Modelica Component Models for Non-diffracting Floating Objects and Quasi-static Catenary Moorings

American Modelica Conference/Sep 22 - 24/2020

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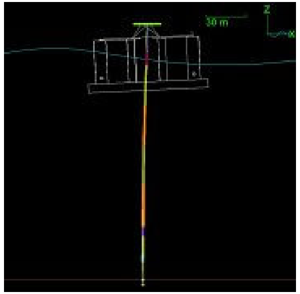
Agenda

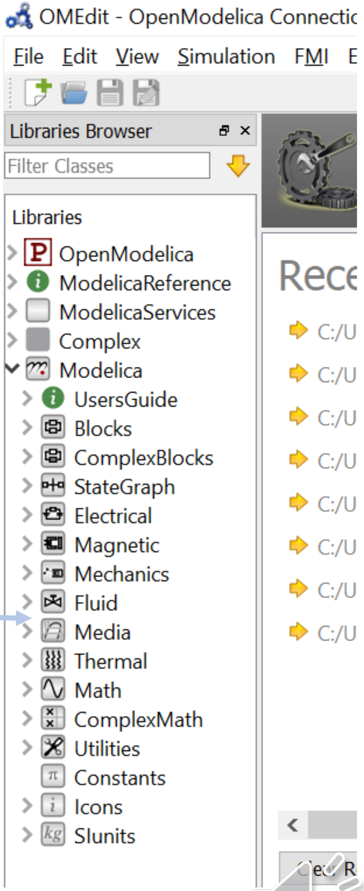
- Introduction
  - Motivation
  - History
  - Current work
- Theory
  - Wave-Body interaction problem
  - Simplifications for a non-diffracting object
  - Catenary mooring (Quasi-static approach)
- Implementation
- Results
- Conclusions

Introduction

- Motivation
  - Multiphysical simulation of systems with strong influence from hydrodynamics.
  - Black box nature of commercial software.
  - High cost of commercial software.
  - As a learning tool for students.

Ocean Engineering





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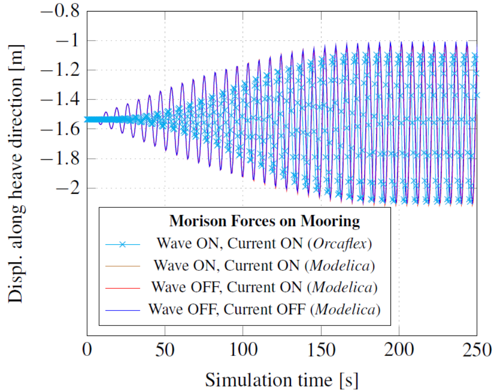
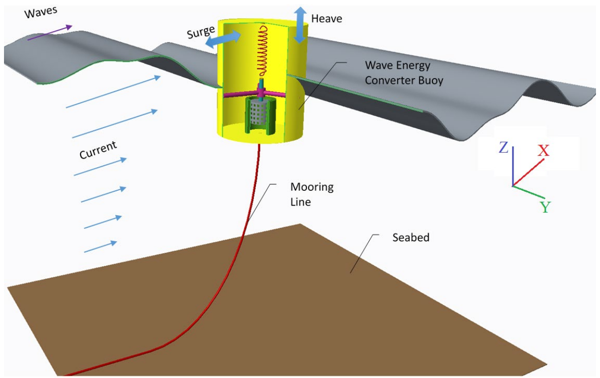
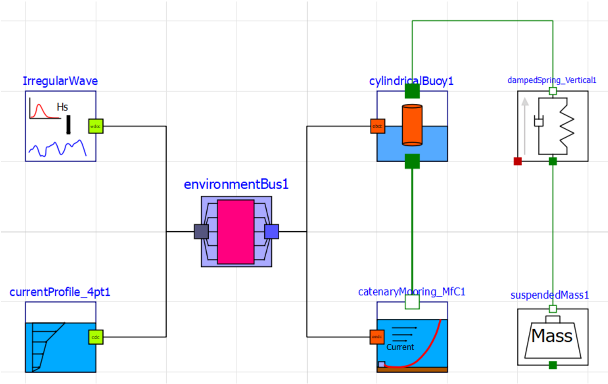
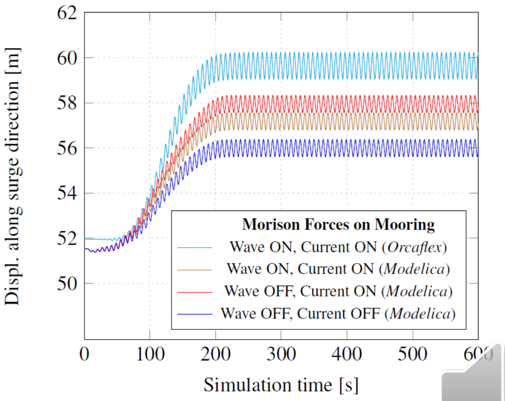
Introduction

- History
  - OMAE2019 : Towards the development of an Ocean Engineering library for OpenModelica.
  - Compared hydrodynamic response of catenary moored buoy modelled in OpenModelica and in Orcaflex.









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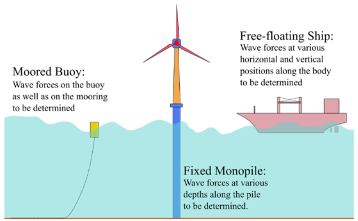
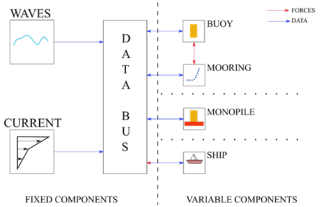
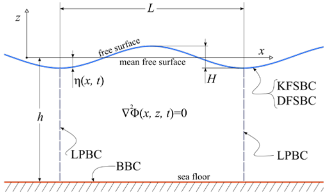
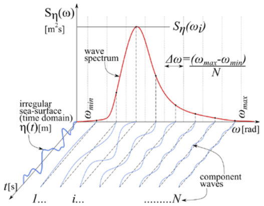
Introduction

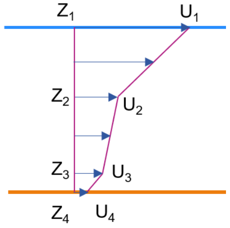
- History
  - American Modelica Conference 2020a: Modelica component models for oceanic surface waves and depth varying current .

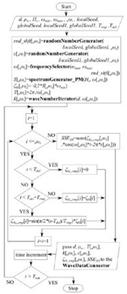


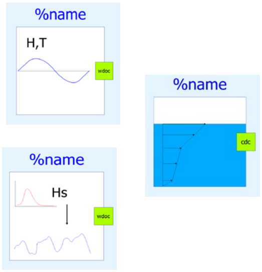












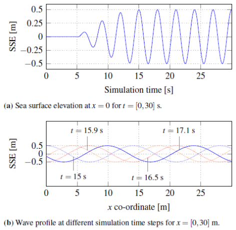


Figure 8. Sea surface elevation and the progressive wave profile.

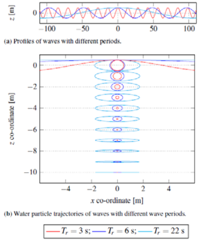


Figure 9. Wave profiles and water particle trajectories.

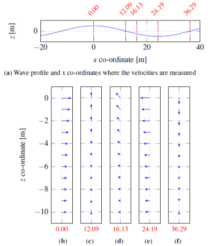


Figure 10. Wave profile (a), water-particle velocities (b)–(f).

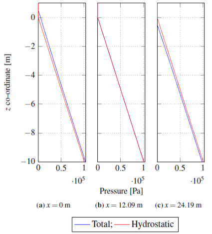


Figure 11. Pressures beneath the wave crest, down-crossing, and trough.

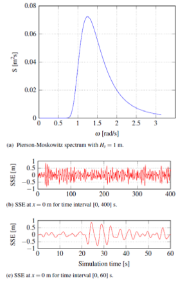


Figure 12. Irregular waves.

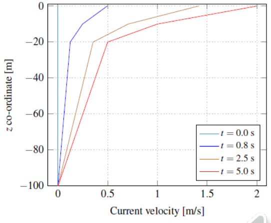


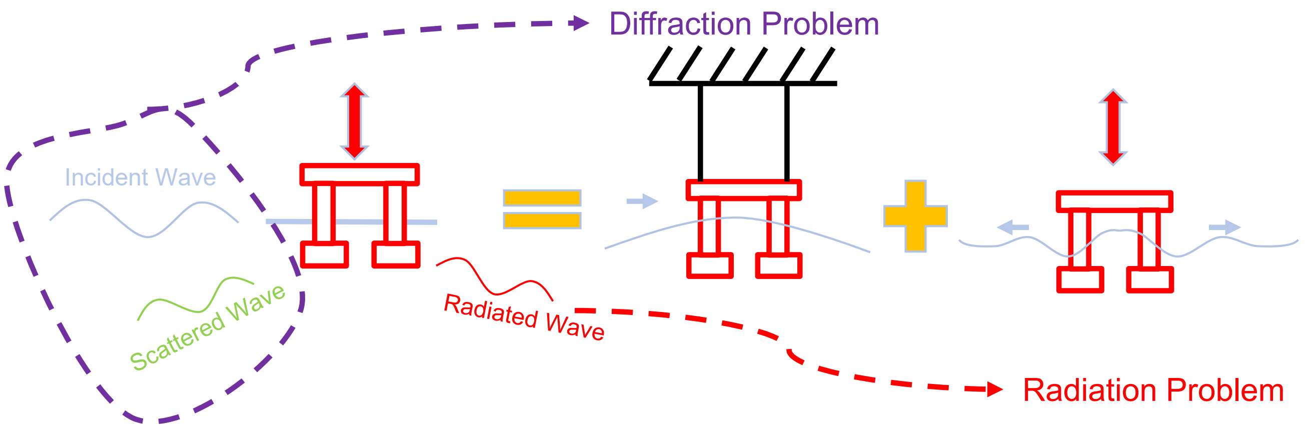
Figure 13. Current profile

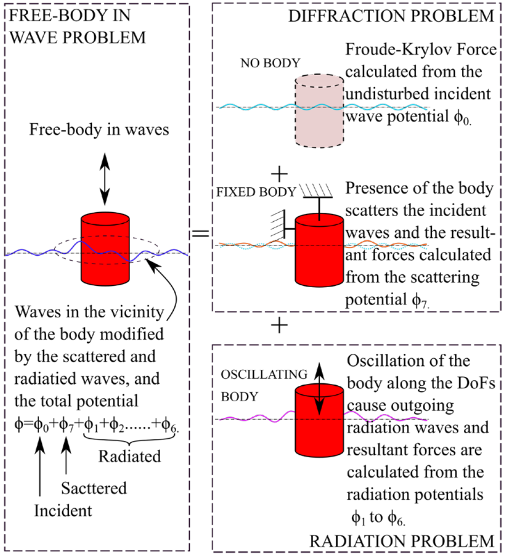
Introduction

- The current work
  - The wave-body interaction problem
  - Hydrodynamic response of a non-diffracting floating object
    - Froude-Kryloff force
    - Morison equation
  - Quasi-static catenary mooring analysis
  - Component model for non-diffracting floating object
  - Component model for quasi-static catenary

Theory

- The wave-body interaction problem



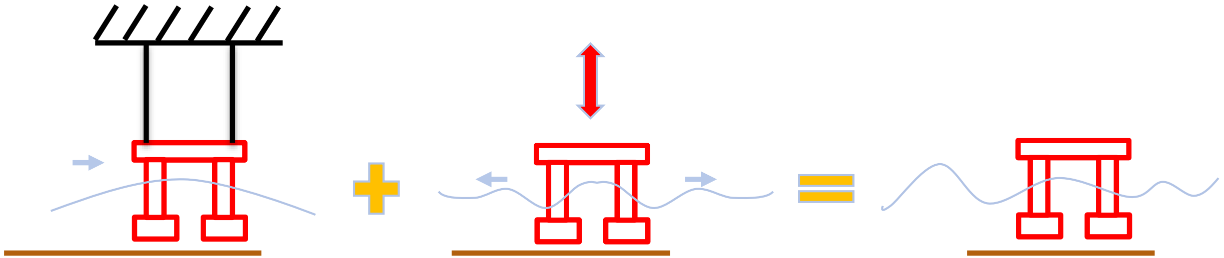


Ref: O.M Flatinsen, Sea Loads on Ships and Offshore Structures- Chapter 3.

**linearity assumed*

Theory

- Simplifications for a non-diffracting object



Wave excitation

Froude-Kryloff loads
Due to the unsteady pressure field generated by the incident wave.

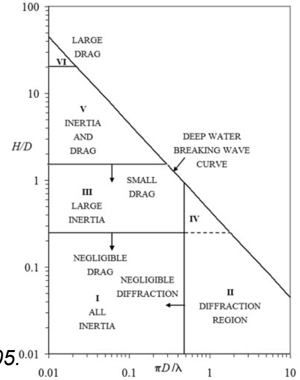
~~**Diffraction loads**~~
~~Due to the disturbance of the incident wave pressure field by the presence of the body.~~

Wave radiation

Added mass coefficients
Hydrodynamic loads in phase with the acceleration of the body.

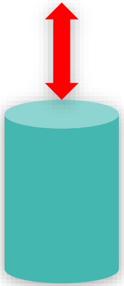
~~**Damping coefficients**~~
~~Hydrodynamic loads in phase with the velocity of the body.~~

Total wave load



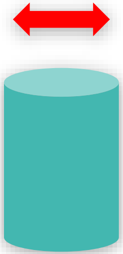
Ref: DNV-RP -C205.

Relatively small structure



Froude-Kryloff loads
significant inertia, small drag.
Due to the unsteady pressure field generated by the incident wave.

$$F_{FK}^{z} \approx \rho g A_{wp} \eta$$



Morison Loads
significant drag, small inertia.

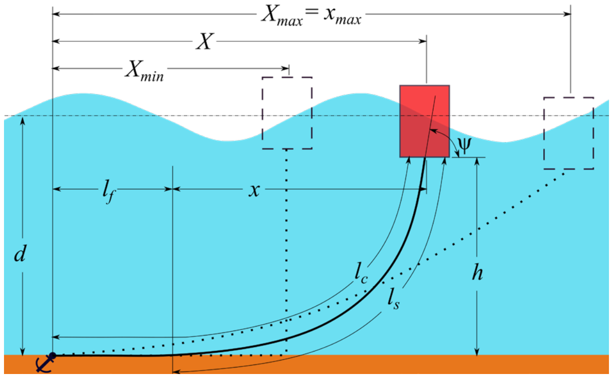
$$M_F^x = C_M^x \rho \frac{\pi}{4} D^2 \dot{u} - C_A^x \rho \frac{\pi}{4} D^2 \ddot{x} + C_D^x \frac{1}{2} \rho D \,|\, u \pm U - \dot{x} \,|\, (u \pm U - \dot{x})$$

$$u = \frac{\pi H}{T} \frac{\cosh\left[k(z+d)\right]}{\sinh kd} \cos(kx - \omega t)$$

$$\dot{u} = \frac{2\pi^2 H}{T^2} \frac{\cosh\left[k(z+d)\right]}{\sinh kd} \sin(kx - \omega t)$$

Theory

- Quasi-static catenary



$$T_H = \frac{xw}{\cosh^{-1}\left(1 + \frac{wh}{T_H}\right)}$$

$$l_s = h\sqrt{\left(1 + \frac{2T_H}{wh}\right)}.$$

$$X = l_c - l_s + x$$

$$a = \frac{T_H}{w}$$

$$z = a\cosh\left(\frac{x}{a}\right)$$

$$l_s = a\sinh\left(\frac{x}{a}\right)$$

$$z = a\sec(\psi) = a + h$$

$$z^2 = l_s^2 + a^2.$$

- Morison loads on the catenary

$$M_F^n = C_M^n \rho \frac{\pi}{4} D^2 a_w^n - C_A^n \rho \frac{\pi}{4} D^2 a_l^n + C_D^n \frac{1}{2} \rho D \mid v_w^n \pm U^n - v_l^n \mid (v_w^n \pm U^n - v_l^n).$$

$$M_F^t = C_M^t \rho \frac{\pi}{4} D^2 a_w^t - C_A^t \rho \frac{\pi}{4} D^2 a_l^t + C_D^t \frac{1}{2} \rho D \mid v_w^t \pm U^t - v_l^t \mid (v_w^t \pm U^t - v_l^t).$$

$$w = \frac{\pi H}{T} \frac{\sinh[k(z+d)]}{\sinh(kd)} \sin(kx - \omega t)$$

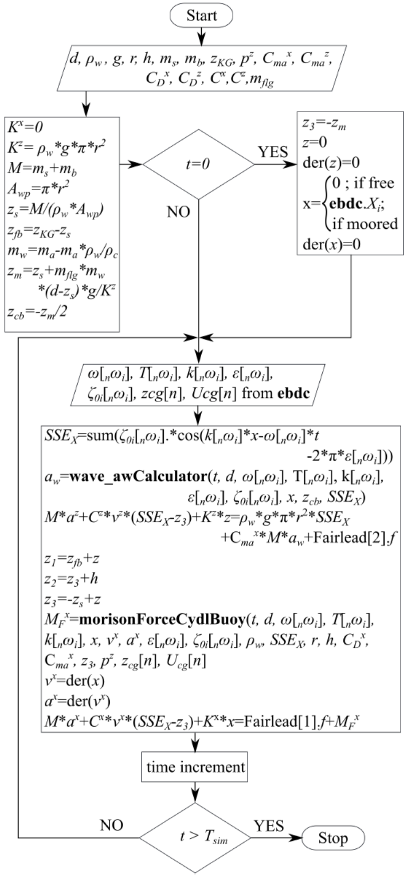
$$\dot{w} = -\frac{2\pi^2 H}{T^2} \frac{\sinh[k(z+d)]}{\sinh(kd)} \cos(kx - \omega t)$$

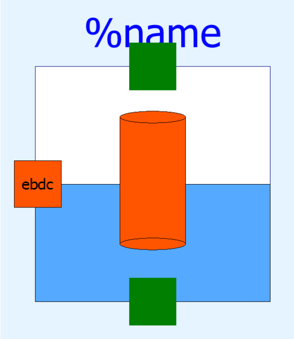
Implementation

- Non-diffracting floating object

EoM:

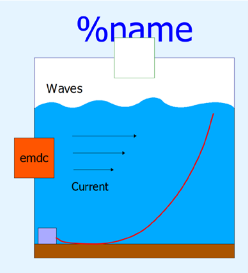
$$M^x\ddot{x}+C^x\dot{x}+K^xx=M_F^x+F_M^x$$
$$M^z\ddot{z}+C^z\dot{z}+K^zz=F_{FK}^z+m_a^z\dot{w}_{cb}+F_M^z$$

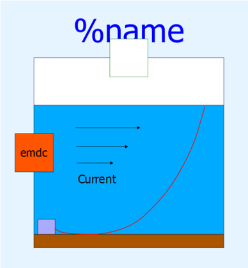


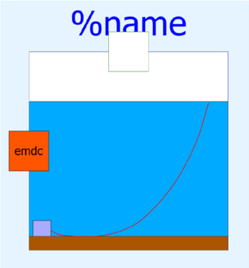


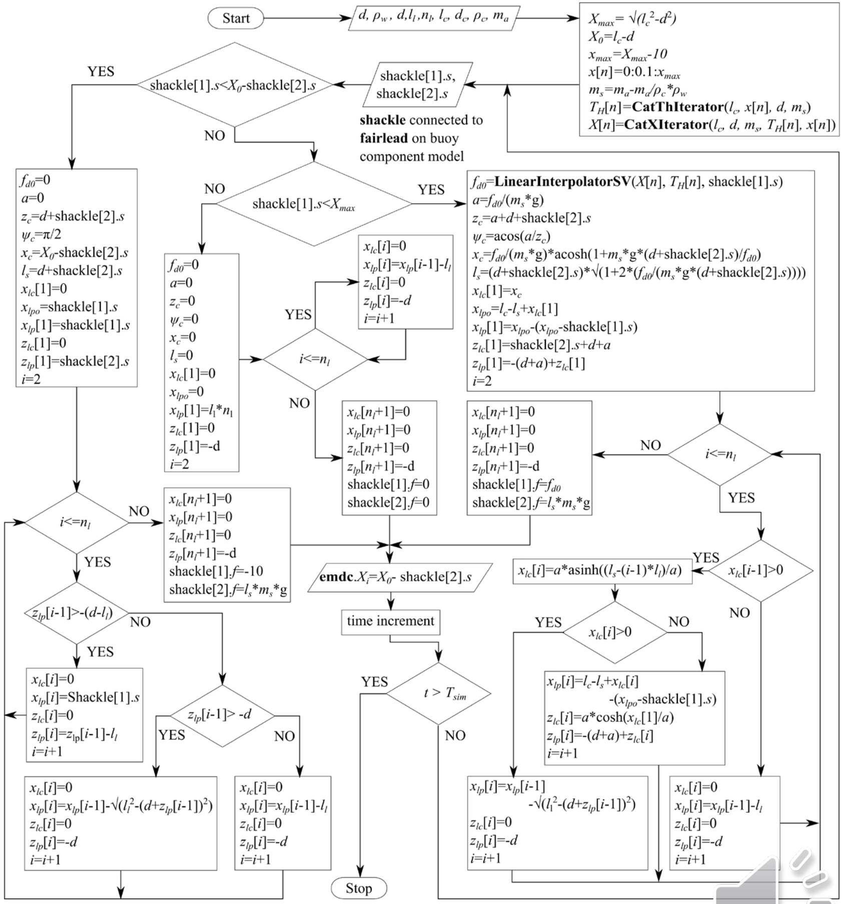
Implementation

- Quasi-static catenary mooring



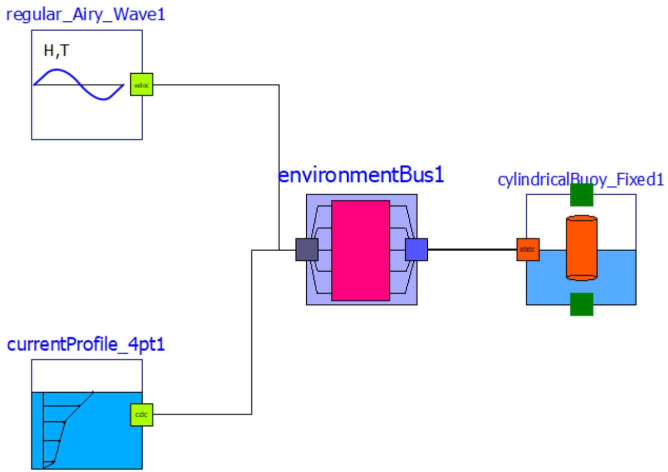


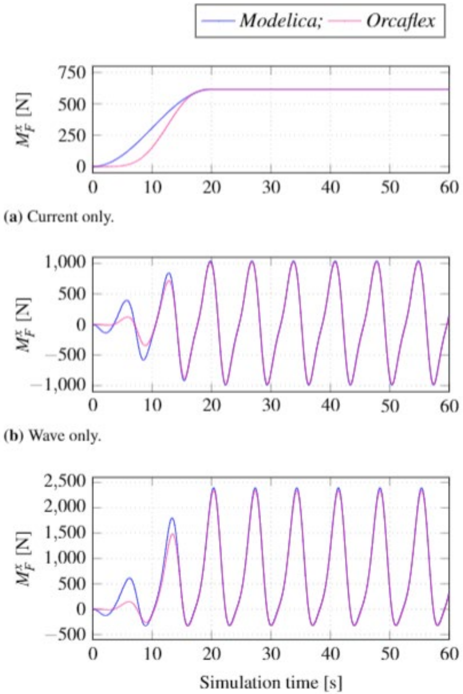




Results

- Fixed cylinder in waves and current





(a) Current only.

(b) Wave only.

(c) Waves and current.

Figure 7. Morison loads on a fixed cylinder.

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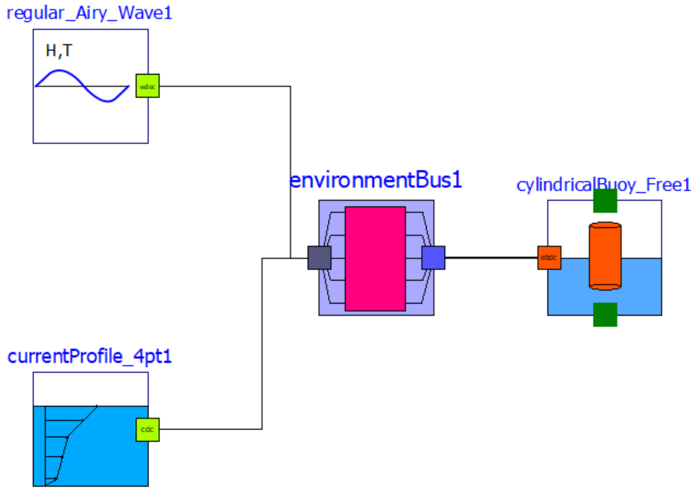
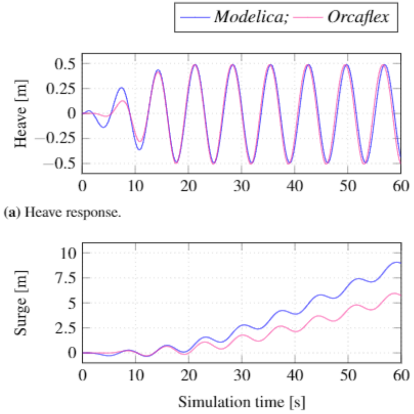
Results

- Free floating cylinder in waves and current

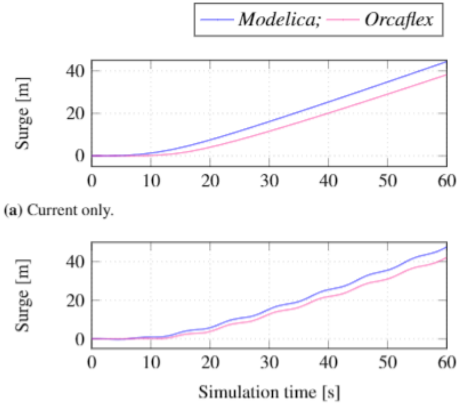




(a) Heave response.

(b) Surge response.

Figure 5. Unmoored cylindrical buoy in waves.



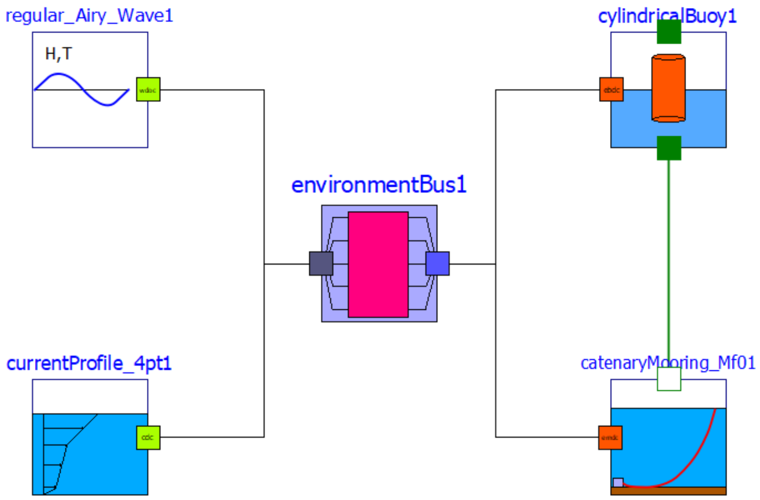
(a) Current only.

(b) Wave and current.

Figure 6. Surge response of an unmoored cylindrical buoy.

Results

- Catenary mooring



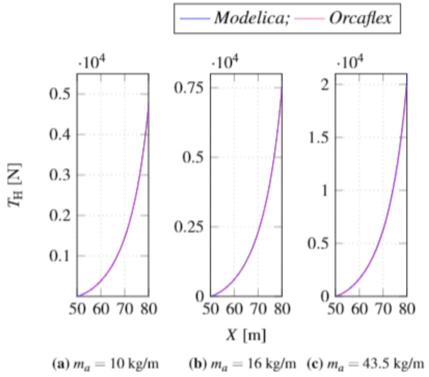


Figure 8. Horizontal tensions for mooring chains with different specific masses (m_a).

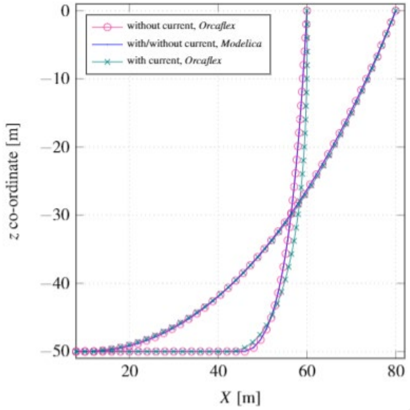
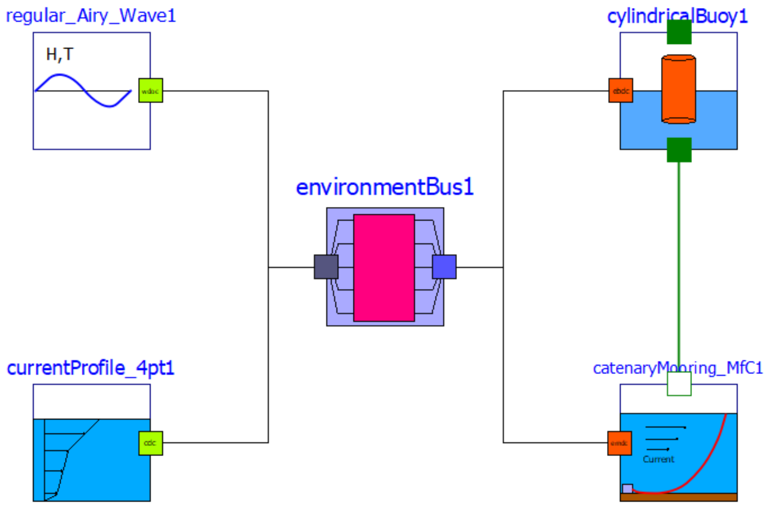
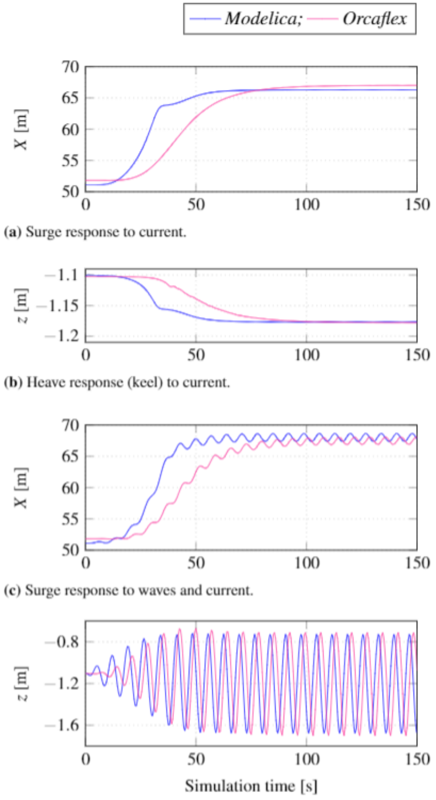


Figure 9. Shape of the mooring line.

Results

- Moored buoy in waves and current (only current loads on mooring chain)





(a) Surge response to current.

(b) Heave response (keel) to current.

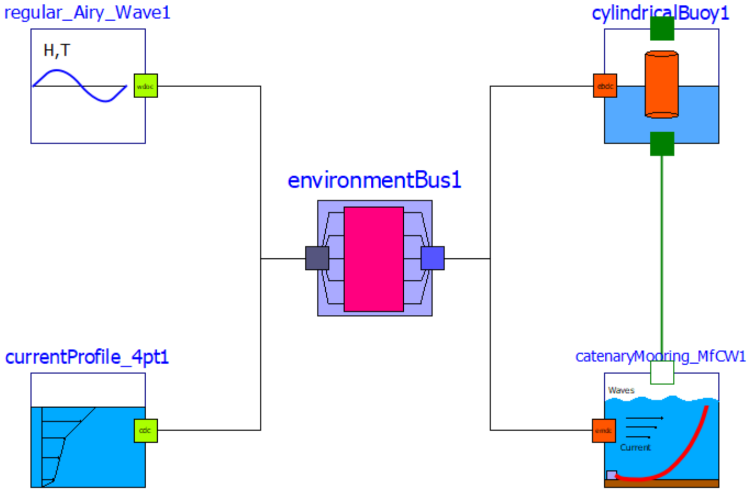
(c) Surge response to waves and current.

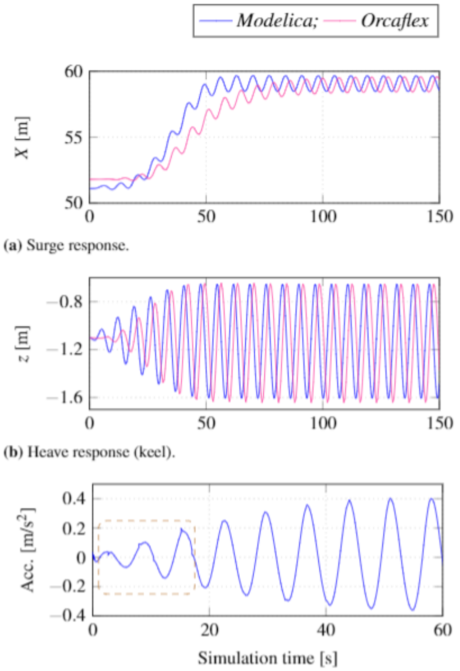
(d) Heave response (keel) to waves and current.

Figure 10. Hydrodynamic response of a moored cylindrical buoy.

Results

- Moored buoy in waves and current (both current and wave loads on the mooring chain)





(a) Surge response.

(b) Heave response (keel).

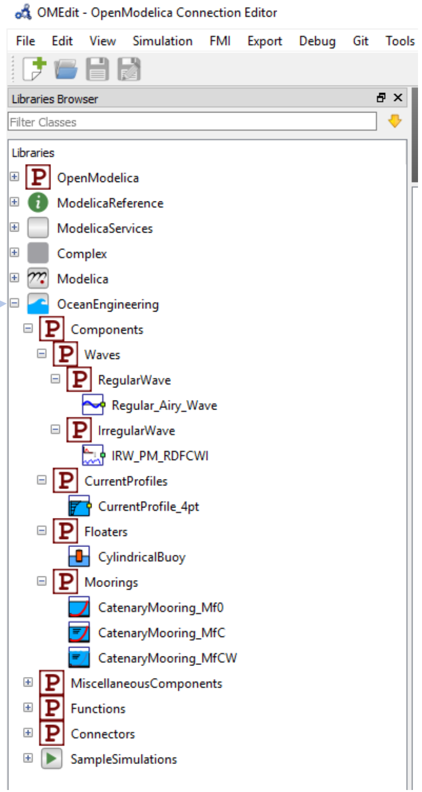
(c) Vertical acceleration of the second chain-link from the fairlead.

Figure 11. Moored cylindrical buoy in waves and reduced current.

Conclusion

- Component models were developed to capture the hydrodynamic response of a cylindrical, non-diffracting floating object and for mooring forces based on the quasi-static catenary approach.
- Morison and Froude-Kryloff forces calculated by the Modelica model were seen to be in agreement with results calculated by *Orcaflex*.
- Mooring forces calculated by the Modelica model were seen to be in satisfactory agreement with those calculated by *Orcaflex.*
- The hydrodynamic response of a moored buoy in waves and current, obtained from Modelica, was seen to be in satisfactory agreement with results for a similar system in *Orcaflex*.
- Differences in the response can be attributed to the inability of the Modelica component model to capture the dynamic effects of the mooring line.
- The component-models thus developed were incorporated into the preliminary Ocean Engineering library for OpenModelica.

Ocean Engineering




Thank you