WEC-SIM STATUS REPORT

FY14 Q1

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PROJECT STATUS

An overview of WEC-Sim's Year 1 efforts was presented to DOE HQ during a video conference held on 10/21/2013. During the teleconference, SNL and NREL demonstrated the status of WEC-Sim's development and application. Documentation on WEC-Sim's Year 1 status can be found in the *FY13 Q4 Deliverables* folder on the WEC-Sim SharePoint site. Uploaded documents include: year-end status report, year-end Gantt chart, and the video conference presentation.

The WEC-Sim project is currently on track, having met both NREL and SNL's FY14 Q1 Milestones, as shown in Table 1 and Table 2 respectively, details of which will be described in the following sections.

Table 1: NREL WEC-Sim Quarterly Milestones

WEC-Sim Milestones	Due Date
WEC-Sim Modeling: Model a point absorber device in WEC-Sim. Verify the WEC-Sim results by comparing with experimental data from Berkeley/SCRIPPS wave tank tests performed as part of the Reference Model 3 Project, Wave-Dyn, and/or AQWA°. Upload the WEC-Sim model, results and a 1-2 page technical report summarizing the results to the WEC-Sim SharePoint website by December 31, 2013.	Q1 (12/31/13)
WEC-Sim Verification: Model a pitching device in WEC-Sim. Verify the WEC-Sim results by comparing with Wave-Dyn and/or AQWA°. Also, compare the results with available wave tank data (e.g., NWEI/WET-NZ and Oyster). Upload the WEC-Sim model and results to the WEC-Sim SharePoint website. A letter report that summarizes the objective, results, and findings of the verification work will also be uploaded to SharePoint. This task will be completed by March 31, 2014. **Coding Competition:** Work with TopCoder to release a mesh generation coding competition with the objective of developing meshing capabilities for the open-source BEM. This task will be completed by March 31, 2014.	Q2 (3/31/14)
WEC-Sim release: Release the beta version of WEC-Sim on the NREL, SNL, and OpenEI websites.	Q3 (6/30/14)
WEC-Sim Testing: Draft a test plan and determine device specifications for a pitching device wave tank validation tests. Upload the test plan and specifications to the SharePoint website by September 30, 2014.	Q4 (9/30/14)

Table 2: SNL- WEC-Sim Quarterly Milestones

WEC-Sim Milestones	Due Date
WEC-Sim point absorber model: Model a point absorber device in WEC-Sim. Verify the WEC-Sim results by comparison with experimental data from Berkeley/SCRIPPS wave tank tests performed as part of the Reference Model 3 Project, Wave-Dyn, and/or AQWA. The WEC-Sim model and results will be uploaded to the WEC-Sim SharePoint website along with a tech memo on the quarter's accomplishments.	Q1 (12/31/13)
WEC-Sim pitching device model: Model a pitching device in WEC-Sim. Verify the WEC-Sim results by comparison with Wave-Dyn, and/or AQWA. Also compare the results with available wave tank data (e.g. NWEI/WET-NZ and Oyster). The WEC-Sim model and results will be uploaded to the WEC-Sim SharePoint website along with a tech memo on the quarter's accomplishments.	Q2 (3/30/14)
WEC-Sim release: Release the beta version of WEC-Sim on the NREL, SNL, and OpenEI websites.	Q3 (6/30/14)
WEC-Sim validation: Draft a test plan and determine device specifications for the pitching device wave tank validation tests. Upload the test plan and specifications to the SharePoint website.	Q4 (9/30/14)

RM3 POINT ABSORBER MODEL

GEOMETRY DEFINITION

The Reference Model 3 (RM3) device, a two-body heaving point absorber design, was chosen as the first application of WEC-Sim. While the WEC is free to move in all 6DOF in response to wave motion, power is only captured in the heave direction. The RM3 device was chosen to leverage a prior DOE funded project, and because the design has already been well characterized both numerically and experimentally as a result of the reference model project, it has relatively simple operating principles, and is representative of WECs currently pursued by the wave energy industry. It is a simple heaving two-body point absorber, consisting of a float and a spar-plate, the full-scale dimensions and mass properties of which are shown in Figure 1 and Table 3. It should be noted that there are several different versions of the RM3 geometry, due to the RM project's iterative design process. This RM3 geometry was chosen because it is the full-scale version of the 1:33 Froude scale device tested at Scripps Institute of Oceanography in San Diego from November 30th – December 2nd 2011. Accordingly, simulations of the RM3 geometry defined below performed by WEC-Sim and commercial codes can be directly compared to experimental data obtained through the reference model project.

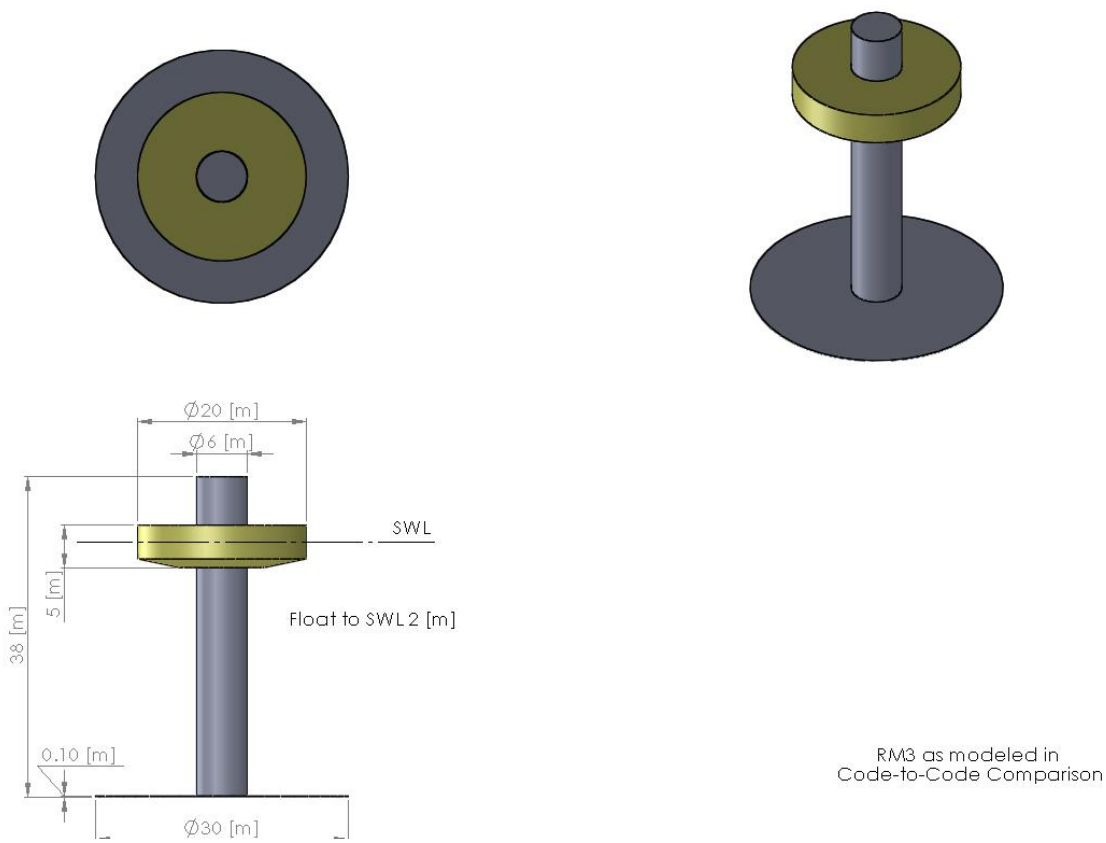

Figure 1. RM3 Heaving Two-Body Point Absorber Full-Scale Dimensions

Table 3. RM3 Heaving Two-Body Point Absorber Full-Scale Mass Properties

Float Full Scale Properties				
CG [m]	Mass [tonne]	Moment of Inertia [kg-m^2]		
0	727.01	20907301	0	0
0		0	21306090.7	4304.89323
-0.72105		0	4304.89323	37085481.1
Spar-Plate Full Scale Properties				
CG [m]	Mass [tonne]	Moment of Inertia [kg-m^2]		
0	878.30	94419614.6	0	0
0		0	94407091.2	217592.785
-21.285		0	217592.785	28542224.8

SIMULATION PARAMETERS

In addition to the device geometry, it is important to define the simulation parameters. These should be representative of the RM3 1:33 experimental setup, shown in Figure 2, and must be the same for all simulations. The full-scale water depth, h = 1.5 [m]*33 = 49.5 [m], and the fluid density is that of water, ρ = 1000 [kg/m^3] (not that of salt water).

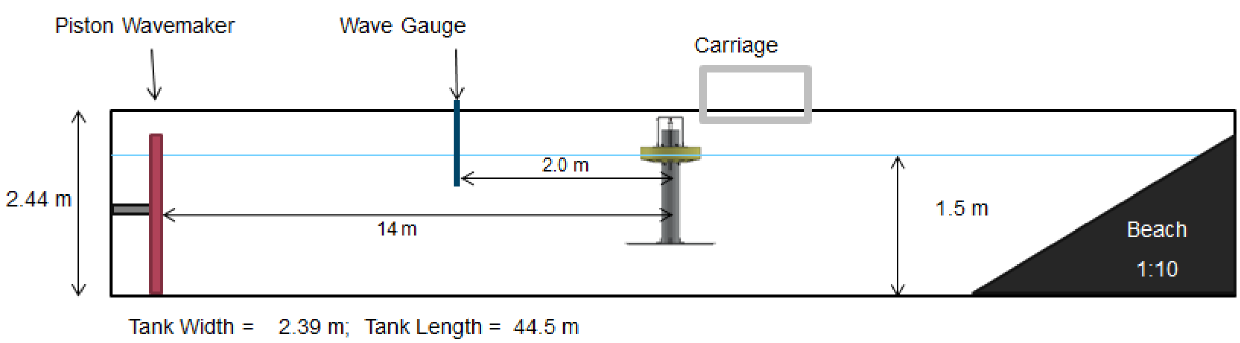

Figure 2. RM3 1:33 Scale Wave Tank Setup

RM3 simulations were run for a representative regular operational wave, of a constant wave height, H = 2.5 [m], and for wave periods, T = 8 [s] and 12 [s].

PRELIMINARY WEC-SIM VERIFICATION

In order to verify the functionality of the alpha version of WEC-Sim, a preliminary code-to-code comparison was performed, where the RM3 point absorber described above was simulated in WEC-Sim, and compared to simulation of the same device using the commercial codes WaveDyn (Garrad Hassan) , AQWA (ANSYS) and OrcaFlex (Orcina). The RM3 point absorber was first modeled with 1DOF (heave only) in WEC-Sim, WaveDyn and AQWA. Then, the RM3 point absorber was modeled with 3DOF (heave, pitch and surge) in WEC-Sim, AQWA and OrcaFlex. In the following subsections, results from the code-to-code comparison for both the 1DOF and 3DOF simulations are shown.

1DOF CODE-TO-CODE COMPARISON

The first verification effort for WEC-Sim was performed by modeling the RM3 point absorber in 1DOF (heave only) using the alpha version of SNL/NREL developed code WEC-Sim, and comparing its results to the commercial codes WaveDyn and AQWA. All three codes were run for regular waves with T = 8 [s] and H = 2.5 [m], where the WEC motion was restricted to heave motion only, and did not include any motion due to coupled DOFs. Simulations were performed for the 1DOF code-to-code comparison with no PTO damping, and for PTO damping = 1200 [kN-s/m] between the float and spar/plate. The full time-series figures show the overall trends in the WEC heave response, and show the different ramping functions for each of the models. WaveDyn uses a simple linear ramping function, whereas WEC-Sim uses a hyperbolic tangent function, and AQWA uses a $\sin^2$ function.

WITHOUT PTO DAMPING

Results from the regular wave simulation without PTO damping for the float response, shown in Figure 3 have very good agreement in terms of both the amplitude and phase between all three codes. The left side shows the full 400 [s] time-series, and the right side shows the same figure zoomed in for the last 100 [s]. For the spar/plate response, results from the regular wave simulation, shown in Figure 4 have very good agreement especially between WaveDyn and AQWA, with an approximately 0.02 [m] difference with the WEC-Sim results. Since the WEC's power performance is a function of the relative motion between the float and the spar/plate, this is a very important metric to gauge overall code performance. As shown in Figure 5, the relative heave motion shows very good agreement in terms of both the amplitude and phase for all three codes, which is very promising.

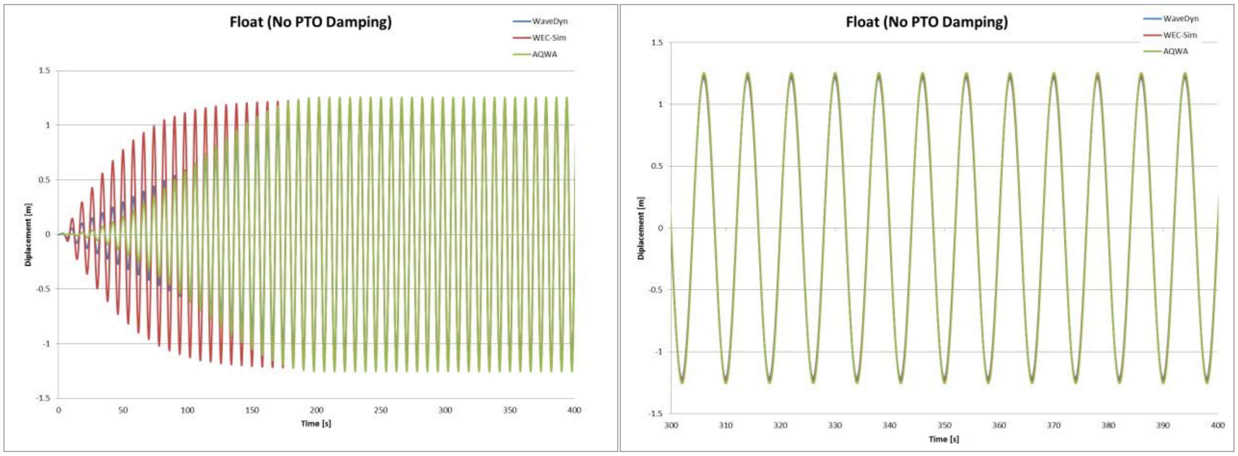

Figure 3. RM3 Float Heave Response: WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 0 [kN-s/m] for the full time series (left) and zoomed in for the last 100 [s] (right)

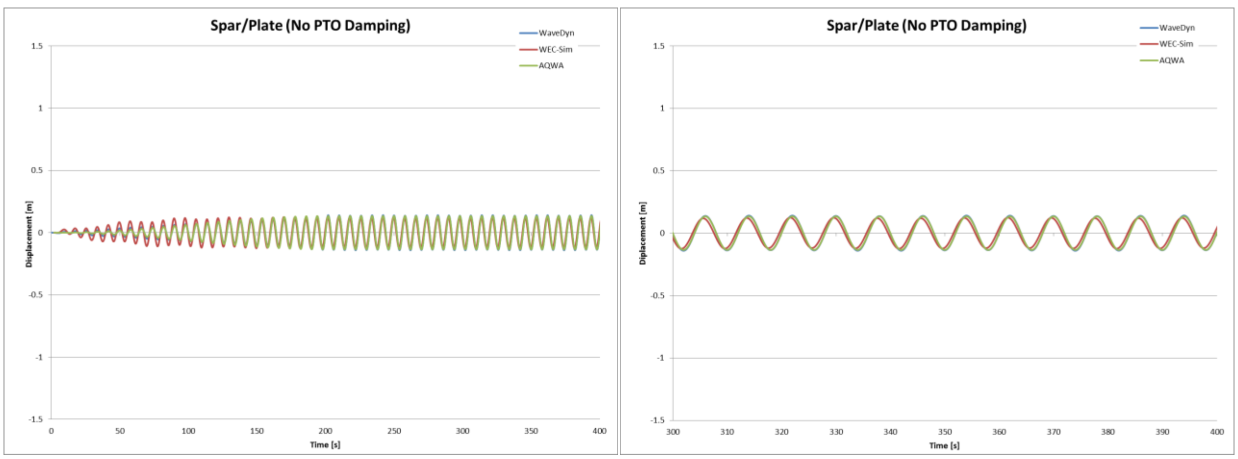

Figure 4. RM3 Plate Heave Response: WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 0 [kN-s/m] for the full time series (left) and zoomed in for the last 100 [s] (right)

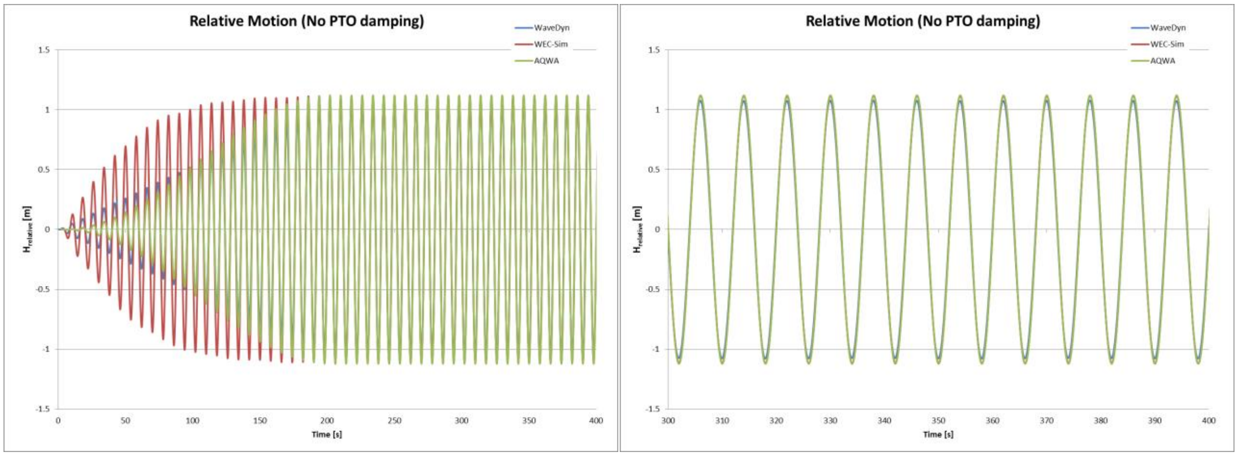

Figure 5. RM3 Relative Heave Motion: WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 0 [kN-s/m] for the full time series (left) and zoomed in for the last 100 [s] (right)

WITH PTO DAMPING

Results from the regular wave simulations with PTO damping = 1200 [kN-s/m] for the float response, shown in Figure 6 have very good agreement in terms of both the amplitude and phase between all three codes. The spar/plate response, shown in Figure 7, has fairly good agreement, with minor differences in amplitude response of approximately 0.04 [m]. The WEC-Sim and WaveDyn results have very good phase agreement, while the AQWA result is slightly shifted. This is an artifact of how AQWA models the PTO damping, because it does not allow for damping between bodies in relative translational motion, instead an external damping value must be applied to each individual body. Since the WEC's power performance is a function of the relative motion between the float and the spar/plate, this is a very important metric to gauge overall code performance. As shown in Figure 8, the relative heave motion shows very good agreement in terms of both the amplitude and phase for all three codes, which is very promising.

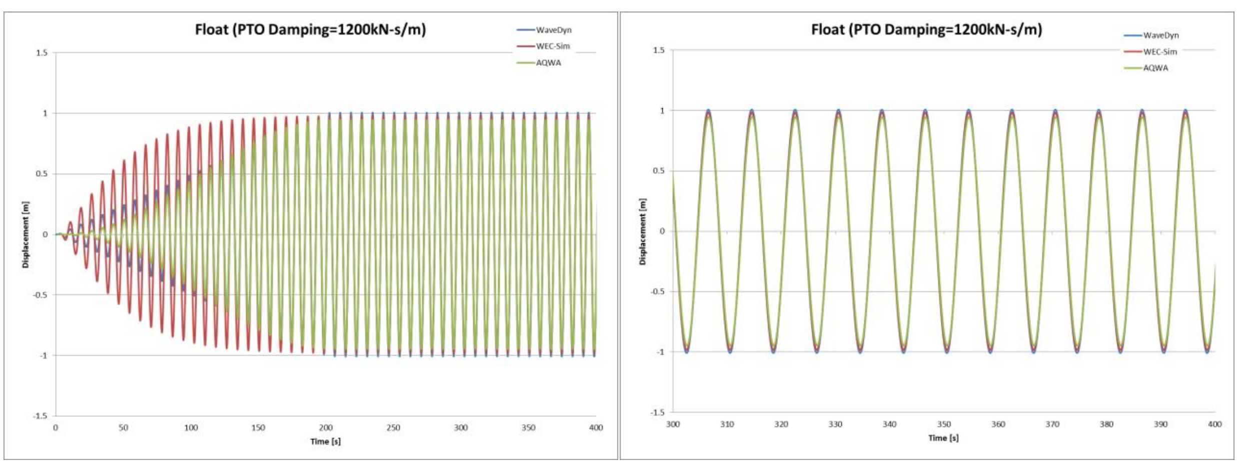

Figure 6. RM3 Float Heave Response: WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 1200 [kN-s/m] PTO damping for the full time series (left) and zoomed in for the last 100 [s] (right)

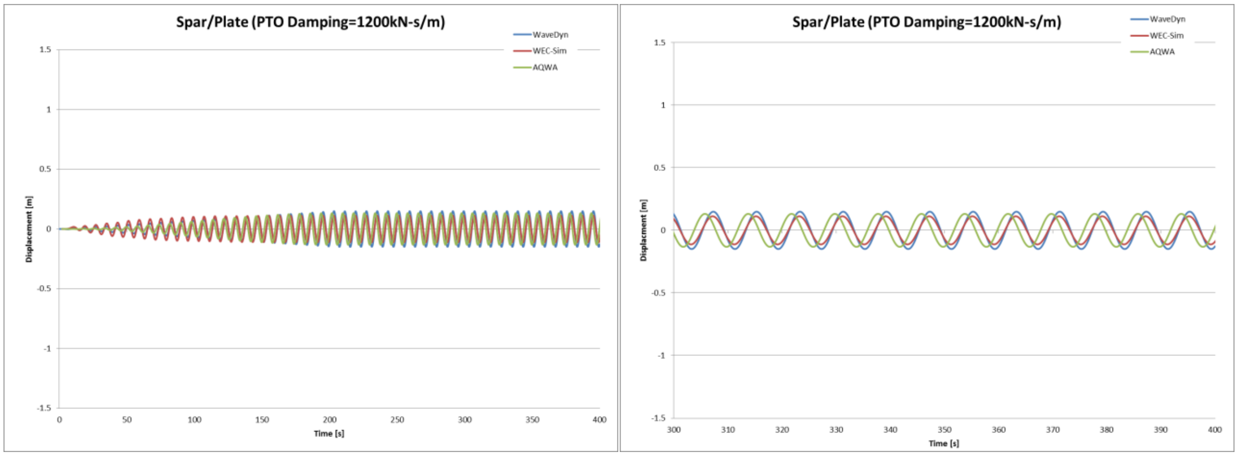

Figure 7. RM3 Plate Heave Response: WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 1200 [kN-s/m] PTO damping for the full time series (left) and zoomed in for the last 100 [s] (right)

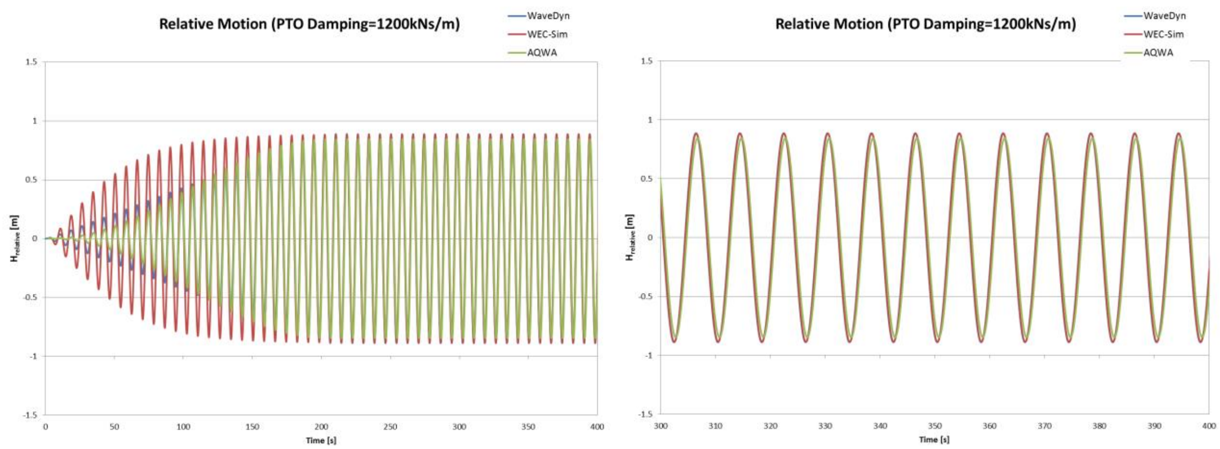

Figure 8. RM3 Relative Heave Motion: WEC-Sim, WaveDyn, and AQWA with H=2.5 [m] and T = 8 [s] and 1200 [kN-s/m] PTO damping for the full time series (left) and zoomed in for the last 100 [s] (right)

Overall the WEC-Sim team is very pleased with the results from the code-to-code comparison for the 1DOF RM3 device, and views this effort as significant progress in the overall code development effort. The very slight discrepancy between the WaveDyn, AQWA, and WEC-Sim results may be explained by the fact that WaveDyn includes additional hydrodynamic terms in the equation of motion that represent the interaction between multiple bodies (e.g., added mass term from other body). The effect of these terms was small for the two-body point absorber, as expected, since the plate is deep in the water and far away from the float. Nevertheless, these additional terms could be important when modeling multiple-body WEC designs (e.g., CPT's SeaRay and StingRay designs), where different bodies are placed close to each other. Differences in the AQWA results for the PTO damped case can be explained by AQWA's inability to define damping between two bodies in relative translational motion.

3DOF CODE-TO-CODE COMPARISON

To further verify WEC-Sim, the WEC-Sim team also performed simulations in 3DOF, where the device was allowed to move freely in heave, surge and pitch. The simulation from the alpha version of WEC-Sim was compared to results from OrcaFlex and AQWA. In the OrcaFlex simulation, the float and the spar/plate were modeled as two separate vessels connected with a spring-damper link, which contained infinite bending stiffness so that the float was only allowed to move along the spar. Because OrcaFlex only accepts single body WAMIT hydrodynamic coefficients for each body, the WEC-Sim code was modified so that the two codes used exactly the same WAMIT hydrodynamic coefficients and simulate the problem in exactly the same way. In the AQWA simulation, the float and spar/plate were modeled in 3DOF with no relative constraints on motion between the bodies, due to AQWA's inability to define translational 'joints'. As a result, the AQWA surge and pitch results are irrelevant, but the 3DOF heave response is valid because it accounts coupling between DOFs for each body.

The analysis was conducted with regular waves, for wave height, H = 2.5 [m], and for wave periods, T = 8 [s] and 12 [s]. The time history of the device pitch response and the relative motion between the float and the spar/plate obtained from WEC-Sim and OrcaFlex were compared, results of which are plotted in Figure 9, Figure 11 and Figure 11. A half cosine ramp function, which was similar to the one used in OrcaFlex was applied in WEC-Sim to slowly start the simulations in order to minimize the transient response. Results from WEC-Sim 3DOF simulation agreed very well with those obtained from OrcaFlex and AQWA.

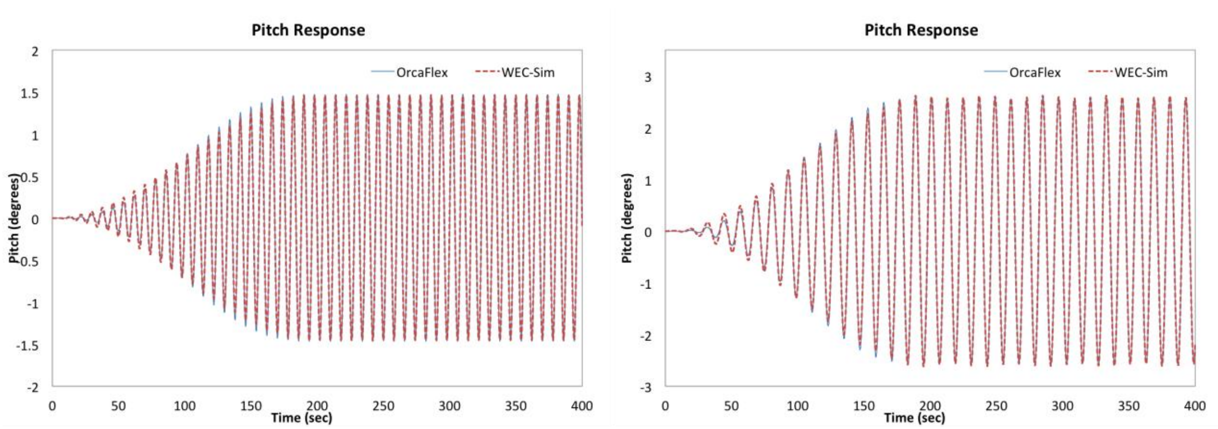

Figure 9. RM3 float pitch response from WEC-Sim and OrcaFlex with incoming wave period, T = 8 [s] (left) and 12 [s] (right)

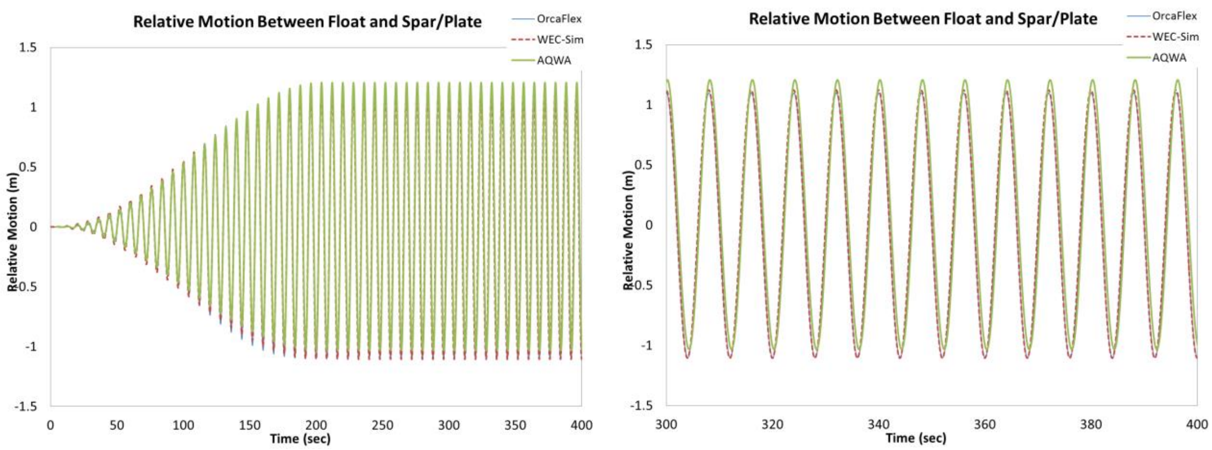

Figure 10. Relative Heave motion between the float and the spar/plate from WEC-Sim, AQWA and OrcaFlex with H=2.5 [m] and T = 8 [s] for the full time series (left) and zoomed in for the last 100 [s] (right)

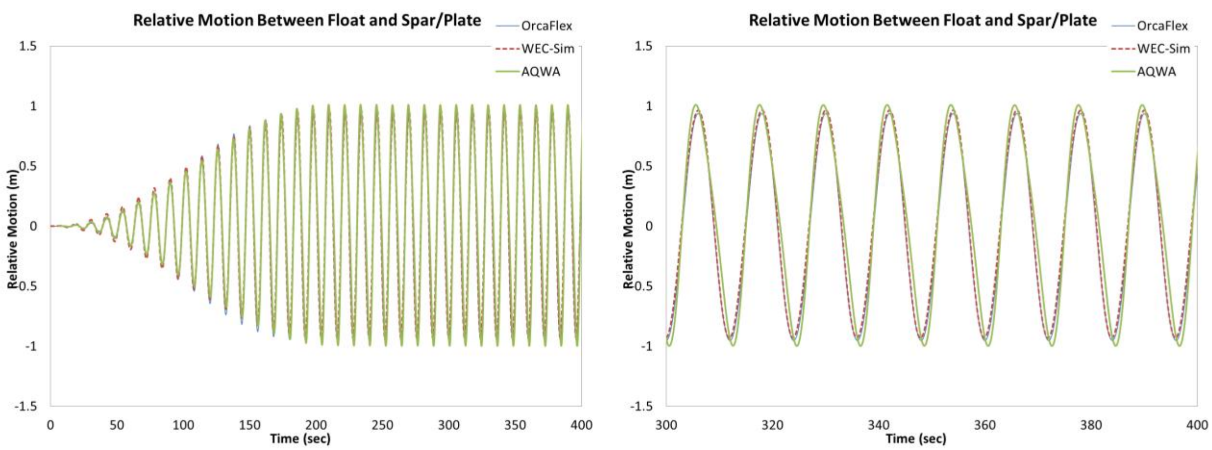

Figure 11. Relative Heave Motion between the float and the spar/plate from WEC-Sim, AQWA and OrcaFlex with H=2.5 [m] and T = 12 [s] for the full time series (left) and zoomed in for the last 100 [s] (right)

In the simulation, mooring connections were not incorporated to constrain the device surge motion. No restoring stiffness or additional damping term was implemented in the surge equation of motion, except surge radiation damping, which was insignificant. Therefore, the device can drift in surge even if the system is subject to monochromatic forces. Generally, the drift is induced by the numerical algorithm and depends on what ramp function and numerical integration schemes are applied. OrcaFlex and WEC-Sim use different time integration schemes, have different methods for handling radiation terms in transition and probably use different matrix solvers. As a result, the device was predicted to drift 2 [m] in WEC-Sim and only 0.03 [m] in OrcaFlex when forced by T=8 [s] waves. Overall the WEC-Sim team is very pleased with the 3DOF code-to-code comparison results for the RM3 device.

LIMITATIONS OF COMMERCIAL CODES

As discussed above, the WEC-Sim team has tested the commercial modeling codes WaveDyn, AQWA, and OrcaFlex. While all of these codes provide basic modeling capability needed to simulate WEC's, each code has limitations that preclude turn-key modeling of WEC devices. The remainder of this section reviews WaveDyn, AQWA, and OrcaFlex and discusses their limitations and nuances.

AQWA

AQWA was not originally developed to model WECs, its intended application was naval architecture and offshore oil and gas, thus AQWA has issues generating a sufficient mesh for complex geometries due to its limited number of diffracting and non-diffracting elements. Additionally, there are several flags specified in the AQWA input file that can keep the program from converging to a solution, and with AQWA's limited help files and user group, it can be difficult to determine the source of the error. An AQWA limitation, relevant for the RM3 design, is that it only allows for definition of rotational joints (hinge, ball and socket, universal and rigid), and does not allow definition of translational 'joints'. Thus applying PTO damping between two bodies with relative linear motion is not a functionality currently built into AQWA, and would require the user to write an external function applying said PTO forcing. Additionally, AQWA's time-domain codes, DRIFT and NAUT have slightly different default formulations and when setting up a model it is important to understand these nuances. For example, NAUT's default is non-linear, and determines wave forcing based on the instantaneous wetted surface area at each time step. This default must be overridden for direct comparison to WEC-Sim and WaveDyn which both use a linear formulation.

WAVEDYN

WaveDyn was developed specifically to model WEC devices and is therefore relatively straight forward to set up and run. The bottom line is that WaveDyn is developed for modeling WECs, but is still in the development process. The currently released version still uses the linear hydrodynamic restoring and excitation model and the robustness of the code, such as the time integration scheme and the use of ramp function, need to be improved so that the simulation will be more stable, particularly when rotational motion is considered.

Moreover, WaveDyn is at a very early stage of development. In fact, it appears that NREL is one of the first commercial users of the code and has found several bugs in the code (e.g. a broken mooring line module) and features that were not sufficiently documented. NREL has worked with the WaveDyn code developer (GL-GH) to address these issues and the result has been an improved WaveDyn code. Nevertheless, a significant amount of improvement to WaveDyn is needed before it is a turn-key commercial product. Specifically, non-linear buoyancy and excitation capabilities are needed, a viscous damping model must be developed, and better documentation and tutorials are needed. GH-GH is working hard to make these improvements and some of these issues will be addressed in the next release of WaveDyn, which is scheduled for early 2014.

ORCAFLEX

OrcaFlex is code developed for modeling the fluid/wave and structure interaction. It has widely been used for modeling the dynamics of offshore systems, such as offshore supply vessels and offshore platforms. OrcaFlex has a strong mooring capability and robust numerical integration algorithm. However, the code was not developed for modeling WECs, particularly multi-body designs. OrcaFlex only accepts single body WAMIT hydrodynamic coefficients for each body. As a result, users have to run a WAMIT run for each body, and the effect of the interaction between different bodies on the hydrodynamic coefficients is neglected. Technically, this can be avoided if users write their own functions to import correct hydrodynamic coefficients for each body from a single multiple-body WAMIT run or manually insert the correct values. However, this makes using OrcaFlex to model WECs more difficult.

CONCLUSIONS AND FUTURE WORK

The WEC-Sim effort is currently on track. The SNL/NREL WEC-Sim team has met all of their FY14 Q1 milestones, as shown in the Gantt chart uploaded to the WEC-Sim SharePoint site in the *FY14 Q1 Deliverables* folder. Results from the code-to-code comparison are uploaded to the SharePoint site, and the WEC-Sim runs are uploaded to the GitHub site. SNL and NREL are currently working together to meet the FY14 Q2 milestone of applying the WEC-Sim code to model a pitching device, and perform a code-to-code comparison. In order to engage the research community, the WEC-Sim team has also submitted abstracts on the code's development, with 2 accepted to OMAE, and 1 to GMREC/METS. NREL presented on the WEC-Sim project at the IEA-OES Annex V numerical modeling workshop in Scotland this past November. The international community showed significant interest in the WEC-Sim project and the BEM code competition. The WEC-Sim team is working to stay engaged with the international community to develop collaborative partnerships in the areas of code-to-code comparisons and joint code development.