TOWARDS THE DEVELOPMENT OF AN OCEAN ENGINEERING LIBRARY FOR OPENMODELICA

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ABSTRACT

The development of component models to populate a proposed *OpenModelica* standard library for the ocean engineering domain is described through the process of modelling the response of catenary-moored wave-energy converters in the 'free-to-use' *OpenModelica* simulation environment and its associated *OMEdit* graphical user interface. A wave energy conversion concept is presented, followed by the implementation of *Modelica* component models and functions to simulate wave, current, and mooring loads on a cylindrical floating object. The irregular sea surface is specified using the Pierson-Moskowitz spectrum and the heave force on the buoy is determined based on the Froude-Krylov formulation. Mooring load formulation is based on the catenary theory. Combined wave and current loads on the buoy and on the mooring chain are arrived at using the Morison equation. The results are verified with the commercial software *Orcaflex*, and the preliminary *OceanEngineering* library is made available for download. The integrated simulation of the multiphysical wave energy buoy system is then carried out to determine the energy harvest potential, and results discussed. An alternative design is then suggested and simulated to demonstrate the advantages of using the component-based approach.

Keywords: *Modelica* ocean engineering library, Multiphysical simulation of offshore systems, *Modelica* component models for ocean waves, non-diffracting objects, and catenary mooring.

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INTRODUCTION

Modelica is a non-proprietary, object-oriented, equation-based programming language to mathematically model complex multiphysical systems for the purpose of dynamic simulation. Since it is based on equations instead of assignment statements, the causality is unspecified and becomes fixed only when the corresponding equation systems are solved (acausal modelling). The main advantage with acausal modelling is that the solution direction of the equations will adapt to the data flow context in which the solution is computed, and this makes *Modelica* component models more reusable than traditional classes containing assignment statements where the input-output causality is fixed [1].

The *Modelica Standard Library* contains about 1600 model components and 1350 functions from the electric, electronic, mechanical, fluid, and control engineering domains. Commercial as well as free-of-charge *Modelica* simulation environments are available, and have been used by industry, especially in the automotive sector, to simulate and analyze product performance [2].

In spite of the many advantages that *Modelica* has to offer, its utilization in the offshore domain, which, even in its simplest engineering applications, is highly multiphysical and interdisciplinary, has been minimal. One of the reasons behind this could be the lack of *Modelica* component models relating to offshore engineering, especially those dealing with simulation of irregular ocean surface waves, hydrodynamics, mooring, etc.

The present work is directed towards the development of a *Modelica* standard library for the ocean engineering domain populated with domain-specific component models and functions. The work is carried out in the free-to-use *OpenModelica* simulation environment and its *OMEdit* graphical user interface. An online search for literature revealed that very little has been published on the subject, the most relevant being Brommundt *et al.* on the experiences of modeling a floating support structure for offshore wind turbines [3].

As a first step, the modelling and simulation of a simple wave energy converter buoy is described, involving the development of *Modelica* component models for the ocean engineering domain. The widely used commercial software, *Orcaflex* is used to verify the satisfactory performance of the hydrodynamics and mooring characteristics. The components and functions are then packaged to constitute the *OceanEngineering* library, which is available for public download at `https://github.com/Savin-Viswanathan/OELib_OMAE2019`. The integrated model of the multiphysical system is then built up using these components and simulated. Following the discussion of the simulation results, an alternative design is proposed and simulated to showcase the benefits of component-based modelling.

Keeping in line with the intent of this work, which is *only* to showcase the advantages of developing an *Ocean Engineering* library for *Modelica*, and *not* the detailed modelling of wave energy conversion devices, modelling is described only to the extent required to simulate the motion of the permanent-magnet core inside the coil of the linear electric generator, as a measure of electrical energy output potential, in both cases.

THE WAVE BUOY CONCEPT

A free-floating point-absorber wave buoy with an internal spring-suspended permanent-magnet core which is free to oscillate inside an induction coil will produce some electrical power when subjected to wave action [4].

Let us consider, for the purpose of developing a *Modelica* model, that we would like to simulate the performance of a system working on the concept of the *DC3* buoy described in [4], but, with some design changes, and the inclusion of a mooring catenary to constrain buoy drift. The present system concept is shown in Fig. 1, and the internal detail of the buoy is depicted in Fig. 2. The power output will be a function of the wave load, the hydrodynamic response of the buoy in the heave direction, and the mooring force. The mooring system response is in turn a function of the hydrodynamic response of the buoy in the surge direction, which is dependent on the wave as well as the current force on both the buoy and on the mooring line itself.

The objective at this stage is to develop an integrated *Modelica* component model to simulate the multiphysics of the whole system so as to determine the motion response of the suspended core, as a measure of power output potential in various sea states.

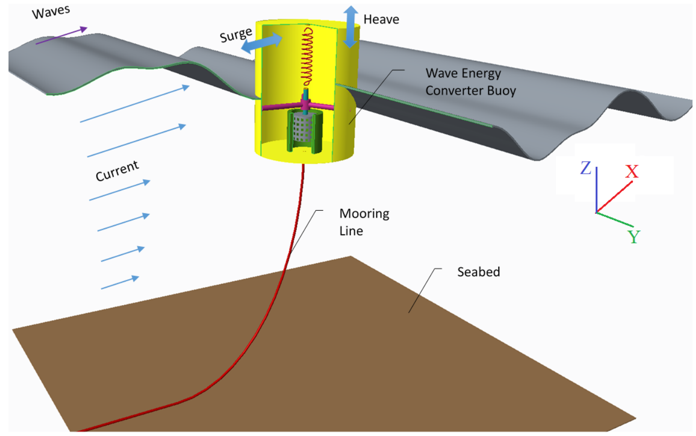

FIGURE 1. CONCEPT OF THE WAVE ENERGY CONVERTER BUOY.

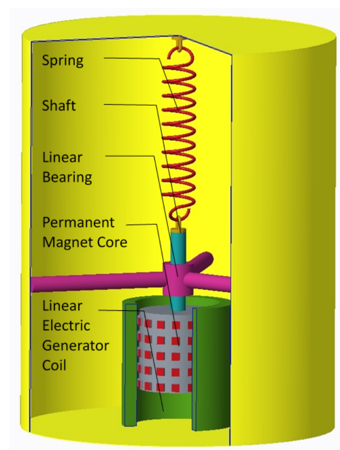

FIGURE 2. INTERNAL ARRANGEMENT OF THE WAVE ENERGY CONVERTER BUOY.

SIMULATING THE OCEAN SURFACE

Considering the Fourier series representation of the irregular sea surface, and the concept of the wave spectrum [5, pp. 87–90, and p. 101], one may represent the sea surface elevation, $\eta(t)$ [m] at a required horizontal coordinate x [m] at time t [s] as [5, p. 123, 124]:

$$\eta(t) = \sum_{i=1}^{N} \eta_{0i} \cos(k_i x - \omega_i t - \varepsilon_i), \tag{1}$$

$$\eta_{0i} = \sqrt{2 S_\eta(\omega_i) \Delta\omega}. \tag{2}$$

Here, N is the total number of wave components (frequency bands), η_0 [m] is the component wave amplitude, ω [rad/s] is the wave angular frequency, and ε [rad] is the phase. Subscript i refers to the number of the component wave under consideration. The wave number k [rad/m] is to be determined from the dispersion relation $\omega^2 = gk\tanh kd$ by iteration. g [m/s^2] is the acceleration of gravity and d [m] is the water depth. $S_\eta(\omega_i)$ [m^{2}s] is the energy spectral density and $\Delta\omega$ [rad/s] is the width of the frequency bands dividing the total wave spectrum.

If the component frequencies are evenly distributed, $\eta(t)$ will be periodic, which is undesirable. Selecting frequency components randomly (uniformly distributed) within each frequency band will avoid this problem and give a quasiperiodic signal [6, p. 209].

The generation of wave records in this work is based on the Pierson-Moskowitz spectrum which may be expressed in terms of its significant wave height H_s [m], as [5, pp. 105–107]:

$$S_\eta(\omega_i) = \frac{5\pi^4 H_s^2}{T_p^4 \omega_i^5} \exp\left(\frac{-20\pi^4}{T_p^4 \omega_i}\right). \tag{3}$$

Here, T_p [s] is the peak period of the spectrum, and is related to H_s through the relations $T_p = \frac{2\pi}{\omega_p}$, and $\omega_p^2 = \frac{0.161g}{H_s}$. Here, ω_p [rad/s] is the peak angular frequency.

A *Modelica* component **IRW_PM_RDFCWI** which calls functions **spectrumGenerator_PM**, **randomNumberGenerator**, **frequencySelector**, and **waveNumberIterator** was implemented to perform the above calculations for specified H_s.

Figure 3 shows the generated sea surface elevation based on a Pierson–Moskowitz spectrum with $H_s = 1$ m, and $d = 50$ m. Sinusoidal ramping of the wave amplitude was implemented to prevent impulse loads at the start of simulation.

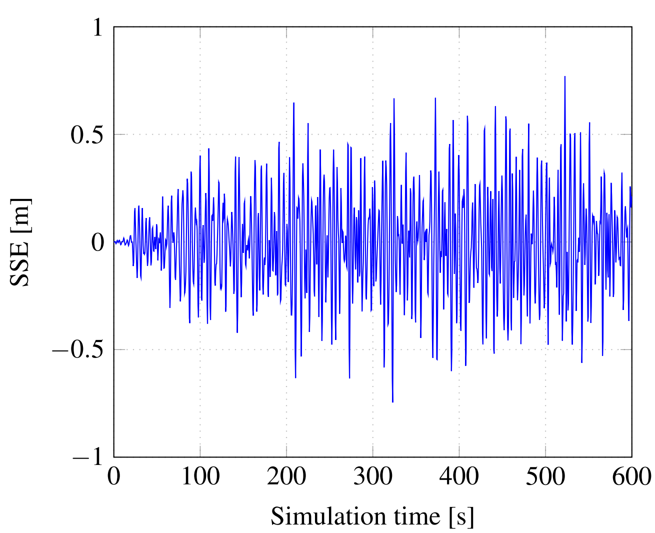

FIGURE 3. SEA SURFACE ELEVATION

To facilitate regular-wave analysis, a *Modelica* component **RegularAiryWave**, which computes the wave elevation $\eta(t) = \eta_0 \cos(kx - \omega t)$, was implemented. Here, η_0 [m] is the specified wave amplitude and $\omega = 2\pi/T$, where T [s] is the specified wave period.

THE CURRENT PROFILE

The current profile is specified as an array of depths z_{cg} and current velocities U_{cg}, at a specified number of points, enabling the interpolation of the current velocity at any depth. A *Modelica* component **CurrentProfile_4pt** was coded to perform this task.

SIMULATING THE HYDRODYNAMICS OF A NON-DIFFRACTING FLOATING OBJECT

Of the 6 degrees of freedom of the cylindrical buoy, it is heave that has the most significant effect on the power generated, and surge that has the most significant effect on the mooring forces. Hence, the present work considers only the uncoupled heave and surge response of the cylindrical floating object. Further, it may be safely assumed in this case that heave and pitch are uncoupled.

Considering the heave motion of a floating object in still waters, the single degree of freedom equation of motion for damped oscillations,

$$M\ddot{z} + C\dot{z} + Kz = F(t), \tag{4}$$

is applicable. Here, $M = m(1 + C_{ma})$, $C = \zeta C_c$, $C_c = 2M\omega_n$, $\omega_n = \sqrt{\frac{K}{M}}$, and $K = A_{wp}\rho g$.

In the above, m [kg] is the mass of the body, C_{ma} [-] is the added mass coefficient, C [Ns/m] is the damping coefficient, K [N/m] is the stiffness, z [m] is the body displacement (from its mean position), $F(t)$ [N] is the time dependent external force acting on the body, ζ [-] is the damping coefficient, C_c [Ns/m] is the critical damping, ω_n [rad/s] is the natural frequency, A_{wp} [m^2] is the water-plane area, ρ [kg/m^3] is the density of water, and g [m/s^2] is the acceleration of gravity. For small structures, C_{ma} and C are obtained from experimental data [5, pp. 331–338]. These may also be determined from a frequency domain analysis using software like WAMIT or ANSYS AQWA. In this example, we are assuming $C_{ma} = 1$ and $\zeta = 0.5$ for heave. Motion in surge direction is considered un-damped and the added mass is taken to be equal to the instantaneous displacement mass.

The external forces constituted by wave, current, and mooring loads are to be specified on the RHS of Eqn. (4) to simulate the forced damped oscillations of a floating object. The wave loading in the heave direction is determined using the Froude-Krylov force formulation which may be applied in cases of small (with respect to wave length) structures if the flow is assumed irrotational and the diffraction effect small [5, p. 233], as is the case here. The Froude-Krylov force is given by $F_z^{FK} \approx \rho g A_{wp} \eta$. [7]. The horizontal wave and current loads are determined using the equation for the Morison force on a cylindrical object free to move in presence of waves and current, given as [5, p. 189]

$$\begin{aligned} M_F = & C_M \rho \frac{\pi}{4} D^2 \dot{u} - C_A \rho \frac{\pi}{4} D^2 \ddot{x} \\ & + C_D \frac{1}{2} \rho D \mid u \pm U - \dot{x} \mid (u \pm U - \dot{x}). \end{aligned} \tag{5}$$

Here, M_F [N] is the Morison force (per unit length, in this case), C_M [-] is the inertia coefficient, ρ [kg/m^3] is water density, D [m] is the body diameter, $\dot{u}$ [m/s^2] is the wave induced water particle acceleration along x, C_A [-] is the added mass coefficient , $\ddot{x}$ [m/s^2] is the body acceleration along x, C_D [-] is the drag coefficient, u [m/s] is the wave induced water particle velocity along x, U [m/s] is the current velocity along x, and $\dot{x}$ [m/s] is the body velocity along x. C_M and C_D are available from numerous field and laboratory tests, which allows the designer to choose appropriate values [5, p. 172]. Also, $C_M = 1 + C_A$ [5, p. 178]. The wave kinematics are given by [5, pp. 48–52]:

$$u = \frac{\pi H}{T} \frac{\cosh k(z+d)}{\sinh kd} \cos(kx - \omega t), \tag{6}$$

$$\dot{u} = \frac{2\pi^2 H}{T^2} \frac{\cosh k(z+d)}{\sinh kd} \sin(kx - \omega t). \tag{7}$$

Here, H [m] is the wave height, T [s] is the wave period, k [rad/m] is the wave number, z [m] is the vertical coordinate of the point at which the wave kinematics are to be calculated, d [m] is the water depth, x [m] is the horizontal coordinate of the point at which the wave kinematics are to be calculated, and ω [rad/s] is the angular frequency of the wave.

A *Modelica* model **CylindricalBuoy** which utilizes the above equations to determine the heave and surge forces was implemented to determine the hydrodynamic response. The *Modelica* function **morisonForceCydlBuoy** calculates the Morison loading on the buoy. The velocity and acceleration profiles for the wave and current are moved with the instantaneous sea surface [8, sec. B1.4.5.5]. Fig. 4 shows the comparison of the heave response between *Modelica* and *Orcaflex* (modelled as a spar buoy of same the dimensions) models, and Fig. 5, the surge response in various situations of waves and current. The buoy is of diameter 1.2 m, height 2 m, and mass 850 kg, while the wave has a height of 1 m and a period of 7 s. The slight phase difference between the model responses is due to the different wave start times between *Orcaflex* and *Modelica*. The minor variation in heave response could be due to the simplified approach adopted in this work as compared to the method used by *Orcaflex*, and is to be investigated. All other responses are found to be a close fit.

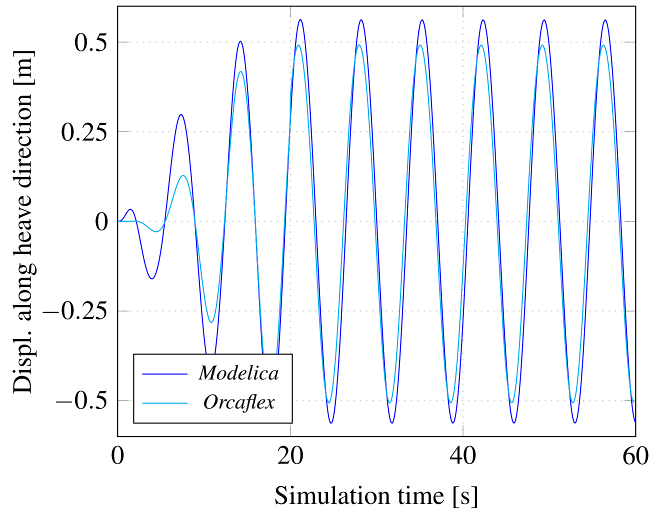

FIGURE 4. HEAVE RESPONSE OF A FREE-FLOATING CYLINDRICAL BUOY.

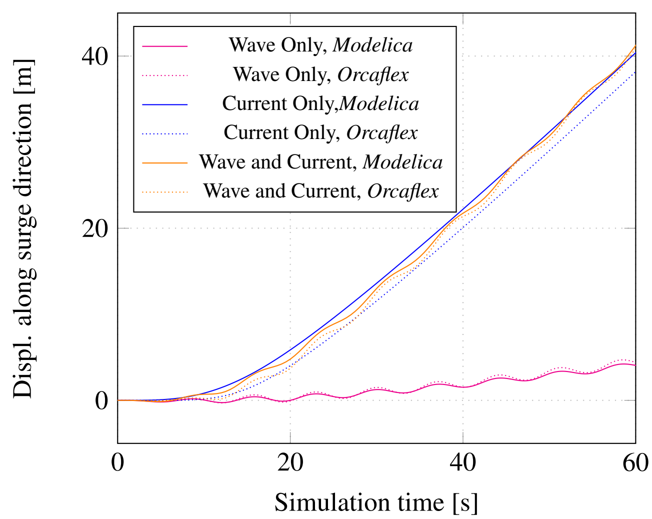

FIGURE 5. FLOATING CYLINDER IN WAVES AND CURRENT.

Since the buoy drifts in the presence of waves and current, it has to be moored. To transfer the mooring loads, a **Fairlead** connector of type *Modelica.Mechanics.Translational.Interfaces.Flange_a*, available in the *Modelica* standard library for mechanical interfaces, is specified at the centre of the bottom surface of the buoy. The **Fairlead** connector is composed of two flanges, one each for transfer of horizontal and vertical components of the mooring load. In addition, another flange connector named **Tophook** was defined at the centre of the top surface of the buoy to suspend the spring-mass system representing the core of the linear electric generator.

SIMULATION OF CATENARY FORCES

When a chain is laid on the ground, and one of its ends is raised to a height, it assumes a half-catenary shape between the ground and the point of suspension. At the point of suspension, the suspended chain weight has a horizontal and a vertical component, the magnitudes of which depend on angle ψ, as indicated in Fig. 6. If the chain is attached to a floating object, this horizontal force component acts to restrain the drifting of the object from its equillibrium, and this constitutes the principle of the catenary mooring system. The equation of a catenary in cartesian co-ordinates is given by $z = a\cosh(\frac{x}{a})$ [9]. Here x [m] and z [m] are the catenary coordinates and a [m] is the catenary parameter.

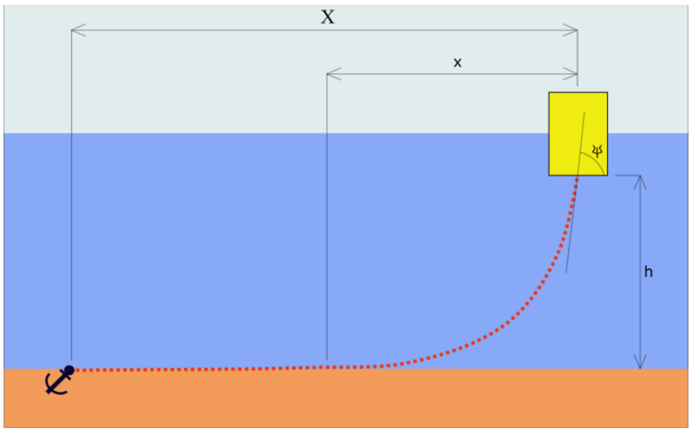

FIGURE 6. THE MOORING HALF-CATENARY.

Considering the relations $a = \frac{T_{\mathrm{H}}}{w}$, $z = a\sec(\psi) = a + h$ and $z^2 = l_s^2 + a^2$, one may arrive at the following relations [10]:

$$T_{\mathrm{H}} = \frac{xw}{\cosh^{-1}\left(1 + \frac{wh}{T_{\mathrm{H}}}\right)}, \tag{8}$$

$$l_s = h\sqrt{\left(1 + \frac{2T_{\mathrm{H}}}{wh}\right)}. \tag{9}$$

Here, T_H [N] is the horizontal tension, w [N/m] is the submerged specific weight of the catenary, ψ [rad] is the angle of the catenary w.r.t. x-axis at the point of suspension, h [m] is the vertical distance of the point of suspension of the catenary from the sea floor, and l_s is the length of the catenary from the point of suspension on the buoy to the touchdown point on the sea floor.

Now, considering that while X varies from $X_{\min} = (l_c - d)$ to $X_{\max} = \sqrt{l_c^2 - d^2}$, x varies from $x_{\min} = 0$ to $x_{\max} = X_{\max}$, where l_c [m] is the total length of the mooring chain and d [m] is the water depth (ref. Fig 6), Eqn. (8) can be iterated to get values for T_H for $x = \{0, 0.1, 0.2 \ldots, x_{\max}\}$. l_s may then be calculated using Eqn. (9) and X can be calculated using the relation

$$X = l_c - l_s + x\,. \tag{10}$$

We can thus arrive at a table of values of T_{H} for specified X. The mooring load at any time step can then be linearly interpolated for the required x coordinate of the body's centre of gravity.

A *Modelica* model **CatenaryMooring**, calling on functions **catXIterator** and **catThIterator**, was implemented to simulate the mooring loads.

The mooring is attached to the fairlead fixed at the centre of the bottom surface of the buoy, the connection being effected through a **Shackle** connector complementary to the **Fairlead** connector.

The mooring catenary will also be acted upon by waves and currents, and this force will be transferred to the buoy through the mooring chain. The assumption made in calculating the Morison loading of the mooring catenary is that the instantaneous catenary shape remains unaltered due to Morison loads on the chain, and that the net effect of the Morison loads is a modification of the vertical and horizontal components of the mooring load. The chain length is discretized into a number of segments, and combined wave and current kinematics calculated at the segment centres are used to determine the Morison loads on the chain based on the hydraulic diameter and drag coefficients. The water particle kinematics are determined using Eqns. (6), (7) and [5, pp. 48–52]:

$$w = \frac{\pi H}{T}\,\frac{\sinh\,k(z+d)}{\sinh\,kd}\,\sin(kx - \omega t), \tag{11}$$

$$\dot{w} = \frac{-2\pi^2 H}{T^2}\,\frac{\sinh\,k(z+d)}{\sinh\,kd}\,\cos(kx - \omega t). \tag{12}$$

Here, w [m/s] is the wave-induced water-particle velocity and $\dot{w}$ [m/s^2] is the wave-induced water-particle acceleration in the z direction.

Figure 7 and Fig. 8 shows the effect of the mooring line on the excursion of a buoy of the same dimensions as earlier, but with a mass of 1100 kg, moored with chain of specific mass 16 kg/m, when subjected to a uniform current of 1 m/s acting over a depth of 10 m and tapering to 0 m/s at a depth of 25 m, in a water depth of 50 m. Fig. 9 shows the corresponding catenary shape of the mooring chain at various simulation time steps. *Orcaflex* approximates the chain as a series of rigid interconnected mass-spring-dampers, while the *Modelica* component uses a catenary approximation approach for the mooring line model, and this results in a minor variation in the mooring load as shown in Fig. 10. The buoys float at the same initial draught of 1.535 m in both models, and this implies that the x coordinate of the mooring line top end should have been positioned at $(50 + 1.535)$ m. However it is observed that *Orcaflex* places it at 51.95 m. The exact reason for this shift is yet to be ascertained.

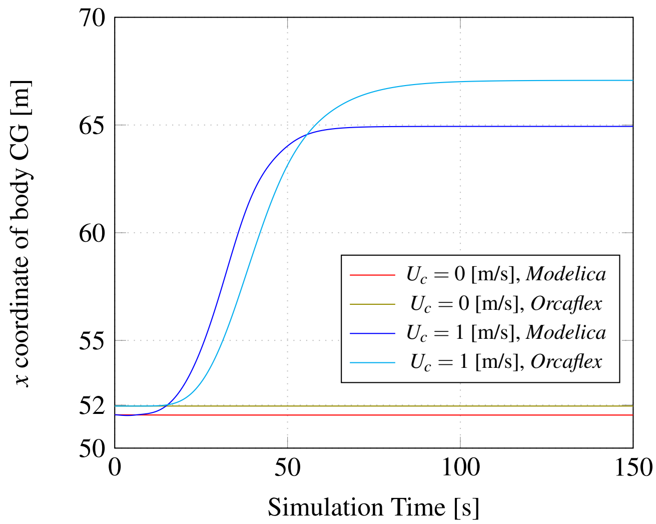

FIGURE 7. SURGE RESPONSE OF MOORED BUOY IN CURRENT.

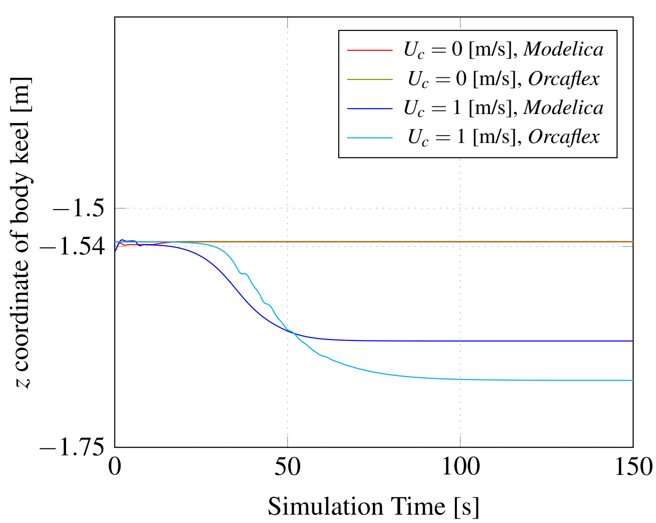

FIGURE 8. HEAVE RESPONSE OF MOORED BUOY IN CURRENT.

Figure 11 compares the surge response of the same buoy in the presence of a regular wave of height 1 m, period 7 s, and a current of 0.5 m/s (profile as discussed earlier), with and without considering mooring chain Morison forces, while Fig. 12 compares the heave response for the same cases by plotting the buoy

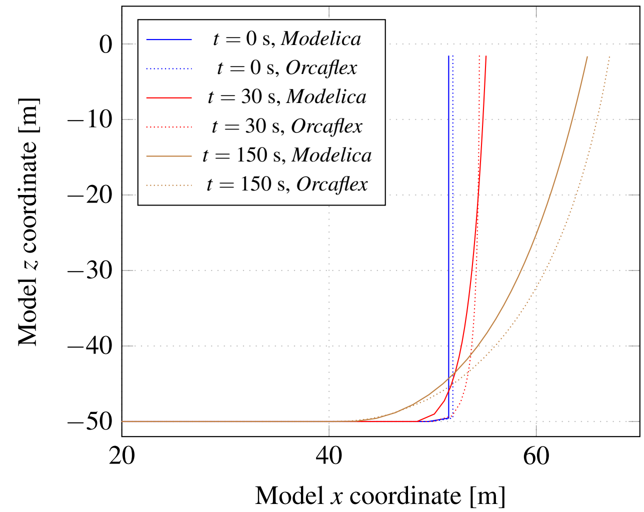

FIGURE 9. EVOLUTION OF THE MOORING CATENARY.

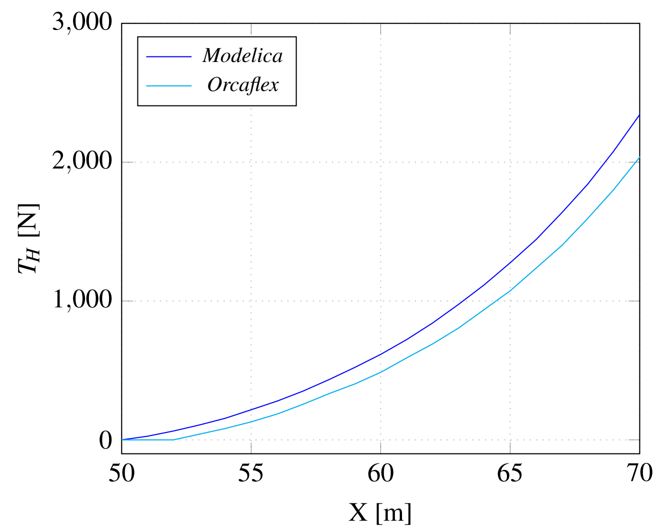

FIGURE 10. COMPARISON OF T_H.

keel position. Note the negligible effect of mooring chain Morison loads on the heave response. The higher surge response of the *Orcaflex* model seen in Figure 11 is due to the lower mooring T_H, as can be inferred from Fig. 10.

The following mooring components have been defined:

CatenaryMooring_Mf0 which does not consider current or wave loads on the mooring line.

CatenaryMooring_MfC which considers only current and wave velocity loads on the mooring line.

CatenaryMooring_MfCW which considers both current and wave velocity as well as acceleration loads on the mooring line.

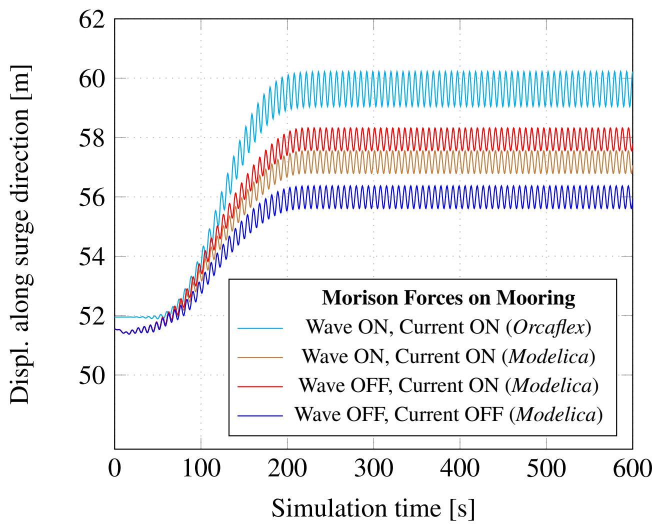

FIGURE 11. EFFECT OF MOORING CHAIN MORISON LOADS ON SURGE RESPONSE OF BUOY IN WAVES AND CURRENT.

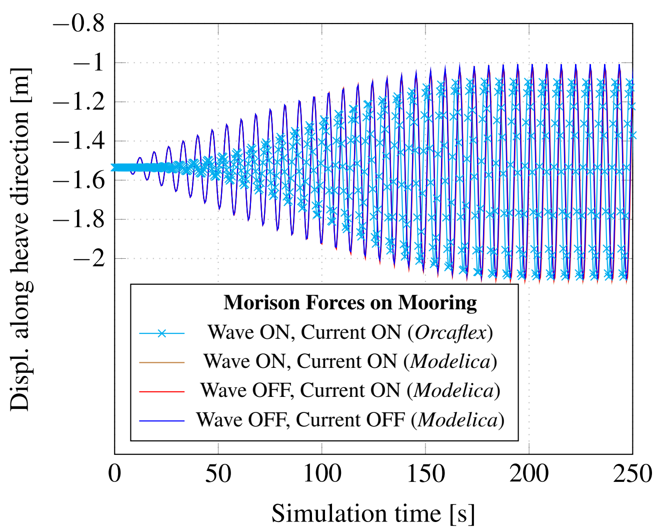

FIGURE 12. HEAVE RESPONSE OF BUOY WITH AND WITHOUT MORISON LOADING OF MOORING.

It has been noticed that the model becomes sluggish when using the **CatenaryMooring_MfCW component**. However, noting the negligible impact of the mooring-line wave Morison loading on the buoy's response, we henceforth consider only current loads on the mooring line.

SIMULATING THE SPRING-MASS SYSTEM

The spring-mass system is modelled using standard components already available in the *Modelica* Mechanics library. A **SpringDamper** component and a **Mass** component are coupled to represent the spring-suspended core of the linear electric generator, as shown in Fig. 15, under the System Integration section.

Figure 13 shows the effect of the oscillations of the spring-suspended mass of 50 kg on a floating buoy of mass 350 kg, in still water. The mass is released from different initial positions and the vertical motions of the mass' centre of gravity and buoy keel are plotted. Note the coupling between the mass and buoy response. Thus, the dynamics of the buoy and the spring-suspend mass are coupled through the **TopHook** connector.

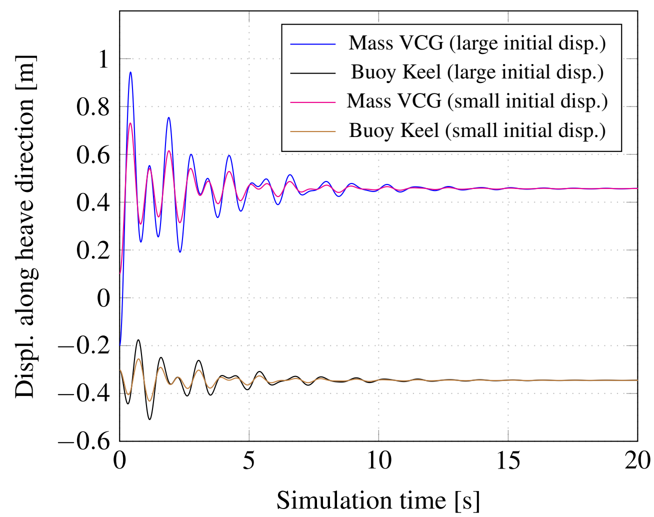

FIGURE 13. COUPLING OF SPRING MASS AND BUOY HEAVE RESPONSE.

THE MODELICA OCEAN ENGINEERING LIBRARY

Having verified the satisfactory simulation of hydrodynamic and mooring loads, we now proceed to build up a preliminary library for the ocean engineering domain.

All the components discussed earlier are packaged to constitute the **OceanEngineeringLibrary** as shown in Fig. 14. The custom-developed models for waves, current profile, floaters, and moorings are grouped together as **Components**, while the modified *SpringDamper* and *Mass* models from the already available mechanics library are grouped under **MiscellaneousComponents**. All the custom-developed functions are grouped as **Functions**, while the custom-developed connectors are grouped as **Connectors**. All the simulations discussed in this paper are grouped under **SampleSimulations**, and are ready for simulation. The library is available for free public download at `https://github.com/Savin-Viswanathan/OELib_OMAE2019`. To use the library, one must download the files to a computer in which the free-to-use *OMEdit* is installed and double click **OceanEngineering.mo**.

The *Orcaflex* simulation files are also accessible through the download link.

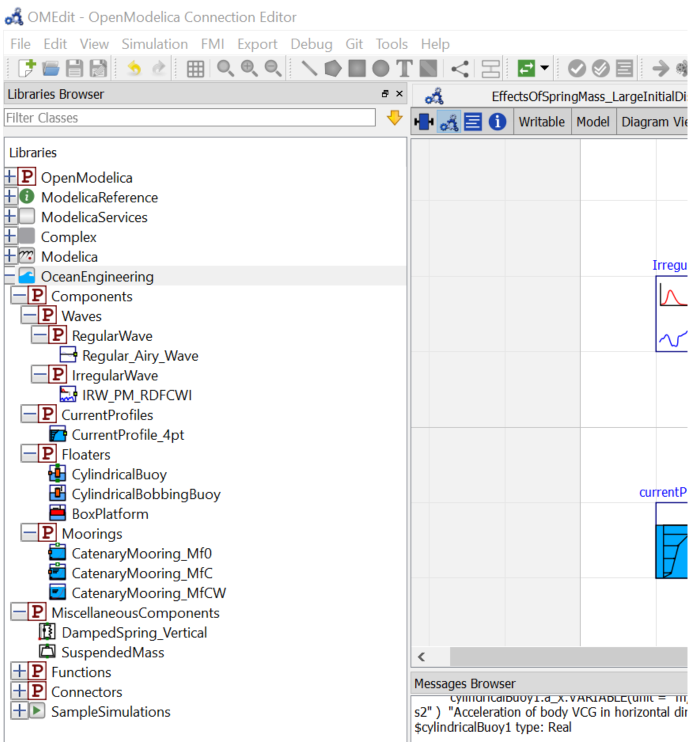

FIGURE 14. SCREENSHOT OF THE OCEAN ENGINEERING LIBRARY.

SYSTEM INTEGRATION

Having thus set up the library, it is very easy to build integrated system models. The drag-and-drop feature of *OMEdit* allows one to easily assemble the components in the *diagram* view.

The integrated multiphysical system model for a wave energy conversion buoy in irregular waves and current is shown in Fig. 15. Here,

1. *Modelica* model **RegularWave/ IrregularWave** determines the wave parameters, viz. $\omega_i, T_i, k_i, \varepsilon_i, \eta_{0i}$.
2. *Modelica* connector **WaveDataConnector** links this information to the *Modelica* expandable connector **EnvironmentBus**.
3. *Modelica* model **CurrentProfile** generates the specified current profile as a vectors of z_{cg} and U_{cg} values.
4. *Modelica* connector **CurrentDataConnector** links this information to the *Modelica* expandable connector **EnvironmentBus**.
5. *Modelica* connector **EnvironmentMooringDataConnector** links the required information from the **EnvironmentBus** to the *Modelica* Model **CatenaryMooring** while *Modelica* connector **EnvironmentBuoyDataConnector** links the required information to the *Modelica* model **CylindricalBuoy**.
6. *Modelica* flange connector **Shackle** of **CatenaryMooring** is connected to flange connector **Fairlead** of **CylindricalBuoy** while the flange connector **TopHook** of **CylindricalBuoy** is connected to the top flange of the **DampedSpring**, and the bottom flange of the **DampedSpring** is connected to the top flange of the **Mass** component.

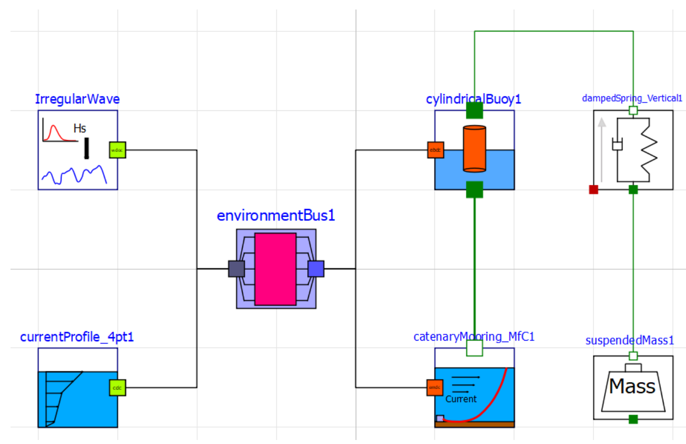

FIGURE 15. SCREENSHOT OF THE INTEGRATED COMPONENT MODEL OF THE WAVE ENERGY CONVERTER BUOY.

RESULTS

Keeping in mind the intent of the work, which is *only* to showcase the benefits of developing an *OceanEngineering* library for *OpenModelica*, the results are to be viewed from such an angle, excluding the tendency to delve into details of wave-energy conversion. Space limitations prevent the listing of all simulation parameters here and these maybe found within the respective simulation files under the *SampleSimulations* of the library. The *Orcaflex* simulations are also accessible via the download link.

Figure 18 shows the surge response of a wave energy converter buoy of diameter 1.2 m and mass 850 kg, moored with a chain of specific mass 16 kg/m, in irregular waves of significant wave height 1 m, in the presence of the earlier specified current profile with velocity 1 m/s, and in a water depth of 50 m. Wave and current Morison loading is applied to the buoy, while only current Morison loads are considered on the mooring line.

Figure 19 shows the variation in the z-displacement of the permanent-magnet core's centre-of-gravity, about an origin fixed to the body of the buoy. This variation in displacement is an indication of the power output, and we observe that, in this case, the variation is very small for any feasible power take-off from the linear electric generator.

The component-based modeling approach followed makes it easier to analyze other design options. For example, in the Wave Energy Platform, as shown in Fig. 16, the linear electric generator coil is mounted on a support structure fixed to the pontoon, and the permanent magnetic core is formed onto the top portion of the cylindrical buoy. A guide allows the buoy to heave freely while restraining motion in other directions. Figure 17 shows the new *Modelica* component model which utilizes most of the previous components. The **CylindricalBobbingBuoy** and **BoxPlatform** are modified versions of the earlier **CylindricalBuoy**. Morison loads are applied on the mooring, pontoon as well as on the cylindrical buoy and are interconnected using flange connectors. The *boxplatform* has a length of 5 m, breadth and depth of 2 m, weighs 15,250 kg and is moored with a chain of specific mass 16 kg/m. The *bobbingbuoy* has a mass of 350 kg and diameter of 1.2 m.

Figure 18 shows the surge response of the wave energy platform under the same environmental conditions as that applied to the wave energy converter buoy earlier, while Fig. 19 shows the variation in the relative z-displacement between the deck of the pontoon and the top surface of the cylindrical buoy. We observe that in this case, the variation is large enough to possibly take off feasible amount of power from the linear electric generator. However, it is to be noted that diffraction effects and hence the hydrodynamic coupling of the multibody system is not considered in this case. The example is cited with the sole intent of showcasing the ease with which *Modelica* components maybe modified to build up similar systems governed by same physical principles.

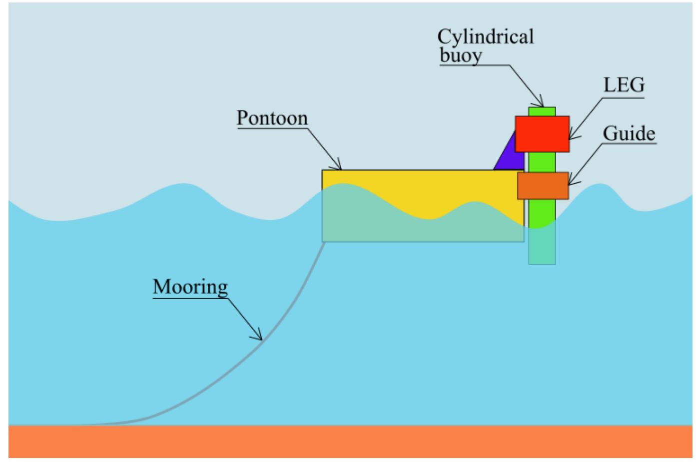

FIGURE 16. CONCEPT OF THE WAVE ENERGY PLATFORM.

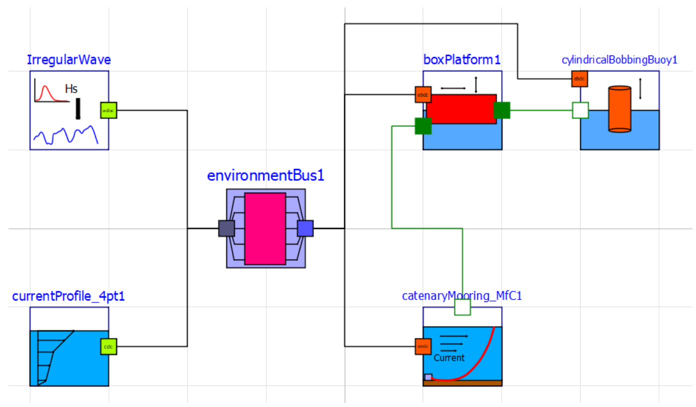

FIGURE 17. SCREENSHOT OF THE INTEGRATED COMPONENT MODEL OF THE WAVE ENERGY PLATFORM SYSTEM.

CONCLUSION

Integrated simulation of simple multiphysical systems in the domain of offshore engineering has been carried out using the free-to-use *OpenModelica* software and its *OMEdit* graphical user interface. The effectiveness of developed components and the ease of integration with already available components from the *Mechanics* library of *Modelica* has been demonstrated through the simulation of the wave energy converter buoy system, while the advantages of following a standard component-based approach has been demonstrated in the simulation of the wave energy conversion platform system.

Preliminary comparison with results from *Orcaflex* shows that the modelica simulation is satisfactory. Minor variations are seen in heave motion and in the mooring response. While the reasons for the variation in the mooring response has been reconciled, the variation in heave, though minor, is to be investigated. Also, in the present work, values have been assumed for the frequency dependent added mass and damping. To generate these values, and also to simulate the hydrodynamics of diffracting objects within *Modelica*, future work is planned towards implementing the Boundary-Integral Method for frequency domain analysis of regular geometries.

Public access to the preliminary *OceanEngineering* library has been provided and interested readers may delve into details of the code used to develop these components and improve/modify the same on their own. All the simulations including *Orcaflex* files are made available to the interested reader for constructive criticism.

Thus, it maybe concluded that the open-source *OpenModelica* software holds great potential in the domain of offshore

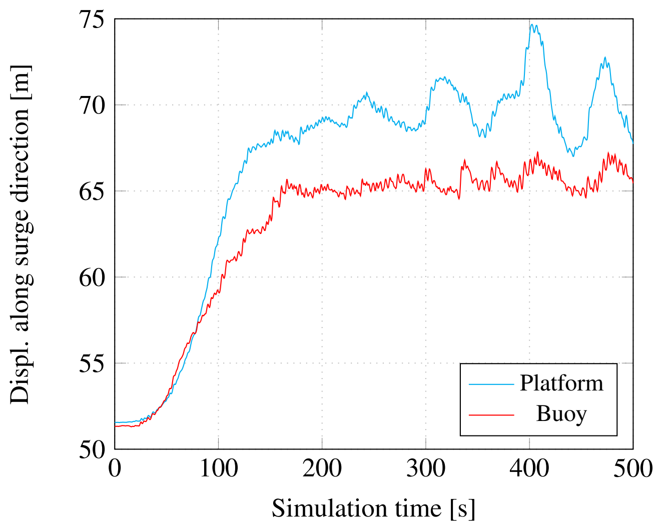

FIGURE 18. SURGE RESPONSES OF THE WAVE ENERGY CONVERTER BUOY AND PLATFORM IN IRREGULAR WAVES AND CURRENT.

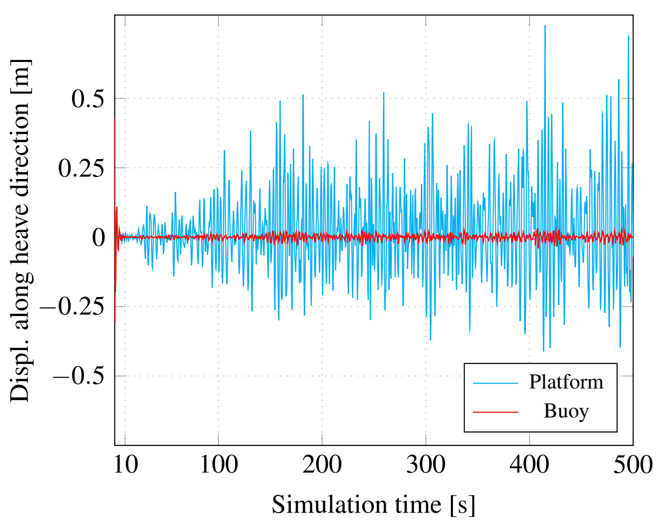

FIGURE 19. RELATIVE DISPLACEMENTS BETWEEN THE MAGNETIC CORE AND LEG COIL CENTERS.

simulations, and the development of a standard library for ocean engineering components would be benificial to academia and industry, especially when finances are constrained. Standard components from other domains can then be easily incorporated into the offshore systems to simulate for e.g., control system performance and other required analyses, thus enabling fully-integrated multiphysical system simulations.

ACKNOWLEDGEMENTS

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