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WEC-SIM

VALIDATION TESTING PLAN
FY14 Q4

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PROJECT STATUS

The WEC-Sim project is currently on track, having met both the SNL and NREL FY14 Milestones, as shown in Table 1 and Table 2. This is also reflected in the Gantt chart uploaded to the WEC-Sim SharePoint site in the *FY14 Q4 Deliverables* folder. The work completed in FY14 includes code verification through code-to-code comparison (FY14 Q1 and Q2), preliminary code validation through comparison to experimental data (FY14 Q2 and Q3), presentation and publication of the WEC-Sim project at OMAE 2014 [1], [2], [3] and GMREC/METS 2014 [4] (FY14 Q3), WEC-Sim code development and public open-source release (FY14 Q3), and development of a preliminary WEC-Sim validation test plan (FY14 Q4). This report presents the preliminary Validation Testing Plan developed in FY14 Q4.

The validation test effort started in FY14 Q4 and will go on through FY15. Thus far the team has developed a device selection method, selected a device, and placed a contract with the testing facility, established several collaborations including industry contacts, and have working ideas on the testing details such as scaling, device design, and test conditions.

Table 1: NREL WEC-Sim Quarterly Milestones. Completed Milestones are highlighted in Green.

NREL 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. Completed Milestones are highlighted in Green.

SNL 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 (3/31/14)
WEC-Sim Release: Release the beta version of WEC-Sim on the NREL, SNL, and OpenEI websites.	Q3 (6/30/14)
WEC-Sim 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)

INTRODUCTION

WEC-Sim is an open-source code used for simulating the performance of wave energy converters (WECs) under operational waves. The code is currently being developed by the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL) with funding from the United States Department of Energy (DOE). It is currently built in the Mathworks MATLAB/Simulink platform, using the SimMechanics multi-body dynamics solver. The hydrodynamic coefficients used by WEC-Sim are currently obtained from WAMIT. Verification of the code was done by comparing simulation results from WEC-Sim to those from commercially available codes. Initial validation of the code was done by comparing WEC-Sim simulations with experimental data. However, the initial validation of the code was limited by the quality of the publicly available data sets. To address this, the WEC-Sim team plans to perform scaled wave tank testing in FY15 aimed at providing high quality data for comprehensive validation of the WEC-Sim code. The dataset will be made publicly available alongside WEC-Sim. Developers and other researchers will be able to download WEC-Sim data, and the associated device designs.

A secondary goal of this effort is to evaluate novel testing techniques for extreme conditions modeling. Specifically, the WEC-Sim experiment will include a collection of pressure load data on the device. This will provide a dataset useful for validating high-fidelity models and will give guidance for possible ECM testing in the future.

This report describes the initial test plan developed to guide these experimental efforts. The WEC-Sim team anticipates that this initial plan will be modified as new information becomes available to the team.

OBJECTIVE

The scale-model experimental testing has three main objectives:

- Experimental validation of the WEC-Sim code
- Evaluate new instrumentation and procedures for load characterization
- Deliver a publicly available, high-quality data set, and associated device geometry specifications

In addition to these goals there are a number of constraints that have been identified as crucial and must be considered during the development and design of this testing effort. First, the device used for validation was chosen based on the dataset that it can generate and not on a prediction of its success in the marketplace. Additionally, a device/experiment combination that has not been previously performed was desired. These objectives and constraints guided the process used by the WEC-Sim team in the initial planning of the experimental validation tests.

The WEC-Sim team also relied on tank testing guidelines whose content was instrumental in the development of the initial validation plan [5], [6], [7], [8]. The team is currently obtaining input from industry on the experimental test plan through direct engagement with US developers, the details of which are found in the Industry Outreach section.

DEVICE SELECTION PROCESS

In order to determine the device archetype for the WEC-Sim experimental testing campaign, the WEC-Sim team used the Pugh Method, also known as the decision matrix method. This method was chosen because of the large number of variables to be evaluated, and the importance of producing a quality publicly available data set. The experimental testing campaign is two-fold, with focus on generation of a WEC-Sim validation data set based on WEC performance data, and WEC loads characterization. As such, the WEC-Sim team deemed it important to include testing criteria that meet both of these objectives. In the following sections, the method the WEC-Sim team used to select a WEC archetype is described. The full device selection spreadsheet with the scores for all of the WEC archetypes considered, and justification for their rating is available on the WEC-Sim SharePoint, ***DeviceSelectionMatrix_9-30-2014.xlsx***.

DECISION CRITERIA

The device selection process was broken into two primary categories:

1. Validation Ability
2. Testability

The Validation Ability was weighted higher (67%) than the Testability (33%) because the primary objective of the experimental testing is to validate the modeling capabilities of WEC-Sim. Each primary category was broken into five decision criteria. The total weighting for each category sums to 100%, and was distributed according to the criterion's relative importance. The final criteria weights were chosen based on the average of each individual team member's weighting preference. Each WEC archetype was then rated according to its ability to meet the Validation Ability and Testability criteria.

VALIDATION ABILITY

Validation Ability is broken into five criteria:

1. **WEC-Sim Modeling** - *Can WEC-Sim model the WEC (ie. dominant degrees-of-freedom and operating principles)?*
2. **DOF Testing** - *Does the device allow for coupled degrees of motion (i.e. surge/pitch) to be tested?*
3. **Wave Directionality** - *Can the effects of wave directionality be tested?*
4. **Body-to-body Hydrodynamic Interaction** - *Can body-to-body hydrodynamic interaction be tested?*
5. **Nonlinear Hydrostatics & Hydrodynamics** - *Can non-linear hydrodynamic and hydrostatic effects be tested?*

Each of these criteria are described and weighted according to their relative importance as shown in Figure 1. This format was used to rate each WEC archetype on a 0-2 scale according to its ability to validate the WEC-Sim code.

Validation Ability						
Title	*WEC-Sim Modeling*	*DOF Testing*	*Wave Directionality*	*Body-to-Body Interaction*	*Nonlinear hydrostatics & hydrodynamics*	***Validation Ability Total***
Description	Can WEC-Sim model the WEC (ie. dominant degrees-of-freedom and operating principles)?	Does the device allow for coupled degrees of motion (i.e. surge/pitch) to be tested?	Can the effects of wave directionality be tested?	Can body-to-body hydrodynamic interaction be tested?	Can non-linear hydrodynamic and hydrostatic effects be tested?	
Ratings	0 = Device allows minimal or no testing of this component 1 = Device allows satisfactory testing of this component 2 = Device allows comprehensive testing of this component					
Weights	23%	23%	13%	20%	21%	67%

Figure 1 - Overview of Validation Ability Criteria, Ratings and Weights

TESTABILITY

Testability is also broken into five criteria:

1. **Modularity of Testing** - Can the device be tested as individual bodies and restrict varying modes of motion?
2. **Performance Instrumentation** - *Will the device be easy to add performance instrumentation (i.e. motion tracking)?*
3. **Ease of Deployment** - *Will the device be easy to set up and breakdown (i.e. changing headings and make modifications)?*
4. **Ease of Construction** - *Will the device be easy to design and fabricate?*
5. **Loads Instrumentation** - *Will the device be easy to add loads instrumentation (ie. pressure/slam panels)?*

Each of these criteria are described and weighted according to their relative importance, as shown in Figure 2. This format was used to rate each WEC archetype on a 0-2 scale according to its testability.

Testability						
Title	*Modularity of Testing*	*Performance Instrumentation*	*Ease of Deployment*	*Ease of Construction*	*Loads Instrumentation*	***Testability Total***
Description	Can the device be tested as individual bodies and restrict varying modes of motion?	Will the device be easy to add performance instrumentation (i.e. motion tracking)?	Will the device be easy to set up and breakdown (i.e. changing headings and make modifications)?	Will the device be easy to design and fabricate?	Will the device be easy to add loads instrumentation (ie. pressure/slam panels)?	
Ratings	0 = Substantial design and construction 1 = Moderate design and construction 2 = Minimal design and construction					
Weights	21%	24%	22%	15%	18%	33%

Figure 2 - Overview of Testability Criteria, Ratings and Weights

SELECTED DEVICE

Based on the device selection process described in the previous section, the device archetype chosen is a floating oscillating surge WEC (OSWEC). The overall score for the floating OSWEC was the highest, with an overall score of 1.88 out of 2.0, as shown in Figure 3. The full device selection spreadsheet, with scores for all WEC archetypes considered, is available on the WEC-Sim SharePoint, see ***DeviceSelectionMatrix_9-30-2014.xlsx***. *It should be noted that the selected device is subject to change based on feedback from the WEC-Sim Team's involvement in IEA Annex VI, and feedback from the industry outreach effort.*

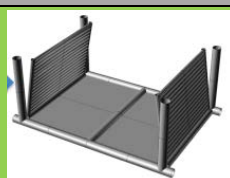
Wave Energy Converter					
Example Image		Archetype	Industry Example	Operating DOF	PTO Type
		Floating oscillating surge device	Langlee 	3: Surge, heave, pitch	Rotational
Validation Ability					
WEC-Sim Modeling	*DOF Testing*	*Wave Directionality*	*Body-to-Body Interaction*	*Nonlinear hydrostatics & hydrodynamics*	***Validation Ability Total***
2	2	2	2	2	**2**
Testability					
Modularity of Testing	*Performance Instrumentation*	*Ease of Deployment*	*Ease of Construction*	*Loads Instrumentation*	***Testability Total***
2	2	1	1	2	**1.63**
Weighted Total					**1.88**

Figure 3 - Floating OSWEC Overall Score

A rendering of what the device archetype looks like is shown in Figure 4 below. The architecture lends itself well to modular construction and component testing. For instance, the model flaps can be designed to be independently locked in place (up or down). Rotary PTO emulators can be installed in the flap joints. Load pressures sensors can be installed in several places such as the flat portions of the flaps or at the ends of the flaps nearest to the water surface. Body-to-body interactions can be tested in an incremental manner, for example, first with one flap fixed, and then with both flaps free to move. The model size will be determined using Froude scaling. *The final device geometry and scale are yet to be finalized.*

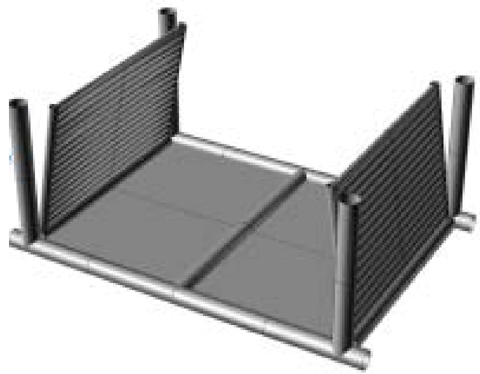


Figure 4: Rendering of a Floating OSWEC

MODULAR TESTING

One of the criteria identified by the WEC-Sim team as being important to the testability of an archetype is the opportunity to perform tests in a modular fashion. The Floating OSWEC is a highly modular device whose rigid bodies can be tested with increasing complexity. An overview of the different possible combinations of device motion is made possible by fixing and freeing each of the rigid bodies, as listed in Figure 5.

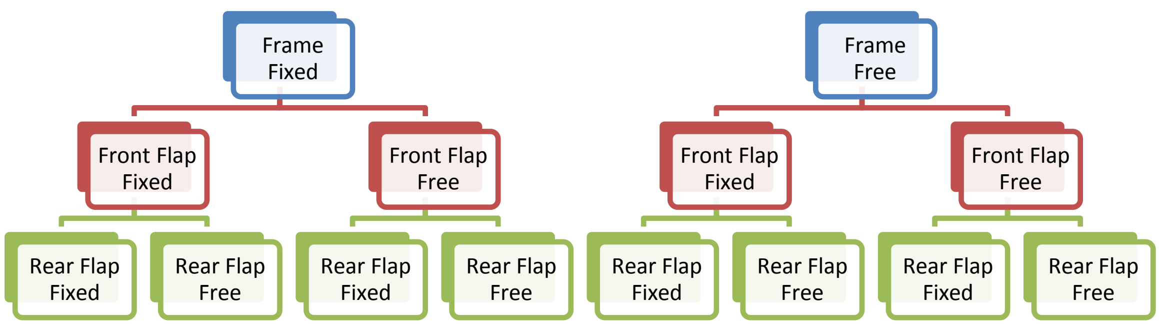


Figure 5 - Modular Testing of the Floating OSWEC

MOORING/DOF CONTRAINTS

Preliminarily, a top-fixed structure is being considered instead of a traditional mooring system. The support structure will be attached to the instrumentation bridge and connect to the device at the centerline between the two flaps (instead of a traditional mooring system). This structure will be designed to incrementally constrain motion in varying DOFs. This approach supports an experimental test set progressing from simple to complex model configurations and allows validation of isolated components.

Several concept drawings have been created to illustrate the flexibility that can be designed into the supporting structure for the device. The first of these, a concept drawing of the design side view, is found in Figure 6. The bridge is a tank structure that allows the device to be suspended in the middle of the tank from above. The heave locking nuts are used to restrict heave motion.

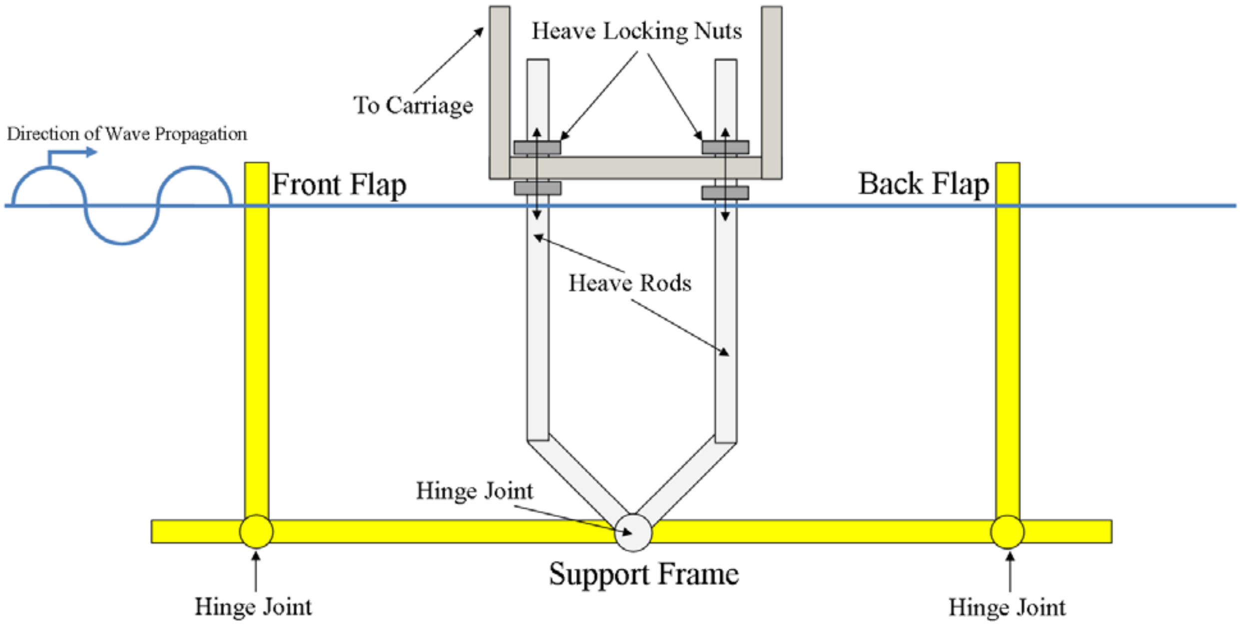


Figure 6: Side View of Experimental Model

A top-down view of the support frame is found in the top half of Figure 7. This shows the control over the surge DOF. The bottom half of Figure 7 shows the isolated side view of the support frame, and shows the yaw directionality control.

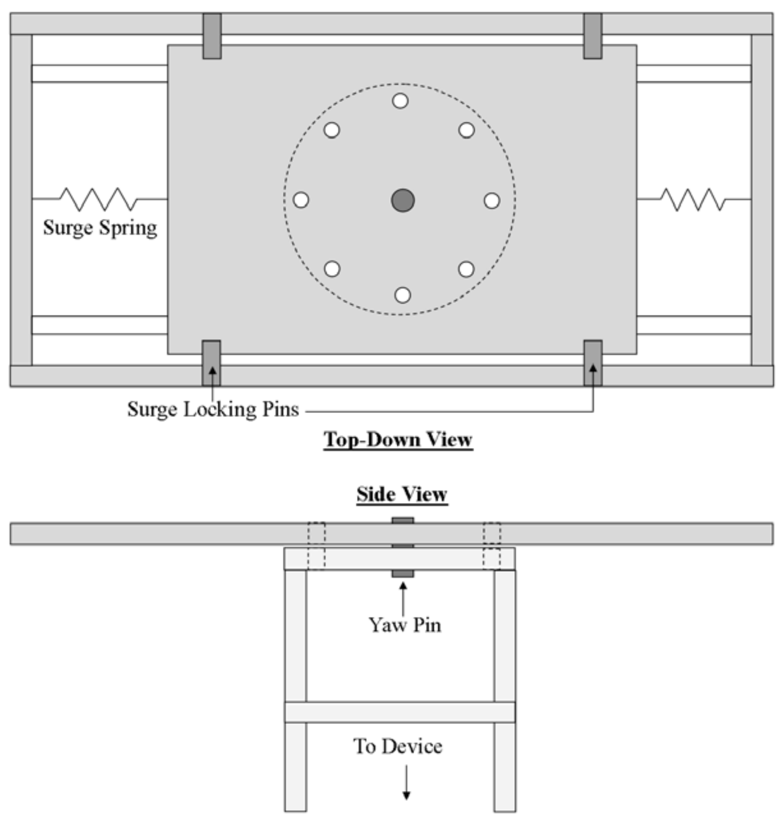


Figure 7: Top-down View of the Experimental Model

Alternatively, there have been discussions with industry on the value of developing a programmable mooring system through WEC-Sim testing that could be used by developers in the future.

POWER TAKE-OFF (PTO)

The model PTOs will be placed at the hinge joints, and will be modeled by programmable linear dampers. The WEC-Sim team plans to work with Oregon State University to develop and fully characterize linear dampers for both hinge joints that can be programmed for a constant damping value.

INSTRUMENTATION

Listed below is the planned instrumentation for the performance and loads characterization of the Floating Oscillating Surge WEC. *The instrumentation used for the WEC-Sim testing is subject to change based on feedback from industry and cost.*

PERFORMANCE INSTRUMENTATION

The performance instrumentation provided by the facility are listed below. For more information, reference Appendix I: Facility Information. *This list reflects the instrumentation that is currently being considered and is subject to change.*

- Wave Gauges
  - Will be placed along the centerline of the device and used to measure the local wave elevation to characterize the incident waves.
- 6DOF Motion Tracking
  - 6 Tracking lights will need to be placed in clear view of tracking cameras. Two cameras are required to track 6 DOF per rigid body where one camera can handle 3 DOF such as surge, heave, and pitch.
- Data Acquisition System
  - The signal from each piece of instrumentation will need to be recorded for post processing. A single unit can allow for several input signals; however, it may require signals to be either single ended or differential which will affect instrumentation chosen
- Video Cameras
  - Two cameras placed perpendicular to the top-down and side plane will allow complete recording of 6 DOF. The recorded information can be used to provide a visual check against instrument signals. In addition, nonlinear effects such as overtopping or body clashing will be easily identifiable.

LOADS INSTRUMENTATION

The loads instrumentation that will be purchased by the WEC-Sim team or provided by the facility are listed below. *This list reflects the instrumentation that is currently being considered and is subject to change.*

- Pressure Sensors
    - Point measurements
    - Surface measurements
- 6DOF Load Cells (for the joints)
- Programmable Mooring System
    - Mooring loads measurements
    - Constraint of the WEC
- Slam Panels

DESIGN AND FABRICATION

The WEC-Sim team plans to subcontract the design and fabrication of the Floating Oscillating Surge WEC. The subcontractor is to be determined and will be based on recommendations from the wave tank testing facility and industry outreach.

EXPERIMENTAL TEST FACILITY

FACILITY SELECTION

Based on the dimensions, wave making capability, cost, and experience testing WECs, the WEC-Sim team has chosen the OSU Hinsdale Tsunami Wave Basin as its test facility. **Error! Not a valid bookmark self-reference.** is a comparison of different tanks in the US, provided to the WEC-Sim team from Diana Bull though her work on the SNL Advanced Controls Project.

Table 3 - Test Facility Evaluation

Basin	Length [m]	Width [m]	Depth [m]	Period [s]		Max Height [m]	Period [s]	Directional Range [deg]	Cost/Day
				min	max				
MASK (Carderock)	109.7	73.1	6.1	0.5	4	0.9	3	-30 to 120	~$14,000
OTRC (Texas A&M)	45.7	30.5	5.8	0.5	4	0.9	3	20	$9,000
Maine	30	10	5	0.5	4	0.6	2.6	15	-
Iowa	40	20	3	0.4	3.33	0.42	1.96	N/A	-
OSU Tsunami Wave Basin	48.8	26.5	1	0.5	10	0.78	5	30	$4,000
Stevens Sea Basin	22.9	22.9	1.5	-	-	0.1778	-	-	-
University of Delaware	20	20	1.1	-	-	0.01	2	-	-

Note: - means information not available

HINSDALE TSUNAMI WAVE BASIN

Oregon State University operates the O.H. Hinsdale Wave Research Laboratory (HWRL). This facility is one of the largest coastal and ocean hydraulic laboratories in North America. The Tsunami Wave Basin is equipped with a high-performance, piston-type, multi-directional wave maker. In addition, HWRL, Energy Systems at OSU (ESOSU) and the Northwest National Marine Renewable Energy Center (NNMREC) have collaborated on the development of processes for high-precision tank testing. This collaboration was directly focused on enabling the development and optimization of efficient WECs [9].

The scale-model experiments will be conducted in the Tsunami Wave Basin (TWB), one of the wave tank facilities located at HWRL. There are several basic features of the TWB that are integral to the various experiments being scheduled. The first of these features is the type of waves that the facility can produce. Using the piston-driven 29 waveboards, the tank can produce regular, irregular, multi-direction and user-defined waves. The second feature is the supporting infrastructure of the TWB, which includes a crane, an instrument carriage that spans the basin, and built-in struts for securing models [10]. This approach maximizes the experimental time in the tank and increases the quality of the data.

HWRL also "has a large inventory of conventional and state-of-the art instrumentation to measure free surface, velocity, pressure, and stress." [11] There are nine types of pressure or strain instruments, three types of velocity instruments, and three types of wave gages the team will have available for use. In addition, HWRL has two types of modular data acquisition (DAQ) systems and five types of video recording available. This instrumentation set should help the team minimize the number of new instruments to be purchased. The team will also engage with the HWRL staff, NNMREC and ESOSU during the device design phase, pulling on the combined expertise of these organizations to implement any best practices that are specific to HWRL instrumentation.

The data sheets for HWRL's TWB and instrumentation capabilities can be found in Appendix I: Facility Information.

TENTATIVE SCHEDULE

The WEC-Sim team expects to complete an extensive list of experimental trials as listed in Table 4. For greater details on the tests planned, refer to ***LaboratoryTesting_09-30-14.xlsx*** on SharePoint. *However, certain trials will require an increased amount of time to design and may be dropped when the final test plan is completed. The detailed schedule is currently in development.*

Table 4 - Preliminary List of Experimental Trials

Experimental Trials			
Test Type	**Description**	**Results Gathered**	**Time [Days]**
Dry Rig	Balance the body so as to prevent rotation	Center of gravity and mass properties	1
Wave Tank Calibration	Run desired wave climates without device in the basin	Calibrate wavemaker gains and quantify reflection coefficients	5
Wet Free Decay	Device is released from an initial displacement. Allow motion to oscillate and decay to its equilibrium position	Natural period of oscillation, infinite frequency added mass, estimate on linear and quadratic viscous damping	1
Forced Oscillation	Drive the device periodically with fixed motion amplitude	Frequency dependent added mass and wave/viscous damping coefficients	2
Wave Excitation	Fix device and measure loads under incident periodic waves	Wave Excitation forces in 6 Degrees of freedom	2
Regular Wave	Device is allowed to move freely under incident periodic waves. Certain degrees of freedom can be restricted to simplify modeling.	Measure the frequency domain response amplitude operator. Tests with different wave amplitudes may provide information about nonlinearities.	16
Irregular Wave	Device is allowed to move freely under summation of incident periodic waves described by a spectrum. Certain degrees of freedom can be restricted to simplify modeling.	Measure the time domain response in real sea conditions (non-periodic). Provide statistics on peak and average loads and power production under operational conditions.	16
Survival Wave	Device is allowed to move freely under summation of incident waves described by a spectrum representing the 50 – 100 yr return period.	Measure the time domain response in extreme sea conditions (non-periodic). Ultimate loads and motions can be measured. Information will help guide final structural and mooring design.	5
Total Number of Days			**48**

COLLABORATION

Since the primary objective of the WEC-Sim project is open source code development, the WEC-Sim team has sought out opportunities to collaborate. The focus in FY15 is on WEC-Sim code validation and the creation of an open source experimental data set. As such, partnerships with internal and external collaborators have been used to shape the WEC-Sim experiment design.

SNL ADVANCED CONTROLS PROJECT

The WEC-Sim team has been interfacing with the SNL Advanced Controls Project (PI: Diana Bull) to learn from their test plan development, and to ensure that their dataset will be valuable to the WEC-Sim Project. The advance controls project plans to test an axisymmetric floating point absorber WEC at the Navy's MASK wave tank facility. The device will be secured to the bridge using a planar motion table to constrain motion in different DOFs, instead of using a traditional mooring system. Details on their test plan will be submitted to DOE FY14 Q4. The experimental setup is shown in Figure 8.

Figure 8: Experimental Setup for Advanced Controls Test

OREGON STATE UNIVERSITY & DOE EERE POST-DOC

In continuing support of WEC research, SNL is working with two of Dr. Ted Brekken's graduate students at Oregon State. Asher Simmons is a Ph.D. candidate who is supporting the WEC-Sim wave tank testing. Ratnak So is a M.S. student who is supporting the development of the PTO-Sim component of the WEC-Sim code.

Additionally, Bret Bosma, a current DOE EERE Post-Doctoral Researcher plans to join the WEC-Sim project in January 2015. Dr. Bosma is a graduate from Oregon State University, and has extensive experience designing and executing experimental wave tank tests with WECs, both at Hinsdale and at other wave tanks.

INDUSTRY OUTREACH

In order to gain knowledge from developer experience, the WEC-Sim team has engaged the US industry in the planning stage of the tank testing effort. This is an ongoing effort, with the status of the interviews outlined in Table 5 below. The method of engagement is based on industry availability (teleconference or in-person), and the interviews are guided by a set of consistent questions. The WEC-Sim team was focused on gathering information from US Industry regarding the following:

1. Wave tank testing experiences, with a focus on preparation, and issue identification and resolution.
2. Ensure that the resulting data set from the WEC-Sim experimental testing is both relevant and useful to the industry at large.
3. Concerns, ideas, and plans in reference to extreme conditions testing.

A copy of the industry outreach questionnaire provided to the developer POCs is provided in Appendix II: Industry Outreach Questionnaire. The feedback from these industry partners will be used to direct the focus of the experimental testing in terms of both performance and loads testing. The findings of these interviews will be presented to DOE once interviews have been completed.

Table 5 - Experimental Testing US Industry POCs

Developer	Developer POC	WEC-Sim POC	Status	Meeting Date	Notes
Columbia Power Technologies (CPT)	Pukha Lenee-Bluhm p.lenee.bluhm@columbiapwr.com Ken Rhinefrank krhinefrank@columbiapwr.com	SNL-Kelley	Kelley sent email on 9/10/14	9/22 Meeting at CPT	Kelley meeting at CPT
Ocean Power Technologies (OPT)	Dr. Kate Edwards, Manager Advanced Engineering kedwards@oceanpowertech.com	NREL - Nathan	Nathan sent email on 9/10/14		Kate forwarded OPT/NREL wave tank testing interview notes, Nathan replied requesting interview directed at performance/loads testing
Resolute Marine Energy (RME)	Bill Staby wstaby@resolutemarine.com Darragh Clabby darragh.clabby@gmail.com	NREL – Mike	Mike sent email on 9/12/14	9/18 Conference Call	Conference call completed with Mike, Kelley, Nathan and Yi-Hsiang
Aquantis/ Dehlsen (Ecomerit)	Alex Fleming (afleming@ecomerittech.com)	NREL – Mike	Mike sent email on 9/12/14		
Northwest Energy Innovations (NWEI)	Steven Kopf skopf@nwenergyinnovations.com Justin Klure jklure@nwenergyinnovations.com	SNL - Kelley	Kelley sent email on 9/10/14		Replied, Kelley called back on 9/18, meeting TBD
Oscilla Power	Tim Mundon mundon@oscillapower.com	NREL - Nathan	Nathan sent email on 9/9/14	9/24 Meeting at OWET	Nathan/Kelley scheduled meeting at OWET
Ocean Energy	John McCarthy jmc@oceanenergy.ie	SNL - Kelley	Kelley sent email on 9/10/14		Sent follow up email

IEA OES CODE VERIFICATION AND VALIDATION ANNEX (ANNEX VI)

As indicated in the SNL and NREL AOPs, the WEC-Sim team will be involved in the proposed IEA OES Annex VI effort. Mike Lawson traveled to attend the Annex V meeting held in Edinburgh in November, 2013 and the Annex VI scope development meeting held in DC on Sept 25-26th.

During the Annex VI scope development meeting, a group of international experts developed an outline for the Annex VI proposal that will be delivered to the OES Executive Committee this November. For reference, the meeting agenda, presentations, reference documents, and an outline for the Annex VI proposal that will be present to the IEA Executive Committee (ExCo) this November can be downloaded here.

Annex VI will be comprised of validation and verification (V&V) tasks for wave and hydrokinetic turbine modeling codes. The WEC-Sim team will participate in the WEC V&V portion of the project, which will consist of code2code comparison and code2expeimental comparison tasks. Determination of the specific details of the Annex VI work scope will be the first task of the Annex VI group after the Annex is approved by the OES Executive Committee.

The WEC-Sim team will also participate in a “Phase 0” of the Annex VI effort. The Phase 0 effort will consist of a short 1-year code2code comparison effort between Innosea, Ecole Central de Nantes, Dynamical Systems Analysis, University of Ireland Manyooth, and the WEC-Sim team. Over the following weeks, the WEC-Sim team will work with the Phase 0 team members to define the scope of this effort.

PLANNED SUBCONTRACTS

The WEC-Sim team plans to collaborate with subcontractors to perform the tasks described in Table 6.

Table 6 - Planned Subcontracts

Task	Contractor
1. Wave tank test facility and support	OSU Hinsdale
2. Design and manufacture the scaled WEC	TBD

Task 1 will be performed by the OSU Hinsdale wave research lab. They will be responsible for working with the WEC-Sim team to finalize the test plan and will run the wave tank facility. They will also be responsible for installing and calibrating their instrumentation, such as the wave gauges and motion tracking system. It has yet to be determined whether the WEC-Sim team or Hinsdale will be responsible for procuring the loads characterization instrumentation. This will be finalized upon completion of the contract, planned for FY15 Q1

Task 2 will be performed by a yet to be determined contractor. They will be responsible for taking the device design provided by the WEC-Sim team and fabricating a scaled model of the device. It will be there responsibility to ensure that the device is built to the desired dimensions and is mechanically functional (the PTO will be handled separately by the WEC-Sim team).

CONCLUSIONS AND FUTURE WORK

The WEC-Sim project remains on track. The WEC-Sim team has met all of their FY14 milestones, as shown in the Gantt chart uploaded to the WEC-Sim SharePoint site in the *FY14 Q4 Deliverables* folder. The work completed in FY14 includes code verification through code-to-code comparison (FY14 Q1 and Q2), preliminary code validation through comparison to experimental data (FY14 Q2 and Q3), presentation and publication of the WEC-Sim project at OMAE 2014 and GMREC/METS 2014 (FY14 Q3), WEC-Sim code development and release (FY14 Q3), and development of a preliminary WEC-Sim validation test plan (FY14 Q4).

In FY14 Q4 a preliminary validation test plan was developed and presented in this report. A decision matrix was developed based on two main categories: validation ability and testability. Each category had several criteria with its own relative weight. Using the decision matrix, a floating oscillating surge wave energy converter (Floating OSWEC) was chosen. This device allows for increasing levels of complexity by restricting motions and isolating components. The details on the testing conditions and device design are not finalized, but our current ideas were presented in this report. An outline of planned tests is provided on SharePoint, see ***LaboratoryTesting_09-30-14.xlsx***. The experiments will be completed at the O.H. Hinsdale Wave Research Laboratory (HWRL). The dataset obtained will allow for comprehensive validation of the WEC-Sim code. The data, WEC-Sim simulations, and device geometry will all be made publicly available.

In FY15, the WEC-Sim team plans to concurrently work on the development of the WEC-Sim validation test plan and WEC-Sim code. The team will continue to reach out to industry to guide the development of the WEC-Sim code and experimental testing. WEC-Sim Version 2.0 release is planned for FY15 Q2, and completion of the WEC-Sim experimental testing is scheduled for FY15 Q3.

WEC-SIM CODE RELEASE STATUS

The WEC-Sim Version 1.0 source code is available for download on the WEC-Sim OpenEI website at http://en.openei.org/wiki/WEC-Sim. This site is linked to from the SNL website at http://energy.sandia.gov/wec-sim and the NREL website at https://wind.nrel.gov/designcodes/simulators/WEC-Sim/. Additionally, the WEC-Sim team put together an online Questionnaire for users to provide feedback on the WEC-Sim code. Feedback from the WEC-Sim Questionnaire is used to guide future development of the WEC-Sim code.

Google Analytics is being used to track the OpenEI WEC-Sim webpage activity, including page visits and downloads. Figure 9 and Table 7 present high-level google analytics data. Due to a bug in the OpenEI download tracking capability, code downloads only started to be tracked in August 2015, and the download stats for the initial code release are, unfortunately, not available. NREL and SNL will work with DOE during FY15 to develop a format for extracting and reporting meaningful statistics from the WEC-Sim OpenEI google analytics data.

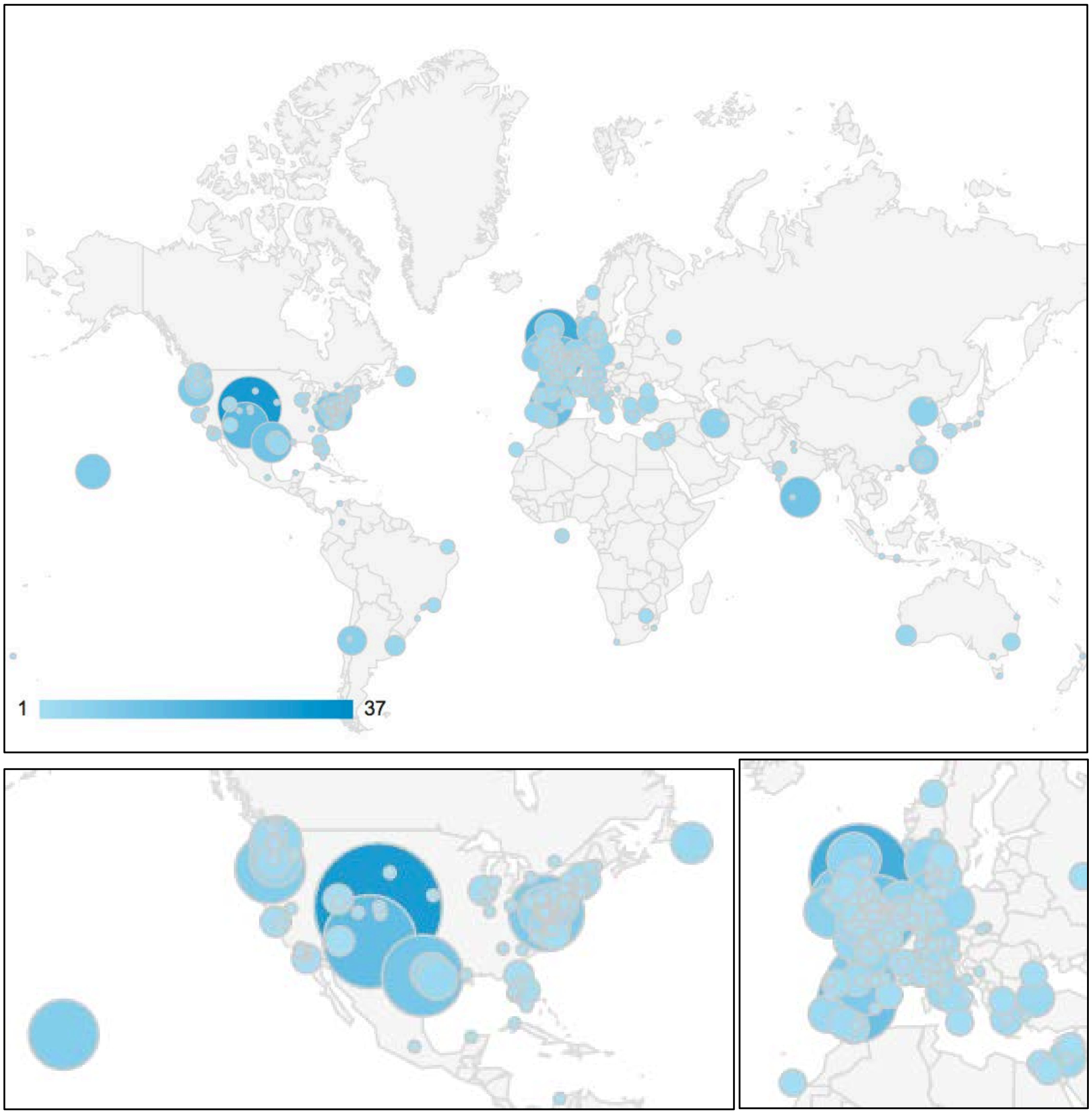


Figure 9. Google Analytics map showing the origin and number of WEC-Sim OpenEI page visits. (Top) Worldwide page views. (Bottom left) North American page visits. (Bottom right) European page visits.

Table 7 – Country of origin and number of users that have visited the WEC-Sim OpenEI webpage.

Country / Territory	Users	Total Events	Pageviews
United States	211	11	913
United Kingdom	93	2	237
Spain	41	1	101
Germany	40	2	82
Italy	29	0	89
France	24	3	81
India	21	1	59
Ireland	20	0	43
Denmark	12	0	25
Taiwan	12	0	33
Iran	11	1	30
Netherlands	11	0	24
Australia	10	0	12
Brazil	10	0	21
Canada	10	1	22
China	10	0	29
Chile	8	0	12
Japan	8	1	16
Portugal	8	2	62
Uruguay	6	0	11
Greece	5	0	46
Israel	5	0	11
Turkey	5	0	29
Egypt	4	0	5
Indonesia	4	1	24
Norway	4	0	9
South Africa	4	0	7
Colombia	3	0	5
Namibia	3	0	8
Belgium	2	0	4
Algeria	2	0	2
Lebanon	2	0	2
Mexico	2	0	9
Poland	2	0	4
Romania	2	0	5
Russia	2	0	4
Sweden	2	0	3
Austria	1	1	1
Bosnia and Herzegovina	1	0	1
Bangladesh	1	0	2
Benin	1	0	1
Switzerland	1	0	1
Cuba	1	0	5
Hong Kong	1	0	1
Honduras	1	0	2
Croatia	1	0	2
New Zealand	1	0	1
Qatar	1	0	3
Singapore	1	0	8
Total	660	27	2107

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O.H. Hinsdale Wave Research Laboratory

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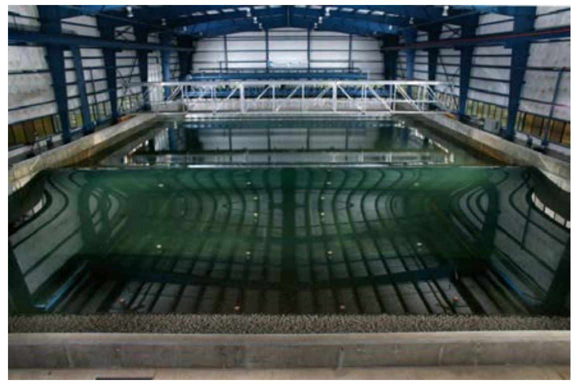
Tsunami Wave Basin

The Tsunami Wave Basin is designed as a shared-use facility to understand the fundamental nature of tsunami inundation and to improve our numerical tools for tsunami mitigation:

- tsunami inundation and overland flow
- tsunami-structure impact
- tsunami debris flow and scour
- harbor resonance

In addition to tsunami research, the facility is used for general testing of coastal infrastructure and for nearshore processes research.



Wave Basin Dimensions

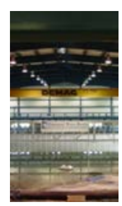
• Length:	48.8 m	160 ft
• Width:	26.5 m	87 ft
• Max depth:	1.37 m	4.5 ft
• Freeboard:	0.6 m	2.0 ft

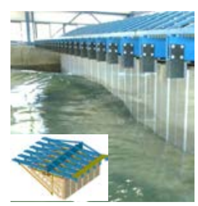
Wavemaker

- Type: Piston-type, Electric motor
- Waveboards: 29 boards, 2.0 m (6.6 ft) high
- Wave types: Regular, Irregular, Tsunami, Multidirectional, User defined
- Period range: 0.5 to 10 seconds
- Max. Wave: 0.8 m (2.6 ft) in 1 m (3.3 ft) depth
- Max. Stroke: 2.1 m (6.9 ft)
- Max. Velocity: 2.0 m/s (6.6 ft/s)

Supporting infrastructure

- 7.5 T capacity bridge crane
- Instrumentation carriage, spans 26.5 m
- Unistrut installed in floor and sides to secure models
- Two access ramps, 14 ft width (4.2 m)
- Steady flow currents installed on project-by-project basis





This facility is partially supported by the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) program of the National Science Foundation

NEES

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O.H. Hinsdale Wave Research Laboratory

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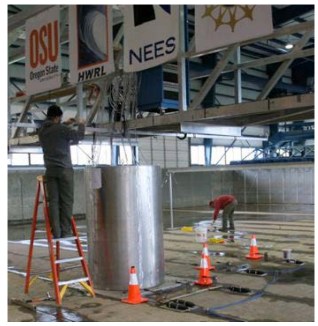
Instrumentation

The HWRL has a large inventory of conventional and state-of-the art instrumentation to measure free surface, velocity, pressure, stress, turbidity, and depth. Data can be made available in near-real time via the web.



Free Surface

- Up to 35 resistance-type wire wave gages
- 3 Acoustic depth gages (Banner Engineering, Corp) 0.2-5m
- 8 Acoustic depth gages (Senix Corp) 0.2-2m

Velocity

- 12 3-D acoustic-Doppler velocimeter (Norteck Vectrino)
- 4 2-D acoustic-Doppler velocimeter probe heads
- 3D Stereo Particle Image Velocimeter system (LaVision)

Pressure/Strain

- 15 miniature pore pressure transducers (Druck PDCR81)
- 12 pressure transducers, 0-15 psig (Druck PDCR830)
- 5 pressure transducers, piezo 0-8.3 psig (PCB,W106B)
- 5 10ch, 1 4ch strain gage conditioner (Vishay 2100)
- 4 50Kip, 4 20Kip pancake load cell (DeltaMetrics)
- 2 10Kip, 6 2Kip rod end load cell (DeltaMetrics)

Turbidity

- 16 optical backscatter sensor (D&A Instr., OBS-3)

Bathymetry

- 2 32 component ultrasonic ranging system (SeaTek)
- 4 laser range finder 0.2-200 m (Dimetix DLS-A30)
- LIDAR survey through subcontract arrangement

Data Acquisition System

3 Modular PXI architecture DAQ systems, each with

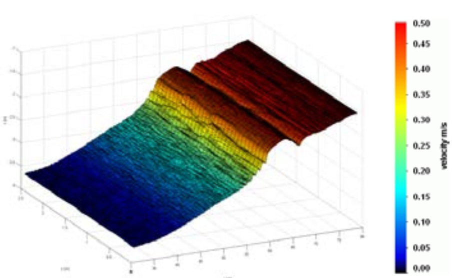
- Built-in signal conditioning and anti-aliasing
- 64 channel, 16-bit analog acquisition
- Digital pulse generation, external device synchronization
- 16 channel RS-232 / serial data recording
- DAQs can be synched to provide 192 analog 48 digital ch

1 Modular PXI architecture DAQ system with

- 4 channel RS-232 serial, 3 channels IEEE 1394a

Video

- PhaseSpace Motion Capture system (8 cameras)
- 3 submersible DeepSea Seacom 2000 cameras
- Atlantis AUW-5800 underwater video
- 10 web cameras (7 Axis 213-PTZ, 3 Axis 211M)
- 2 Sanyo 9.1MP handheld camcorders
- ARRI Lighting System (Chimera Perfect Lighting)
- 2 DeepSea Sealite submersible lights



Acoustic profiler for sediment transport

Pressure Druck PDCR830

DeltaMetrics Load Cell

ADV 3D probehead

This facility is partially supported by the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) program of the National Science Foundation

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APPENDIX II: INDUSTRY OUTREACH QUESTIONNAIRE

Experimental Testing
US Industry Outreach Questions

Background

The US Department of Energy has tasked the WEC-Sim team at Sandia National Laboratories (SNL) and the National Renewable Energy Laboratory (NREL) with completing experimental wave tank tests in Spring 2015. The objective of these tests is three-fold: 1) validate the WEC-Sim code, 2) to generate a publicly available dataset, and 3) evaluate new measurement techniques for quantifying loads as a prelude to simulation-based extreme conditions testing.

Purpose

The WEC-Sim team would like to engage US industry in the planning stage of the tank testing effort. The method of engagement is to be a phone interview guided by a set of consistent questions. The WEC-Sim team has a strong desire to gather information from US Industry regarding the following:

1. Wave tank testing experiences, with a focus on preparation, and issue identification and resolution.
2. Ensure that the resulting data set from the WEC-Sim experimental testing is both relevant and useful to the industry at large.
3. Concerns, ideas, and plans in reference to extreme conditions testing.

Interview Type

Type: ____

Time: ____

Attendees:____________________________________

Questions

1. What wave tank tests has your company completed? For each test, please provide:
    a. Test Objectives
        i. Specific tests completed and usefulness to development/modeling
            1. Dry Tests
            2. Wave Tank Calibration Tests (no device in water)
            3. Free Decay Tests
            4. Wave Excitation Tests
            5. Forced Oscillation Tests
            6. Regular Wave Tests
            7. Irregular Wave Tests
            8. Survival Wave Tests
    b. (Scale, facility, date)
    c. Instrumentation used, and reasons said instrumentation was chosen
    d. How was the power-take-off (PTO) mechanism modeled
        i. What methods were employed to control the PTO
    e. Post processing methods
    f. Outcomes
2. Do you have future wave tank tests planned? If so, what are the objectives of these tests?
    a. When are they scheduled
    b. Is there data our testing will provide that can improve, inform, or replace testing you have planned?
3. What wave tank tests have you not completed that you wish you would have?
4. Model construction suggestions or pitfalls that should be avoided?
5. What kind of instrumentation and loads/performance data would your company be most interested in? What would the data be used for? (Performance modeling? Extreme conditions? Mooring? ...)
6. What can the WEC-Sim team do to make these experiments most useful to your company?
7. Any additional comments or insight your company would like to provide?