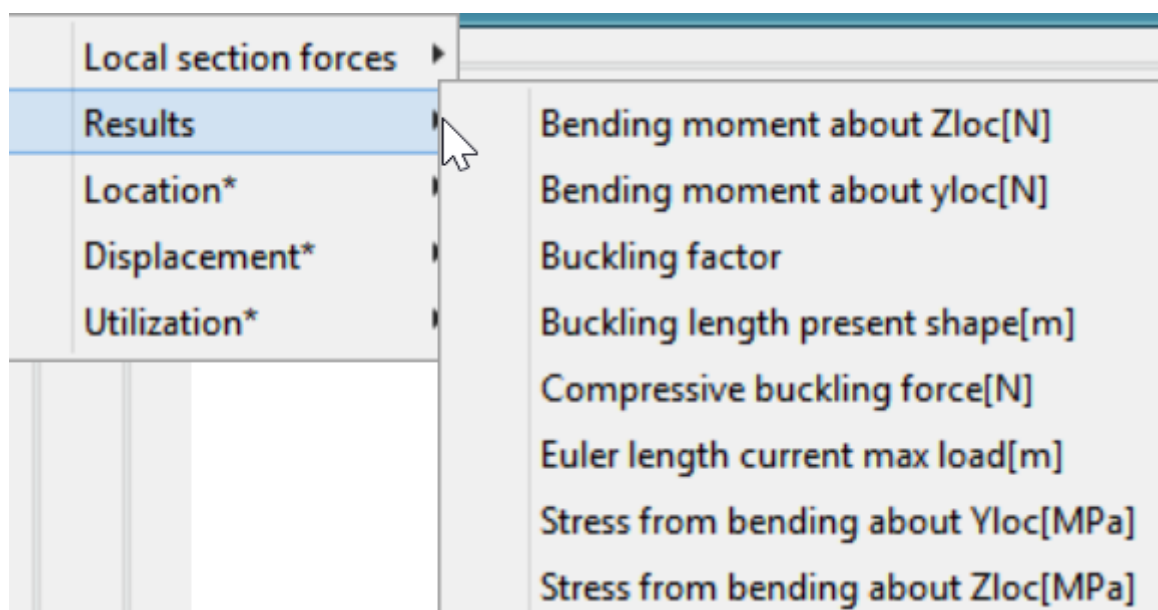

Figure 10 Results buckling

Note that the value "Euler length current max load" is theurethical Euler length calculated from the max load at each component and is hence not related to the buckling shape. "Bending moment..." is the bending moment about the local axis given that the buckling vector with the max amplitude given as input is applied. This will be larger for buckling shapes where the beams curves than for buckling shapes where there is mostly translations and rotations of the system.

Figure 11 shows a case where the buckling vector is associated with large stress and hence a design buckling shape. Figure 12 shows a case where the buckling shape is rotation of the beam and the stress level internally in the structure is much lower.
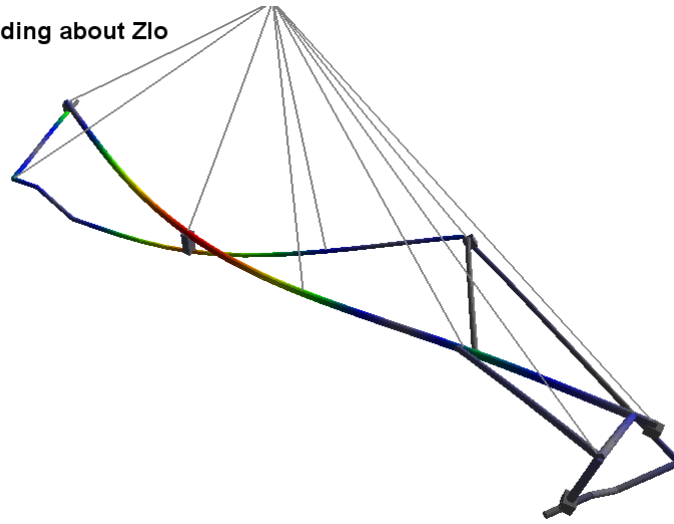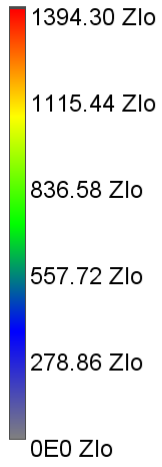
Results > Stress from bending about Zlo

1394.30 Zlo

1115.44 Zlo

836.58 Zlo

557.72 Zlo

278.86 Zlo

0E0 Zlo

Figure 11 Stress level buckling shape with amplitude 6 m

Results > Stress from bending about Zlo

37.20 Zlo

29.76 Zlo

22.32 Zlo

14.88 Zlo

7.44 Zlo

0E0 Zlo
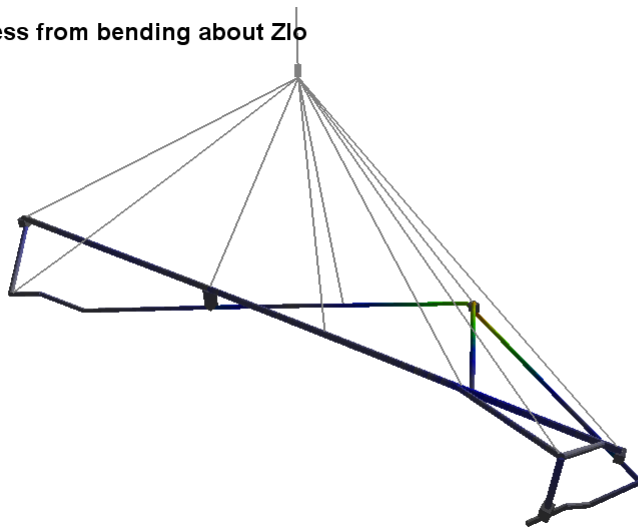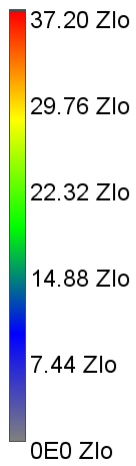
Figure 12 Stress level buckling shape with stiff rotation

Data in the key-files is shown and commented in *Italic* below:

-Buckling eigenvalues at step --- 1

4 Eigenvalues asked for
12 Eigenvalues calculated at step
8 positive eigenvalues sorted *The found positive safety factors for buckling from low to high*
1 1.007215
2 2.127825
3 7.892285
4 35.35070
5 43.39595
6 52.26348
7 61.09991
8 74.51562

The max stress level associated with the found buckling shapes:

max stress level beams shape [MPa] 1 37.20175
max stress level beams shape [MPa] 2 52.32512
max stress level beams shape [MPa] 3 1394.259
max stress level beams shape [MPa] 4 4738.869
max stress level beams shape [MPa] 5 740.0619
max stress level beams shape [MPa] 6 7129.525
max stress level beams shape [MPa] 7 7622.816
max stress level beams shape [MPa] 8 4615.530

The shapes written to AVS/AVZ file:

max stress level beams shape written to files [MPa] 1 37.20175
max stress level beams shape written to files [MPa] 2 52.32512
max stress level beams shape written to files [MPa] 3 1394.259
max stress level beams shape written to files [MPa] 4 4738.869

4 Conclusions

The AquaSim buckling plugin handles well calculation of buckling modes. Validation shows good correspondence in results.

Parameters in key file