Proceedings of the 3rd Marine Energy Technology Symposium
METS2015
April 27-29, 2015, Washington, D.C.

IMPROVING AND VALIDATING THE WEC-SIM WAVE ENERGY CONVERTER MODELING CODE

Michael Lawson[1] and Yi-Hsiang Yu
National Renewable Energy Laboratory
Golden, CO, USA

Kelley Ruehl and Carlos Michelen
Sandia National Laboratories
Albuquerque, NM, USA

[1]Corresponding author: michael.lawson@nrel.gov

INTRODUCTION

In 2013 the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL) initiated the WEC-Sim project with the objective of developing a verified and validated open-source wave energy converter (WEC) simulation tool to promote and support the wave energy industry and research community. To achieve this objective, NREL and SNL identified three main tasks. (1) Develop WEC-Sim, an open source MATLAB based wave simulation tool, (2) Verify the accuracy of WEC-Sim through code-to-code comparison, and (3) Validate the WEC-Sim code with existing data and/or generate experimental data for WEC-Sim code validation.

The first version of WEC-Sim (v1.0) was released in Summer 2014 and the most recent version of the code (v1.1) was released in Spring 2015, and available via GitHub [1]. Since the initial release, the WEC-Sim development team has focused on improving the WEC-Sim code, adding features, and on code verification and validation. In this extended abstract updates are provided on the status of the WEC-Sim project, focusing on:

1. Version 1.1 release of WEC-Sim with stability improvements and feature additions.
2. The WEC-Sim experimental testing campaign whose objective is to create an open source experimental data set that can be used to verify and validate WEC-Sim and other wave energy converter simulation tools.
3. WEC-Sim's participation in Maynooth University Center for Ocean Renewable Energy (COER) Hydrodynamic Modeling Competition [2].
4. The Wave Energy Converter Code Comparison (WEC3) project

Starting with a brief review of the WEC-Sim code, this extended abstract provides detail on each of these ongoing WEC-Sim research activities.

WEC-SIM CODE OVERVIEW

WEC-Sim is a mid-fidelity MATLAB based open source code that models WEC devices by solving the Cummin's Equation [3],

$$(m + m_\infty)\ddot{x} = -\int_{-\infty}^{t} f_r(t-\tau)\dot{x}(\tau)d\tau - F_{hs} + F_e + F_v + F_{ext} \quad (1)$$

Where m and m_∞ are the mass and the added mass matrix, respectively. The convolution integral represents the wave radiation damping forces. And F_{hs}, F_e, F_v and F_{ext} are the hydrostatic force, the wave excitation force, the viscous drag force, and externally applied forces (e.g. the power-take-off system forces and mooring system forces), respectively. Multi-body dynamics are solved using SimMechanics (MATLAB's multi-body solver), while time-domain hydrodynamic forces are derived from frequency-domain Boundary Element Method (BEM) simulations. BEM codes such as NEMOH [4], WAMIT [5], or AQWA [6] can be used to run the WEC-Sim code. For more information, refer to [7]–[9] on WEC-Sim's numerical methods and implementation in the MATLAB/SimMechanics environment.

WEC-Sim Version 1.1 Release

The initial version of WEC-Sim provided basic WEC device simulation capabilities. Since the initial release, the WEC-Sim team has worked to improve code stability and provide feature improvements. WEC-Sim-1.1 was released Spring 2015 [1] with the following improvements:

- Improved code stability due to bug fixes in the added mass force calculations and improvement in the impulse response function calculation.
- Implementation of a state space representation of wave radiation forces [10]
- Support for AQWA, NEMOH, and user defined hydrodynamic data through development of a standard hydrodynamic data input format. (WAMIT is still supported)
- Development of the Boundary Element Method Input/Output (bemio) scripts [16] that read, process, and visualize WAMIT, AQWA, and NEMOH data and save the data in the HDF5 data format used by WEC-Sim (see Figure 1).
- GitHub is now used as the WEC-Sim release platform. A stable 'master' branch provides the release version of WEC-Sim and a 'dev' branch that contains features still under development for advanced users.

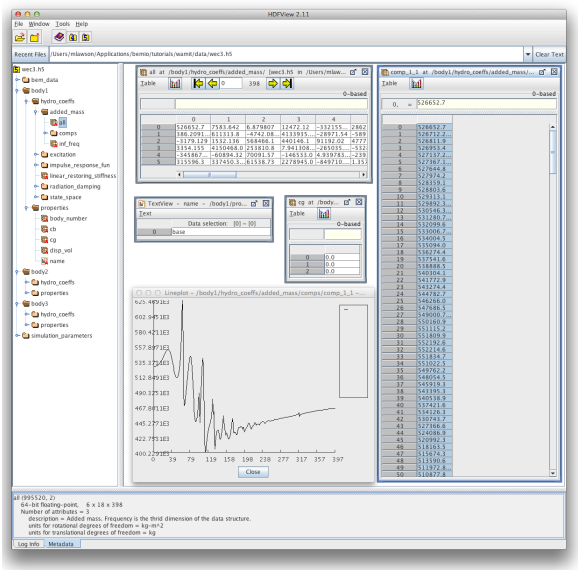

FIGURE 1. THE NEW WEC-SIM HYDRODYNAMIC DATA FORMAT AS VIEWED IN THE HDFVIEW (HTTP://WWW.HDFGROUP.ORG/PRODUCTS/JAVA/HDFVIEW) SOFTWARE PACKAGE

WEC-SIM EXPERIMENTAL TESTING CAMPAIGN

Experience from the wind energy industry [10], [11] shows that it is critical to verify and validate numerical modeling tools that are used to design and analyze renewable energy generation systems. Numerical code validation campaigns require high quality experimental data, and although there have been several WEC device testing campaigns (e.g. [12]), there are very few high quality WEC data sets in the public domain. Accordingly, the U.S. Department of Energy has funded the WEC-Sim team to perform a series of wave tank tests to develop a high quality experimental WEC data set that will be useful for validating WEC-Sim and other WEC modeling codes. WEC-Sim plans to perform experimental validation testing in Summer 2015 .

The WEC-Sim team decided that it was critical to test a device that allowed the most possible WEC-Sim modeling capabilities to be tested and validated. After a thorough review and ranking of existing WEC archetypes, it was determined that testing a Floating Oscillating Surge WEC (FOSWEC), provide the most comprehensive WEC-Sim validation data set.

The device will be tested in the Oregon State University Hinsdale Directional Wave Basin. The testing campaign will be divided into two phases: Phase 1 will be 4 weeks in duration (focusing on system ID), and Phase 2 will be 6 weeks in durations (focusing on operational wave response). During the first phase, the team will work to perform baseline tests and to characterize the WEC design, and identify device design features that need to be refined. During Phase 2, all required experimental tests will be performed. Specifically, the following experimental tests will be performed (during the two phases testing) to gather data needed for WEC-Sim code validation:

- Measurement of hydrostatic restoring stiffness
- Free decay tests to measure natural frequency of oscillation for each body and the system as a whole and estimate viscous damping coefficients on the device bodies
- Forced oscillation tests to determine the added mass and radiation damping coefficients of the bodies that comprise the WEC system
- Wave excitation tests in which the position of the device is locked and the device is subjected to regular waves. The objective of these tests is to measure the wave excitation force on the bodies that comprise the WEC system
- Regular wave tests to determine Response Amplitude Operators (RAO)
- Irregular wave tests
- Survival test may be performed pending time and practicality.

All experimental data will be made publically available following the experimental testing campaign using OpenEI [13] web portal or a similar online forum.

CODE VERIFICATION AND VALIDATION EFFORTS

COER Hydrodynamic Modeling Competition

The Center for Ocean Energy Research (COER) at the University of Maynooth in Ireland developed a blind code-to-experiment hydrodynamic modeling competition for the 2015 Offshore Mechanics and Arctic Engineering (OMAE2015) conference. COER challenged researchers to predict the dynamic response of a floating rigid-body device (shown in Figure 2) that was experimentally tested in a series of wave-tank tests. COER provided device specifications, regular wave test condition and results [14], while temporally resolved irregular wave results were kept private until competition participants submitted their simulation results.

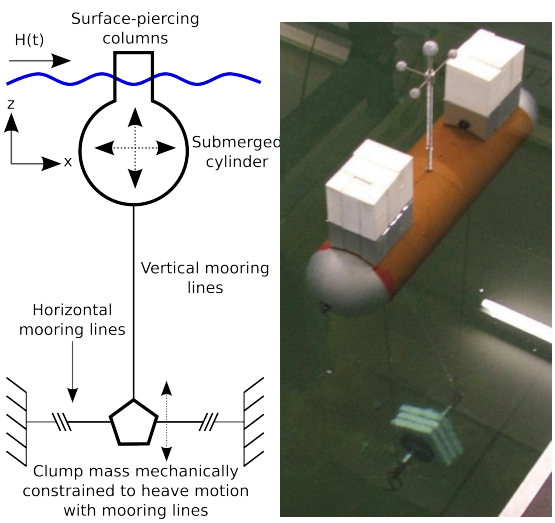

FIGURE 2. (LEFT) SCHEMATIC OF THE EXPERIMENTAL SETUP. (RIGHT) ILLUSTRATION OF THE EXPERIMENTAL DEVICE (ADAPTED FROM [14]).

The WEC-Sim team participated in this competition. An example of the WEC-Sim predictions of device response compared to the experimental data that was provided by COER [2] is shown in Figure 3. While the WEC-Sim results compared well with the experimental results, the WEC-Sim team identified several areas in which numerical features in WEC-Sim may lead to improved correlations with the experimental data. Specifically, inclusion of nonlinear Froude-Krylof forces and Morrison element viscous drag predictions may lead to better correlations with the experimental data. These features are in the WEC-Sim 'dev' code branch and the team is working to move them in to the stable release as previously described. More details on the WEC-Sim simulations and the CORE presentation will be presented in the OMAE2015 conference and in [15].

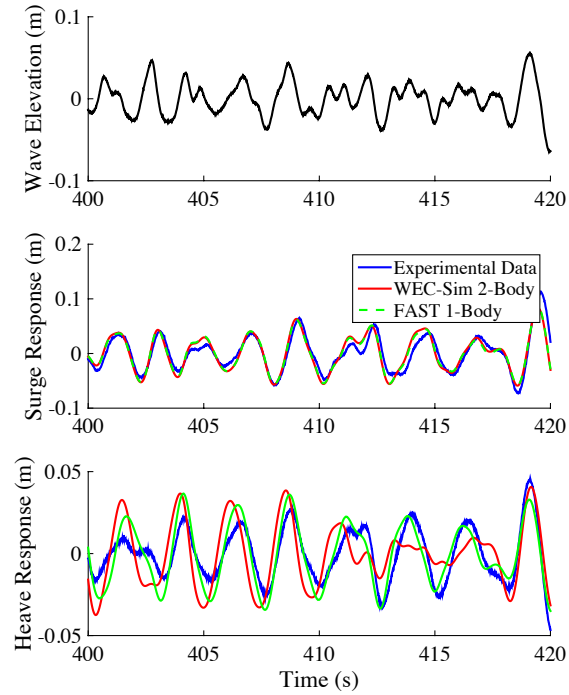

FIGURE 3. DYNAMIC RESPONSE OF THE COER DEVICE BETWEEN 400 AND 420 S. DURING THIS PERIOD OF TIME, THERE IS GOOD QUALITATIVE AGREEMENT IN BOTH THE HEAVE AND SURGE RESPONSE. NOTE THAT RESULTS FROM THE FAST MODELING CODE ARE ALSO SHOWN.

THE WAVE ENERGY CONVERTER CODE COMPARISON PROJECT (WEC3)

The success of the offshore wind IEA OC3, OC4, and OC5 [10], [11] code verification and validation projects has demonstrated the value of international collaboration on code-to-code and code-to-experiment comparison projects. The International Energy Agency Ocean Energy Systems recently initiated Annex VI – Ocean Energy Modeling Verification and Validation (IEA OES Annex VI), which is an international wave and tidal design and analysis code verification and validation effort modeled after the IEA OC3, OC4, and OC5 projects. The Annex VI efforts do not kick off in earnest until 2016, leaving a need for a near term code verification and validation effort.

The WEC3 effort was initiated to meet this short term need. WEC3 is a grassroots code comparison effort initiated by SNL/NREL, INNOSEA, Dynamic Systems Analysis, DNV-GL, Wave Venture, and DNV-GL. The project has the objectives of verifying and validating numerical modeling tools that have been developed specifically to simulate wave energy conversion devices and to inform the upcoming IEA OES Annex VI effort.

Phase 1 of WEC3 consists of a code-to-code comparison between the participating members.

In Phase I a three-body oscillating surge device (shown in Figure 4) is used for a code-to-code comparison. Hydrodynamic coefficients, decay tests, and device motions in regular and irregular wave fields will be simulated and compared.

Phase II of WEC3 is comprised of blind code-to-experiment validation. The WEC3 project considers mid-fidelity modeling tools that simulate WECs using time-domain multibody dynamics methods and an upcoming EWTEC paper [15] provides details on the WEC3 project as well as preliminary results from Phase 1 of the project.

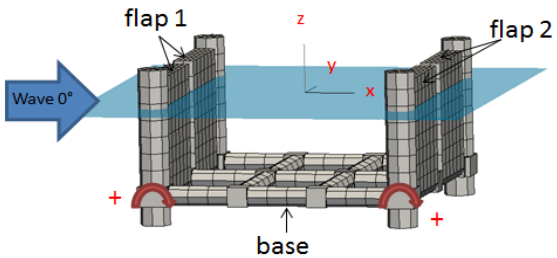

FIGURE 4. SCHEMATIC OF THE THREE BODY OSCILLATION FLAP DEVICE USED DURING PHASE 1 OF THE WEC3 PROJECT.

CONCLUSIONS

In this paper we described ongoing WEC-Sim development, verification, and validation work that is ongoing at NREL and SNL. Specifically, we described new features that were added to the code in 2015, presented results from the upcoming COER OMAE2015 competition, and described a set of planned experimental tests that will be performed over the next year to gather high-quality data for code validation.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding for the work was provided by the DOE Office of Energy Efficiency and Renewable Energy, Wind and Water Power Technologies Office.

Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly-owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Administration under contract DE-AC04-94AL85000.

REFERENCES

[1] "WEC-Sim GitHub Webpage." [Online]. Available: https://github.com/WEC-Sim/WEC-Sim. [Accessed: 01-Apr-2015].

[2] "COER OMAE 2015 competition." [Online]. Available: https://www.maynoothuniversity.ie/electronic-engineering/events/coer-omae-2015-competition. [Accessed: 01-Apr-2015].

[3] Cummins, WE, "The Impulse Response Function and Ship Motions," *Schiffstechnik*, vol. 47, no. 9, pp. 101–109, 1962.

[4] Aurélien Babarit, "Nemoh BEM Code on OpenORE." [Online]. Available: http://openore.org/2014/01/21/nemoh-open-source-bem/. [Accessed: 02-Jan-2014].

[5] C. H. Lee and J. N. Newman, "WAMIT® User Manual." WAMIT, Inc.

[6] "AQWA." [Online]. Available: http://www.ansys.com/Products/Other+Products/ANSYS+AQWA.

[7] Kelley Ruehl, Carlos Michelen, Samuel Kanner, Michael Lawson, and Y. Yu, "Preliminary Verification and Validation of WEC-Sim, an Open-Source Wave Energy Converter Design Tool," in *Proceedings of OMAE 2014*, San Francisco, CA, 2014.

[8] M. Lawson, Y.-H. Yu, A. Nelessen, K. Ruehl, and C. Michelen, "Implementing Nonlinear Buoyancy and Excitation Forces in the WEC-Sim Wave Energy Converter Modeling Tool," in *Proceedings of the 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2014)*, San Francisco, CA, 2014.

[9] Y. Yu, Michael Lawson, Kelley Ruehl, and Carlos Michelen, "Development and Demonstration of the WEC-Sim Wave Energy Converter Simulation Tool," in *Proceedings of the 2nd Marine Energy Technology Symposium*, Seattle, WA, USA, 2014.

[10] N. Tom, M. Lawson, and Y.-H. Yu, "Recent Additions in the Modeling Capabilities of an Open-Source Wave Energy Converter Design Tool," in *25nd International Society of Offshore and Polar Engineers Conference.*, Kona, HI, USA, 2015.

[11] A. Robertson, J. Jonkman, F. Vorpahl, W. Popko, J. Qvist, L. Frøyd, X. Chen, J. Azcona, E. Uzunoglu, C. G. Soares, and others, "Offshore code comparison collaboration continuation within IEA Wind Task 30: Phase II results regarding a floating semisubmersible wind system," in *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering*, 2014, pp. V09BT09A012–V09BT09A012.

[12] "ReDAPT Project." [Online]. Available: http://www.eti.co.uk/project/redapt/. [Accessed: 01-Apr-2015].

[13] "Open Energy Information." [Online]. Available: http://en.openei.org/. [Accessed: 01-Apr-2015].

[14] R. Costello, J. Davidson, D. Padeletti, and J. V. Ringwood, "Comparison of Numerical Simulations With Experimental Measurements for the Response of a Modified Submerged Horizontal Cylinder Moored in Waves," in *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering*, 2014, pp. V09BT09A038–V09BT09A038.

[15] A. Combourieu, M. Lawson, A. Babarit, K. Ruehl, A. Roy, R. Costello, P. L. Weywada, and J. Bailey, "WEC3: Wave Energy Converters modeling Code Comparison project," in *European Wave and Tidal Energy Conference*, Nantes, France, 2015.

[16] "bemio GitHub Webpage." [Online]. Available: https://github.com/WEC-Sim/bemio. [Accessed: 01-Apr-2015].