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Update on WEC-Sim Validation Testing and Code Development

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ABSTRACT

This paper provides an update on the status of the WEC-Sim project, both the code development and experimental testing efforts. Code development has been focused on adding features that improve the fidelity of the simulation, including: non-linear hydrostatic and excitation forces calculation, body-to-body interactions through coupled radiation forces, Morison drag, and more direct modeling of power take-off and mooring components through integration with PTO-Sim and MoorDyn. The experimental testing effort has the main objective of providing a comprehensive dataset with which to validate both the WEC-Sim code as a whole, as well as some of the newest features. The testing was divided into two phases, the first of which was completed in December 2015, and are being conducted at the O.H. Hinsdale Wave Research Laboratory.

1. INTRODUCTION

Wave Energy Converter Simulator (WEC-Sim) is an open-source code for simulating the dynamic response of wave energy converters (WECs) when subject to operational and extreme waves. The code is jointly developed by Sandia National Laboratories and the National Renewable Energy Laboratory (NREL), and was first released through GitHub in summer 2013. The WEC-Sim code solves the governing WEC equations of motion based on the time-domain Cummins equation [1] in six degrees of freedom, and accounts for articulated bodies, mooring, and power-take-off (PTO).

WEC-Sim has been verified through code-to-code comparison, and preliminary validation has been performed through comparison to publicly available experimental data [2, 3, 4]. However, until recently the extent of the WEC-Sim code validation has been limited to publicly available data, which was not collected explicitly for code validation, and therefore is limited in its ability to fully validate the code. For this reason, the WEC-Sim team is performing experimental testing with the objective of WEC-Sim code validation, in order to provide the necessary data to validate the different features in the code. While the primary motivation behind the WEC-Sim experimental testing is to develop a validation data set for WEC-Sim, this data set will be made publicly available so that it can be used by the wave energy community at large. WEC-Sim experimental testing is broken into two phases, where Phase 1 is focused on system identification, and Phase 2 is focused on dynamic response to waves. Phase 1 of testing was completed in December 2015 at Oregon State University's O.H. Hinsdale Directional Wave Basin, and Phase 2 is planned for spring 2016.

The following sections provide an overview of the WEC-Sim open source code development, code feature additions, and update on the experimental testing.

2. CODE DEVELOPMENT

Recent WEC-Sim code development has focused on the addition of new features. The latest version of WEC-Sim (v2.0), released in February 2016, includes new capabilities such as: body-to-body interactions (coupled radiation forces), non-linear hydrodynamics, Morison drag, updated joint and body blocks, batch runs, and improved visualization using ParaView.

The addition of body-to-body interactions, or coupled radiation forces, allows for the motion of one body to have an effect on the other bodies. That is, the radiation forces on a body (added mass and radiation damping) have components due to the movement of all degrees of freedom in the system, rather than on that body's degrees of freedom alone.

The implementation of Morison drag allows for more realistic modeling of the viscous drag as a set of Morison elements rather than using a single quadratic coefficient. This considers for vortex shedding and other viscous effects that are not accounted for in traditional linear potential theory. The model was successfully applied, and the simulation results were verified with theoretical solutions [5].

Non-linear hydrostatic and excitation forces were implemented to more accurate resolve these forces for larger motions. Linear approximations of these forces are often sufficient, but when the motions get larger or the device's water plane area changes significantly, the linear approximations are no longer accurate. The non-linear calculation of these forces is implemented by using the meshed device geometry, the instantaneous body position and wave elevation profile, calculating the pressure at each cell, and integrating over the whole wetted surface.

The latest version of the code includes integration with PTO-Sim [6] and MoorDyn[7]. PTO-Sim is a module that allows for more realistic modeling of the power take-off (PTO) components. Rather than using linear PTO coefficients the PTO components (e.g. hydraulic components) can be directly modeled. MoorDyn is an open source mooring model that uses a lumped-mass formulation, and MoorDyn integration allows for more realistic mooring modeling. The mooring can be defined using lines, nodes, and material properties. To validate and verify the coupled WEC-Sim/MoorDyn model, it was applied to model a 1/25 model scale floating power system connected to a traditional three-point catenary mooring with an angle of 120 between the lines. The simulation results agreed well with the measurements from a wave tank test and results from a commercial code (OrcaFlex) [8].

Some of the new features do not change the simulation implementation, but rather improve the usability of the code. A WEC-Sim simulation can now be visualized in ParaView, which allows for visualization of the wave field, and of the cell-by-cell non-linear hydrodynamic forces. The code can now also be run in batch mode, allowing the user to easily run large numbers of simulations.

These features are all included in the latest release of WEC-Sim (v2.0). Some of these features will be validated using the WEC-Sim experimental testing results. Being able to test these features was one of the reason the experimental device was chosen. For example, due to the proximity and fore-aft configuration of the two flaps, body-to-body interactions are expected to be strong. Similarly, due to the changing profile of the water plane as the flaps pitch and to the wedge shape of the flaps, non-linear buoyancy is also expected to be important.

3. EXPERIMENTAL TESTING

The primary motivation for WEC-Sim experimental testing is to develop a validation data set for the WEC-Sim code. In addition to the main goal of providing validation data for WEC-Sim, there are two secondary objectives for the experimental campaign. The first is to provide a high quality, publicly available, comprehensive dataset that can be used by the wave energy community for code validation. The second is to obtain data relevant to the joint Sandia and NREL project on extreme conditions modeling [9].

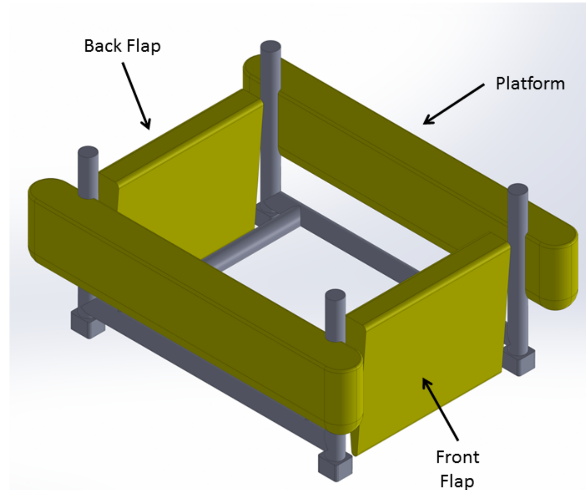

Figure 1: FOSWEC HYDRODYNAMIC DESIGN, CONSISTING OF A FLOATING PLATFORM AND TWO PITCHING FLAPS

The WEC-Sim experimental testing is being performed at the O.H. Hinsdale Wave Research Laboratory in the Directional Wave Basin, and has been split into two phases. Phase 1 is focused on performing a range of tests to verify the WEC and its instrumentation is functioning properly. Additionally, Phase 1 is focused on characterizing the device through a series of system identification tests. Phase 1 of WEC-Sim experimental testing was completed in December 2015, and Phase 2 is schedule for spring 2016. As a result of the findings from Phase 1 testing, the WEC-Sim team is currently making WEC design and instrumentation modifications before going back to the tank for Phase 2. In Phase 2, the WEC-Sim team will run a range of incident wave cases in order to characterize the dynamic response and performance of the WEC. The WEC-Sim code will be validated through comparison of the experimental data with results from WEC-Sim simulations. The objective is to validate WEC-Sim as a whole, and to also validate some of the newest features including non-linear hydrodynamics and body-to-body interactions [10]. For more information about WEC-Sim Phase 1 experimental testing, refer to [11], and for preliminary WEC-Sim code validation as a result of comparison to Phase 1 experimental data refer to [12].

3.1 Device Selection

The floating oscillating surge wave energy converter (FOSWEC) device geometry was chosen for WEC-Sim validation testing after a rigorous comparison of existing WEC technologies. A decision matrix was developed to select the WEC-Sim validation testing device based several criteria, including the ability to test different code features (body-body interactions, non-linear hydrodynamics, wave directionality, Morison drag), and the abil-

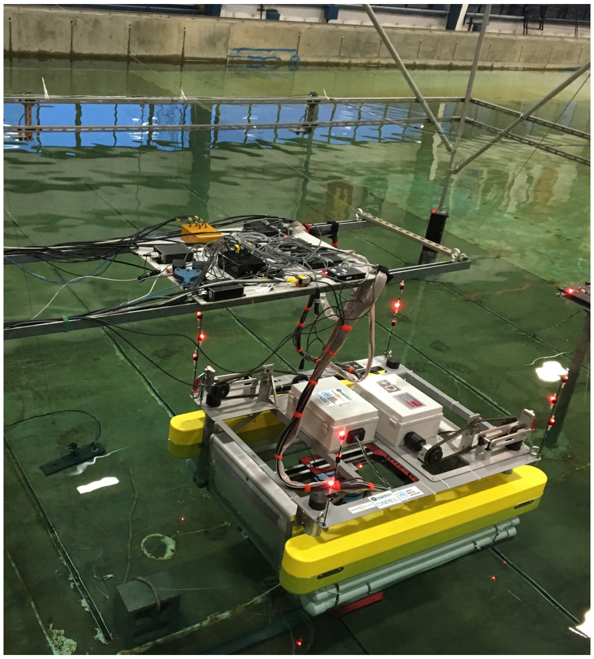

Figure 2: EXPERIMENTAL TESTING OF THE 1:33 SCALE FOSWEC

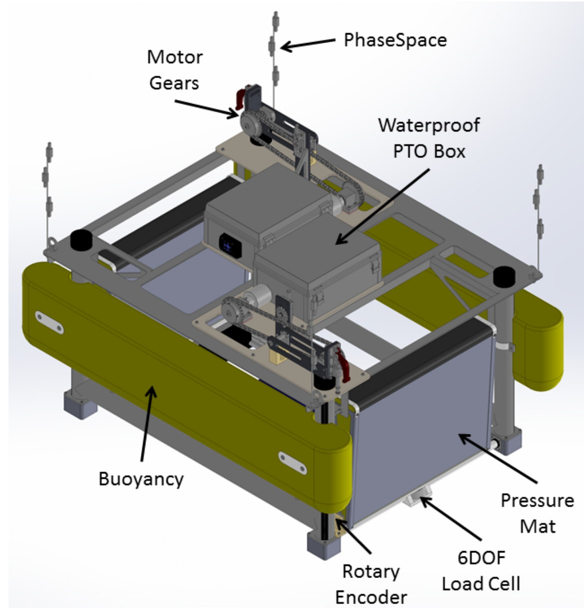

Figure 3: OVERVIEW OF FOSWEC INSTRUMENTATION

ity to iteratively increase the complexity of the device dynamics [11]. The FOSWEC device was selected based on its highest rating according to the decision matrix. The FOSWEC consists of a floating platform with two pitching flaps; its hydrodynamic design is shown in Figure 1. Two power take-off system [13] provides the ability to add programmable damping to each flap, as well as to drive the flap motions for forced-oscillation tests. The device was tested at 1:33 Froude scale. An image from the FOSWEC in operation during WEC-Sim Phase 1 testing in the Hinsdale Directional Wave Basin is shown in Figure 2.

In order to generate and high quality data set for code validation, the FOSWEC device was heavily instrumented. A rendering of of the FOSWEC mechanical design and instrumentation is shown in Figure 3. The FOSWEC instrumentation can be divided into two categories: primary and secondary. The primary instrumentation provides the necessary data for WEC-Sim validation, such as motion tracking in every degree of freedom. This is the most relevant information for WEC-Sim code validation, and each of these measurements have redundancy. The motion of the FOSWEC platform is measured in two different ways: through a camera-based tracking system PhaseSpace [14], and with tape extension position sensors in heave and surge, and an inclinometer in pitch. The rotary motion of each flap is measured both with rotary encoders mounted on the shaft of each flap, and with the motor encoder in the PTO box. The secondary instrumentation includes additional measurements that will be useful to the extreme conditions project and to guide future experiments in the wave energy community at large. This includes 6DOF load cells at the attachment between the flaps and the platform, and between the platform and the arm to characterized the constraint loads on each joint. The secondary instrumentation also includes two pressure mats, placed at the front of each flap, and three pressure gauges on the back of each flap. This kind of pressure measurement is innovative, and can provide useful data for high fidelity CFD model validation.

In order to isolate the FOSWEC's hydrodynamic response, remove the nonlinear forcing of a traditional mooring system, and iteratively lock and release degrees of freedom (DOF), a motion constraint was designed to constrain the motion to three degrees of freedom: surge, heave, and pitch. The motion constraint provides the ability to free or lock any combination of the three degrees of freedom, and provides a restoring force in surge. The motion constraint, together with the ability to lock the flaps, allows for the ability to iteratively increase the complexity of the FOSWEC's response during experimental testing. During both phases of testing, FOSWEC DOFs will be locked. For example, in Phase 1 experimental testing, the FOSWEC platform was isolated to heave, pitch, or surge motion during the free decay tests. Similarly, for the flap decay tests, the FOSWEC platform motion was locked in all DOF in order to isolate the flap pitch motion. An overview of the results from these Phase 1 tests is given in the following section.

3.2 Phase 1 Testing

Phase 1 of WEC-Sim experimental testing was completed in December 2015 at the O.H. Hinsdale Wave Research Laboratory in the Directional Wave Basin. Phase 1 was focused on characterizing the device through a series of system identification tests, and performing the range of planned tests to verify the WEC and its instrumentation were functioning properly. The test completed in Phase 1 include swing tests to characterize the FOSWEC mass properties, PTO characterization, static offset, free decay, and forced oscillation. The static offset tests are used to characterize the restoring stiffness in each DOF. Similarly, the free decay tests are used to obtain the natural frequencies and damping ratios of the FOSWEC in each DOF. Results from the WEC-Sim free decay tests are shown in Figure 5 for flap decay. The experimental results are shown in a solid line with a 90% confidence interval, and the numerical simulations are shown with a dotted line. For each decay test, the FOSWEC was displaced to several different initial conditions, and then released. In Figure 5, the responses have been normalized by their initial displacement, which highlights the FOSWEC's nonlinear response. For linear response, the normalized decay test results would collapse on one another and be independent of initial displacement. This is not the case for the experimental decay tests, which demonstrates the nonlinearity of the FOSWEC in these DOFs. Consequently, the WEC-Sim simulations of these experiments must account for the these nonlinearities. For more information about WEC-Sim Phase 1 experimental testing and numerical simulation, refer to the the following OMAE 2016 publications [11] and [12].

As a result of the findings from Phase 1 testing, the WEC-Sim team made WEC design and instrumentation modifications before going back to the tank for Phase 2. Some of the challenges experienced during Phase 1 testing included: frame bending during motor operation, inaccurate flap displacement measurements from the motor encoder, issues with the pressure mat waterproofing, limited range of the flap rotary encoder due to its original mounting location, and weight of motion constraint arm larger than expected. Allowing for time to iterate on the FOSWEC design and instrumentation was the motivation behind the two phases of testing.

The objective of Phase 2 testing is to characterize the dynamic response and performance of the WEC. Phase 2 of testing will include forced oscillation and wave excitation tests to obtain the radiation and excitation coefficients [15]. These coefficients will be compared to those obtained from a Boundary Element Method (BEM) code, and will be used in WEC-Sim simulations. Additionally, during Phase 2 of testing the FOSWEC's response will be characterized when subject to a range of incident wave cases, with waves of varying size, period, and angle of of incidence.

3.3 Numerical Simulations

In order to validate the WEC-Sim code, WEC-Sim used to simulate all the tests that were performed during Phase 1 experimental testing. As described in previous sections, one of the reasons this FOSWEC was selected for validation testing was because the device includes characteristics such as having non-linear hydrodynamics and body-to-body interactions. These characteristics parallel the new code features implemented in WEC-Sim v2.0 that need validation. For instance, for large pitch motions the dynamics of the flap are expected to be highly nonlinear. In order to validate these individual features and WEC-Sim as a whole, simulations were performed with and without these features on. For further analysis and description of the WEC-Sim Phase 1 numerical simulations, please refer to [12].

WEC-Sim requires hydrodynamic coefficients such as

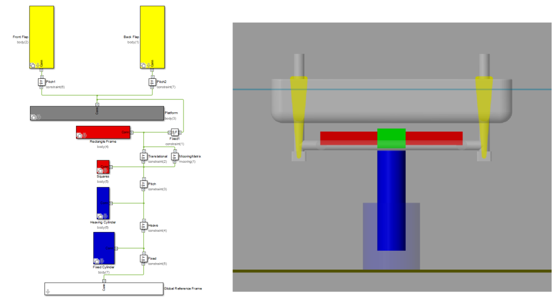

Figure 4: WEC-Sim MODEL OF EXPERIMENTAL DEVICE

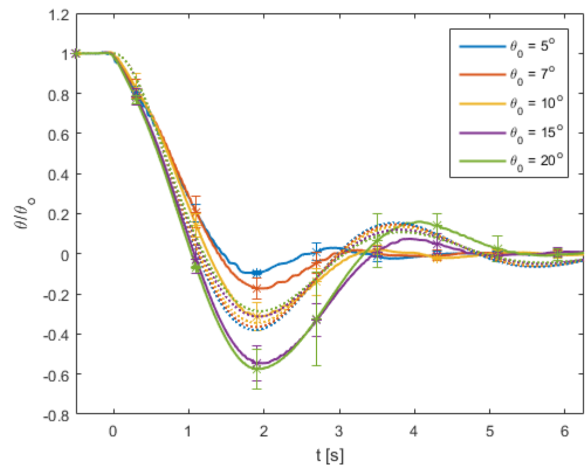

Figure 5: EXPERIMENTAL (SOLID) AND NUMERICAL (DASHED) FLAP DECAY RESULTS FOR DIFFERENT INITIAL DISPLACEMENTS

added mass, radiation damping, and excitation coefficients, which are typically obtained from a BEM code. In this case, AQWA was used to generate the hydrodynamic coefficients. Completion of Phase 2 tests will allow the WEC-Sim team to obtain these coefficients from the experimental data, and compare to the AQWA generated coefficients. WEC-Sim simulations will be run with both the AQWA and the experimentally determined coefficients. Figure 4 shows the WEC-Sim model of the FOSWEC device and constraint arm, and Figure 5 shows results from the flap decay simulations. The WEC-Sim code shows good agreement with the experimental data in terms of the period of response and decay rate.

4. SUMMARY

Recent WEC-Sim code development has focused on the addition of new capabilities. These include body-to-body interactions, Morison drag, and improved visualization. In Recent months WEC-Sim has seen increased use, as well as increased collaboration in the form of discussions, example sharing, and external code contributions.

The WEC-Sim team is currently in the middle of a testing campaign which will provide validation data. Phase 1 was completed in December 2015 at Oregon State University, and focused on device characterization and instrumentation check. The team is currently working on redesigning components and preparing for phase 2 of testing. The experimental results are being compared to WEC-Sim simulations. These simulations highlight the importance of the different features of the code, including non-linear hydrodynamics and body-to-body interactions. The experimental and numerical results are being presented at OMAE 2016.

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