Wave Energy Prize Testing and Data Analysis

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Abstract— **The United States' Department of Energy's Wave Energy Prize (the Prize) contest encouraged the development of innovative deep-water wave energy technologies that at least doubled device performance above the 2014 state-of-the-art. The prize developed the ACE and HPQ metrics as a proxy for LCOE that provide an equitable comparison of low Technology Readiness Level (TRL) Wave Energy Converter (WEC) concepts. The ACE calculation was based on technical submissions that included paper studies and simulations, as well as, measured energy capture. To account for real world performance and loading, an extensive testing program was included in the Prize and factors were calculated that scaled the ACE metric to the HPQ. This paper describes the Prize testing program and the analysis of the measurements. Non-dimensionalized and anonymous results are presented. Finally, a section of lessons learned is provided to disseminate the experience gained in the intensive test program.**

***Keywords*— Wave Energy, WEC Testing and Development, Wave Energy Prize**

I. Introduction

The United States' Department of Energy's Wave Energy Prize contest encouraged the development of innovative deep-water wave energy technologies that at least double device performance above the 2014 state-of-the-art.

The Prize was comprised of three phases that progressively evaluated each team's technology [1] (Table 1). The first phase evaluated the wave energy converter (WEC) concepts using the technology performance level (TPL) methodology and 20 teams qualified to proceed to Phase II. In Phase II, each team used numerical simulations to estimate their WEC performance. They then developed 1:50 scale physical prototypes that were tested at various smaller wave tank facilities. The nine teams and two alternates that had the best combination of the criteria in Table 1 proceeded to phase III. The nine finalists each built and tested a 1:20 scale physical prototype at the NSWC-CD's Maneuvering and Seakeeping (MASK) Basin. Data from the 1:20 scale testing, in combination with a first-order capital expenditure estimate for the WECs, were used to determine the winners. This paper discusses the testing and analysis methods for the 1:50 and the 1:20 scale testing.

An incremental testing approach was adopted (Fig. 1). Many teams entered the prize with a concept at a technology readiness level (TRL) of about 2, and they did not have physical evidence to back up their claims. The first testing stage at 1:50 scale was performed early in the competition to evaluate the team's claims against the measured response. This first round of testing also required the teams to build physical and numerical models, and these were another check used to verify a team's capability to succeed at subsequent stages. A dry run test was performed as a mock 1:20 scale test using a representative instrumented physical model. All test sea states were run and data analysis and quality assurance (QA) were performed to verify Prize readiness for team tests and to identify deficiencies with sufficient time for them to be corrected. Because of the tight 1:20 test schedule, the Prize organizers needed to be certain of all systems, software and procedures. Just prior to the 1:20 scale testing, the test readiness of all teams were evaluated to ensure that all teams that proceeded to testing had a high probability of success. It was determined that all 9 teams were ready and thus, while the 2 alternates could have been ready, they did not proceed. The 1:20 test provided quantitative data on WEC performance that were used to determine the ACE and HPQ metrics.

Table 1. High level Prize schedule

Phase	Activity	Date
1: Design	Registration	4/15
	Initial Technical Submission	7/15
	Top 20 Qualified Teams Announced	8/15
2: Build	1:50 Scale Testing	11/15 to 12/15
	9 Finalists and 2 Alternates Announced for 1:20 scale testing	3/16
	Test Readiness Review	
3 Test & Evaluation	1:20 Scale Testing in the MASK Basin and Data Analysis	8/16-10/16
	Winners Announced	11/16

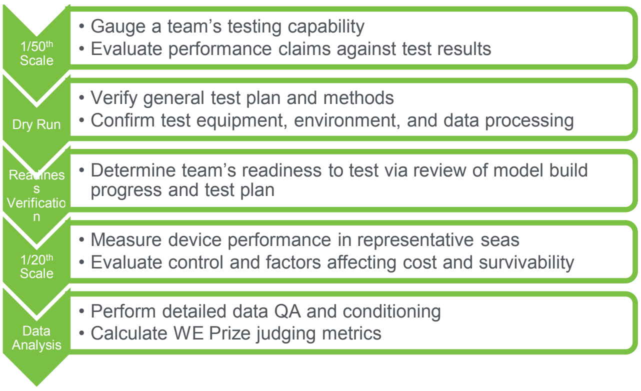

Fig. 1. Schematic showing the flow of Prize testing activities

II. 1:50TH SMALL SCALE TESTING

The 20 semi-finalists were notified by mid-August 2015 of being selected to participate in Phase II. The teams had a three-month window, until November 23rd, to design, build and deliver their model to the small scale test facilities. In parallel, each team developed numerical models of their concepts and simulated their WEC operation. Scoring of the WECs for Phase II was based on four criteria (Table 2), of which testing results are used to calculate the first two criteria.

Table 2. Phase II judging criteria

	Criteria	Weighting
1	Measured net capture width for each wave set	15%
2	Correlation of numerical results with test results	25%
3	Re-evaluation of the TPL	30%
4	Predictions of ACE [1] expected in Phase III.	30%

A total of 31 waves were specified for simulation and testing. The waves are divided in five sets: three sets of seven monochromatic waves with a steepness of 1/80 (Table 3); one set of five monochromatic waves with a steepness of 1/40 (Table 4); and one set of five irregular polychromatic waves (sea states), Table 3. Each of the three sets of monochromatic waves with a 1/80 steepness have the same height and period, but each have a different direction of propagation relative to the WEC. The small scale testing was performed at five different tanks that had different depths that ranged from 1.3 to 5 m (Table 5). To account for the changes in depth, the 26 monochromatic waves were adjusted for each tank by changing the wave height and holding the wave energy fluxes and wave periods constant. The dispersion relation was used to ensure that each team experienced the same wave energy flux for the different water depths. The teams worked with the test facilities, with oversight from the judges, to ensure that the moorings and other components were appropriately scaled for the different tanks.

Table 3. Full Scale (1:1) parameters for Wave sets 1 – 3, the three sets of waves with a steepness of 1/80. Three different wave directions were specified for each combination of wave height, *H,* and period, *T*. Thus, each WEC experienced the same waves from three different approach angles.

Wave Set			T (s)	H (m)
1	2	3		
Direction relative to the forward facing direction of the WEC [deg]				
0	20	50	6	0.7
0	20	50	7.5	1.1
0	20	50	9	1.58
0	20	50	10.5	2.15
0	20	50	12	2.79
0	20	50	13.5	3.48
0	20	50	15	4.19

Table 4. Full Scale (1:1) parameters for wave set 4, the waves with a steepness of 1/40 and wave set 5, the irregular polychromatic waves. These waves were only performed with a heading of 0 deg.

Set 4		Set 5	
T (s)	H (m)	T_P (s)	H_S (m)
6	1.41	5.8	1.75
7.5	2.20	8.95	2.5
9	3.16	15.5	5.2
10.5	4.30	12.5	2.7
12	5.58	11.4	1.35

Table 5. Water depth of the Small Scale Test Facilities.

Facility	Water Depth (m)
University of Maine	5.0
Stevens Institute of Technology	1.97
University of Iowa	3.0
Oregon State University	1.3
University of Michigan	2.93

WEC power takeoff (PTO) design for the 1:50 scale models was limited to a linear response between the dynamic (force, torque, or pressure) and the kinematic (linear velocity, angular velocity, or volumetric flow rate) components of power. For testing, different PTO settings could be specified for each wave type but the settings could not change during a run – adaptive control was not allowed [1]. For criteria 1, the net capture width was calculated for each set of waves by summing the capture widths in that set:

$$NCW_j = \sum_{i=1}^{n} \frac{\sum_{k=1}^{m} \bar{P}_k^i}{J_i}$$

where NCW_j is the net capture width for wave set j, n is the number of waves in wave set j, m is the number of PTOs, $\bar{P}_k^i$ is the average absorbed power for PTO k during wave i, and J_i is the wave energy flux for wave i.

The correlation, criteria 2, was estimated with the correlation coefficient calculated between the simulated and measured magnitude of the response amplitude operators (RAOs) for the six degrees of motion of each body (surge, sway, yaw, roll, pitch, and heave) and the kinematic and dynamic components of power. RAOs were calculated for each of the four sets of monochromatic waves and for each of the five polychromatic waves, yielding a total of nine RAOs for each of the eight response variables. Each set of monochromatic waves yielded one RAO for each response variable:

$$H_i(f_r) = \frac{S_i(f_r)}{\zeta_i(f_r)}.$$

where f_r denotes the frequency of monochromatic wave *r*, $H_i(f_r)$ is the RAO for the monochromatic wave set *i* at a wave frequency f_r, $S_i(f_r)$ is the square root of the variance of the response variable and $\zeta_i(f_r)$ is the square root of the variance of the wave height.

III. 1:20TH SMALL SCALE TESTING

Nine finalists were notified on March 1, 2016 of being selected to participate in the Phase III testing at the MASK basin. The teams then had until July 18 to design, build, and deliver their 1:20 scale model to the MASK. Unlike the smaller scale tests, there was no limit placed on the WEC controller. All controller software was required to be submitted on August 1st to ensure equal development time for all teams.

The MASK is an indoor basin having an overall length of 360 feet, a width of 240 feet and a depth of 20 feet except for a 35-foot deep trench that is 50 feet wide and parallel to the long side of the basin (Fig. 2). The basin is spanned by a 376-foot bridge supported on a rail system that permits the bridge to transverse to the center of the basin width, as well as to rotate up to 45 degrees from the centerline. The wavemaker system consists of 216 paddles. There are 108 paddles along the North edge of the basin, 60 paddles in a ninety-degree arc, and 48 paddles along the West edge of the basin. The large number and orientation of the wave makers allows for a wide range of multi-directional polychromatic waves to be generated, yielding capabilities to produce complex waves. The 0 and -70 degree wave directions are shown in Fig. 3.

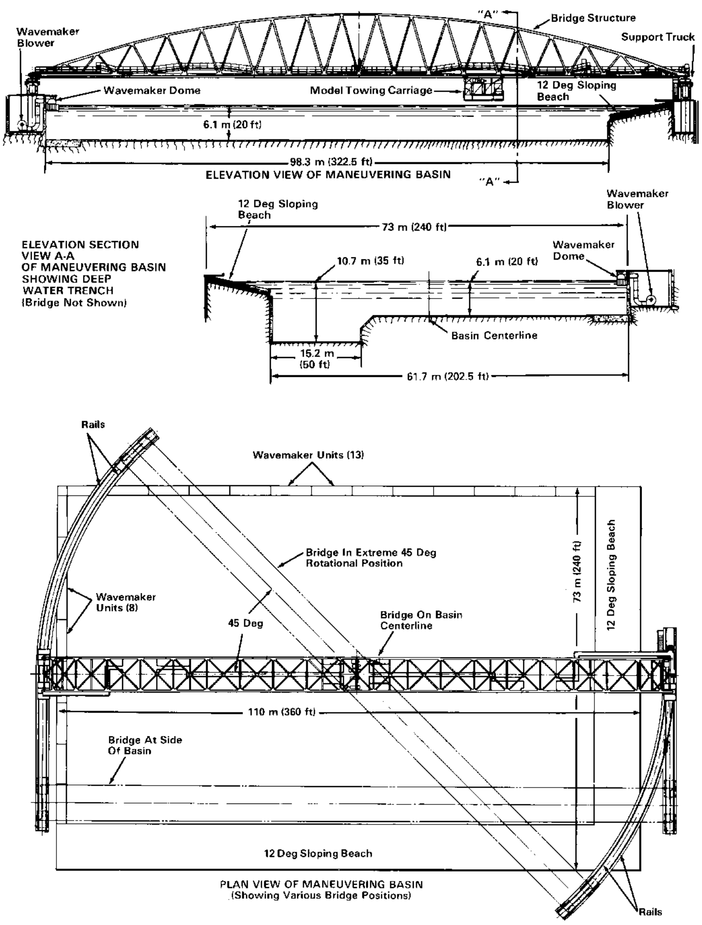

Fig. 2 General Schematic of bridge and MASK basin

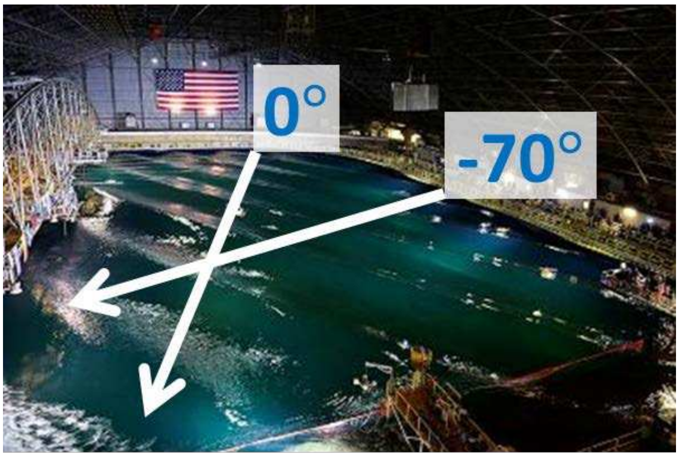

Fig. 3. The MASK basin with arrows depicting the direction of wave propagation

Each team had two consecutive weeks at MASK. During the first week, each team assembled their WEC outside the basin and the Prize Administration Team (PAT) and test lead verified dimensional compliance and sensor performance. During the second week, the WEC was deployed, tested and recovered. Tests were conducted sequentially leading to a 10-week test program.

Scoring for Phase III was solely based on the Hydrodynamic Performance Quality, HPQ, metric. Only teams that met or exceeded the ACE threshold of 3 m/$M had HPQ evaluated. HPQ can be visualized as the ACE score weighted by the device performance during testing in the following areas:

- station keeping,
- mooring loads,
- peak to average absorbed power,
- absorbed power in realistic (bimodal) seas
- PTO behavior, and
- control effort

Details of how the HPQ and ACCW were calculated can be found in [1] and [2], and details of the sea states tested in the MASK basin can be found in [3] and [4].

A. Test Waves

Each WEC was subjected to ten different irregular wave states with the parameters for each wave given in Table 6 [4]. A JONSWAP spectral representation was used to specify the distribution of wave energy with frequency for each of the waves. The energy capture for each device was calculated from the six unidirectional long crested irregular wave states (IWS) that are representative of the west coast of the United States, including Alaska and Hawaii [3,4]. The HPQ was calculated from all 10 sea states, including two bi-modal and multi-directional "realistic wave states" (RWS) and two storm "large irregular wave states" (LIWS). The IWS sea states were assigned a JONSWAP gamma value of 1 for each of the spectra (e.g., a Bretschneider spectrum), the LIWS spectra used gamma = 3.3 (more peaked), and the RWS spectra used gamma = 2.

Table 6. Parameters for the ten sea states at full scale. Direction is specified relative to the forward facing direction of the WEC [deg] and spreading is based on $\cos^{2s}$

Wave Designation	T_P (s)	H_S (m)	Dir (deg)	s
IWS 1	7.31	2.34	10	none
IWS 2	9.86	2.64	0	none
IWS 3	11.52	5.36	-70	none
IWS 4	12.71	2.05	-10	none
IWS 5	15.23	5.84	0	none
IWS 6	16.50	3.25	0	none
LIWS 1	13.9	7.9	-30	3
LIWS 2	11.2	9.2	-70	7
RWS 1	14.38	1.52	-70	7
	7.18	2.16	0	10
RWS 2	14.83	1.59	-70	7
	8.65	1.30	-10	10

All WECs were moored so that they had the same undisturbed location in the wave basin, centered underneath the carriage. Prior to testing, the wave maker was tuned so that each wave spectrum closely matched the spectrum of the specified sea state within the limits of the wave maker. To do this, an array of 12 ultrasonic wave probes were located underneath the carriage and judiciously placed to cover the range of expected WEC positions that may occur during testing. These 12 probes were removed during testing because the WEC and supporting wiring would interfere with measurement. Thus, three other sets of five wave probes were positioned upstream to provide wave measurement during testing. These 15 probes were located at least 17 m from the carriage so that the wave field would be minimally affected by the WEC under test. Time series of wave height were simultaneously recorded at 50Hz by all 27 wave probes during the calibration runs – no WEC was in the water during the calibration runs. The 12 wave probes under the bridge provided the calibration data and the 15 upstream probes measured the baseline wave fields used for test data QA. For repeat runs, the wave spectra were virtually identical. To quantify the spatial variability of the wave field within the test area, for each of the 10 test sea states, the spectra for each of the 12 wave probes were calculated. The spectra from the 12 wave probes and the average spectra, along with the specified spectra are shown for four of the 10 sea states in Fig. 4 to Fig. 11 – one small, one medium, one storm, and one multi-directional sea state.

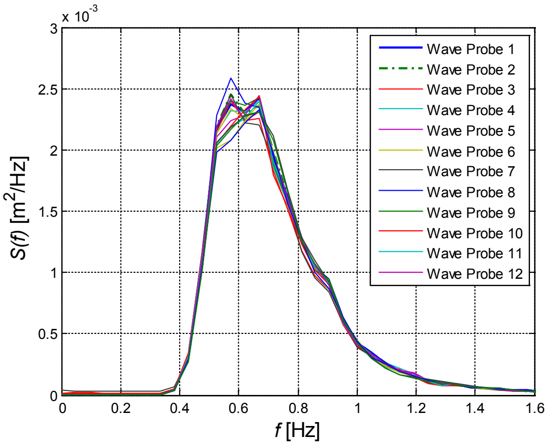

Fig. 4. The spectra for all 12 calibration wave probes for IWS 1

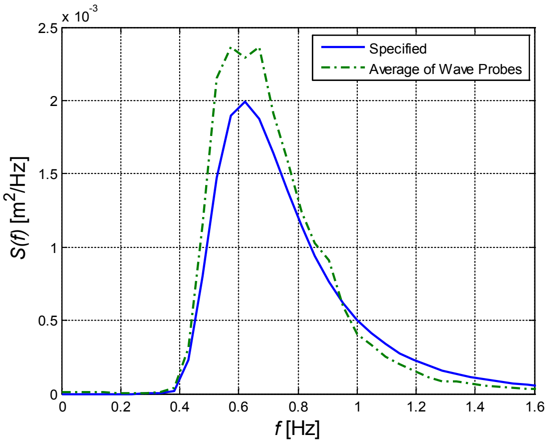

Fig. 5. The average spectra for all 12 calibration wave probes and the specified JONSWAP for IWS 1

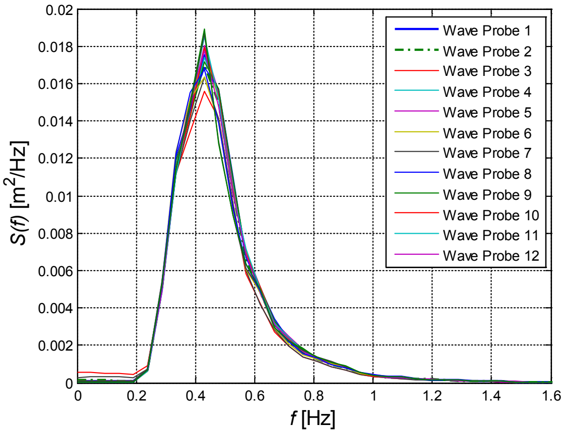

Fig. 6. The spectra for all 12 calibration wave probes for IWS 3

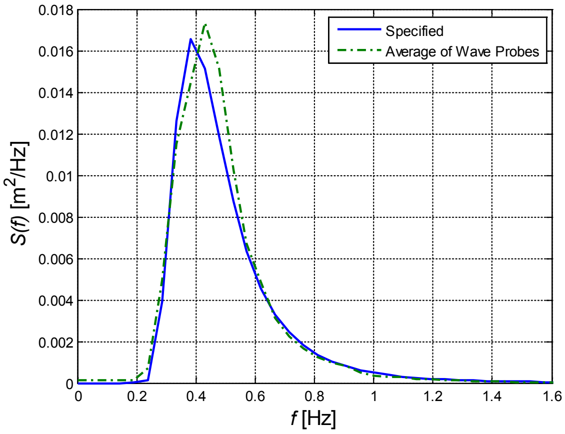

Fig. 7. The average spectra for all 12 calibration wave probes and the specified JONSWAP for IWS 3

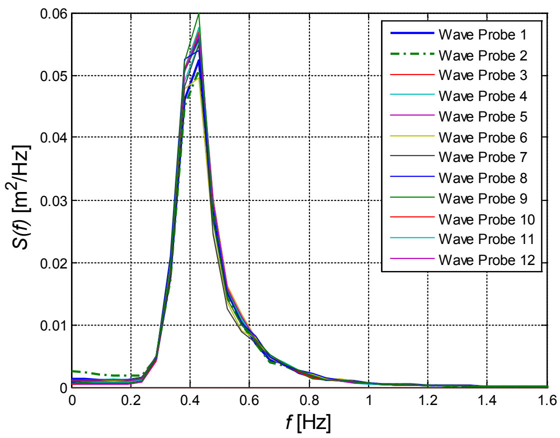

Fig. 8. The spectra for all 12 calibration wave probes for LIWS 2

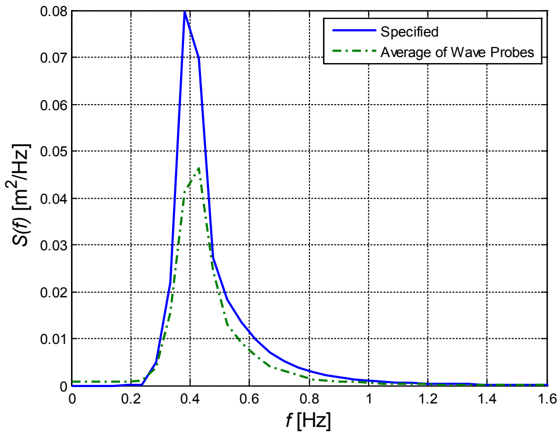

Fig. 9. The average spectra for all 12 calibration wave probes and the specified JONSWAP for LIWS 2

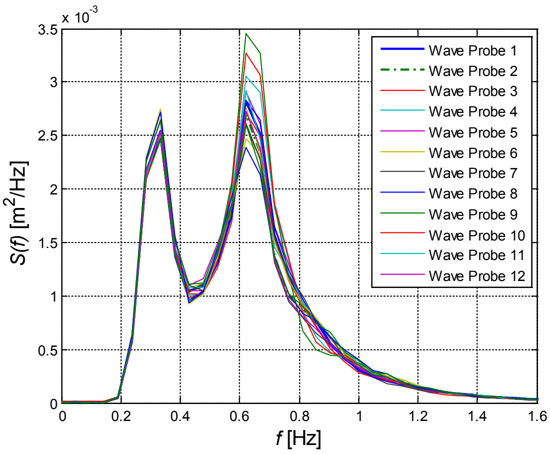

Fig. 10. The spectra for all 12 calibration wave probes for RWS 1

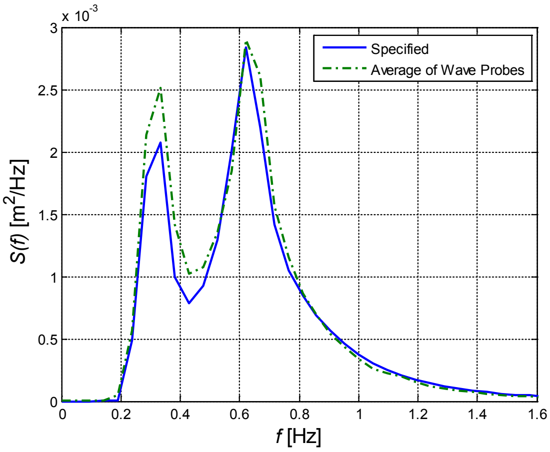

Fig. 11. The average spectra for all 12 calibration wave probes and the specified JONSWAP for RWS 1

The significant wave height, H_S , the wave energy flux, J, and the wave energy period, T_E were calculated for each wave probe and each test wave using:

$$H_S = 4\sqrt{m_0}$$

$$J = \rho g \sum_{k=f_0}^{f_N} S(f_k) c_g(f_k) \Delta f$$

$$T_e = \sqrt{\frac{m_{-1}}{m_0^i}}$$

where $S(f_k)$ is the spectral density at frequency f_k, $c_g(f_k)$ is the group velocity at frequency f_k, Δf is the frequency resolution of the spectra, g is the gravitational constant, ρ is the density of water, and the spectral moment is:

$$m_j = \sum_{k=f_0}^{f_N} f_k^j S(f_k) \Delta f$$

For each of the 10 sea states, the average value of the 12 wave probes and the standard deviation between the individual values of the wave probes were calculated, H_S , J, and T_E (Table 7). The typical standard deviation of the significant wave height to average significant wave height for each wave set was less than 1% with a maximum value of 1.6%. The wave energy flux and period also showed similar consistency within the test area with typical standard deviation to average being less than 1.5% and 1.6%, respectively. The wave field was consistent throughout the test area under the carriage and the wave makers reproduced the specified spectra for all but the storm waves.

Table 7. The average and standard deviation of the wave height, energy flux and energy period within the test area for all 10 test sea states.

Wave Designa-tion	$\overline{H_S}$ (m)	$\sigma_{\overline{H_S}}$ (m)	$\overline{J}$ (W/m)	$\sigma_{\overline{J}}$ (W/m)	$\overline{T_E}$ (s)	$\sigma_{\overline{T_E}}$ (s)
IWS 1	0.125	0.0009	11.1	0.145	1.49	0.033
IWS 2	0.142	0.0006	18.5	0.148	1.90	0.004
IWS 3	0.277	0.0039	84.6	0.921	2.27	0.087
IWS 4	0.108	0.0007	13.9	0.146	2.40	0.005
IWS 5	0.318	0.0023	158.6	2.49	2.99	0.019
IWS 6	0.165	0.0014	45.4	0.776	3.13	0.004
LIWS 1	0.391	0.0055	217.7	5.19	2.83	0.061
LIWS 2	0.411	0.0046	193.6	3.201	2.47	0.117
RWS 1	0.138	0.0022	18.7	0.389	1.98	0.0251
RWS 2	0.101	0.0003	12.4	0.108	2.40	0.016

Equitable testing between teams requires that all waves are repeatable. Therefore, for each sea state, the same wave parameters and phases were used for all tests to ensure each team experienced the same wave time series. Comparing wave measurements for four random teams using the capacitive wave probes located 17 m ahead of the WEC test area demonstrates that the waves are repeatable between tests, (Fig. 12 to Fig. 15). The correlation coefficient between the wave time series measured for the four different teams was typically great than 0.9. The spectra for all four teams were in very close agreements. The WECs were in the water and operating, thus any discrepancy is likely due to the WECs influence on the wave field and measurement error; during calibration runs, wave spectra for repeated waves were identical.

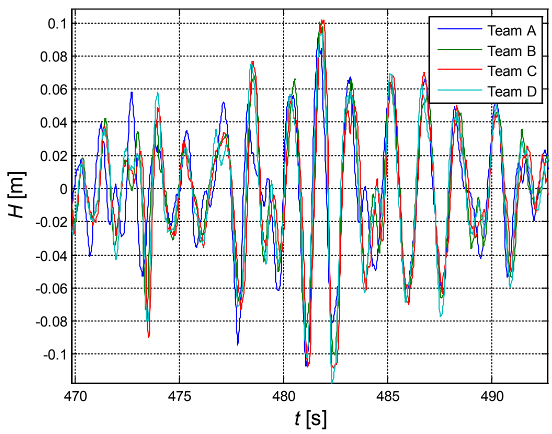

Fig. 12. Time series of the same IWS 1 wave for 4 different teams

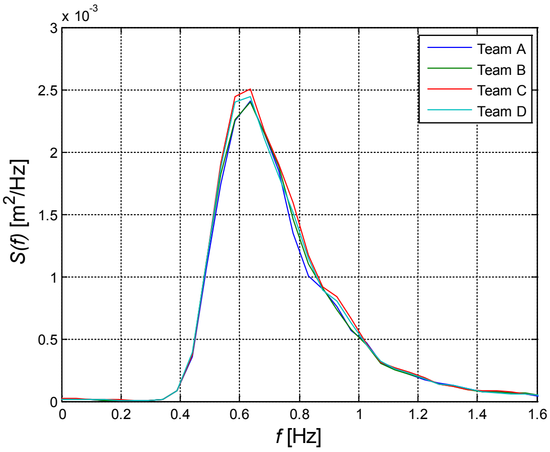

Fig. 13. Spectra of the same IWS 1 wave for 4 different teams

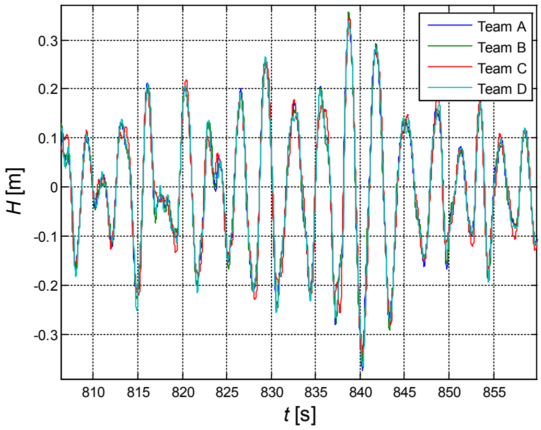

Fig. 14. Time series of the same LIWS 1 wave for 4 different teams

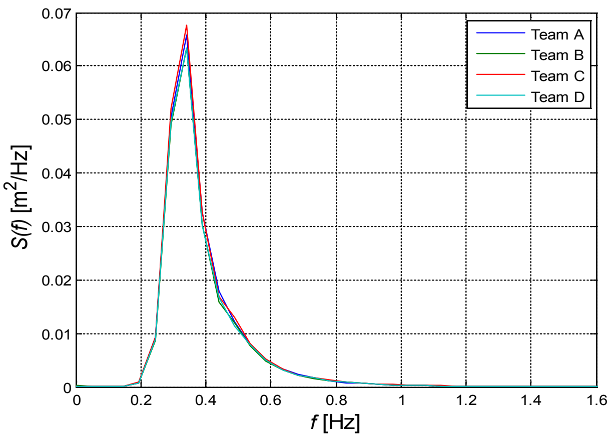

Fig. 15. Spectra of the same LIWS 1 wave for 4 different teams

B. Testing

Each test run was about 50 minutes with 10 - 20 minutes allocated between runs for basin settling and to allow configuration changes. The schedule of events is given in Table 8. The tuning stage allowed teams to adjust their control settings or allow their adaptive controller to self-tune. Thereafter, teams could not interact with their WEC. Teams could also elect to skip this step. The 25 minute interval for testing provided a sufficient window to ensure stationarity.

Table 8. Breakdown and duration of each wave test

Event	time from t = 0 (start of test)
Start-up (time for waves to fully develop)	0 – 5 min
Optional Tuning (teams tune their controller and PTO settings for the waves)	5 - 15 min
Testing (data to be used for analysis)	15 – 40 min
Basin Settling, Re-Configuration as needed, Data Checks	40 – 60 min

A 25 minute analysis window was chosen to ensure stationarity in the wave field statistics regardless of the time span of the analysis window. The significant wave height, wave energy flux and wave energy period were calculated for each sea state at 3 different 25 minute windows, each starting 5 minutes apart from each other – the first started at 5 minutes, the second at 10 minutes and the third at 15 minutes. The values for $\overline{H_S}$ and T_E were typically less than 1% for the different windows while the values for $\bar{J}$ were typically less than 3% (Table 9).

Table 9. The average and standard deviation of the wave height, energy flux and energy period within the test area for all 10 test waves calculated for the three 25 minute window data sets with start times staggered by 5 minutes.

Wave Designa-tion	$\overline{H_S}$ (m)	$\sigma_{\overline{H_S}}$ (m)	$\bar{J}$ (W/m)	$\sigma_{\bar{J}}$ (W/m)	$\overline{T_E}$ (s)	$\sigma_{\overline{T_E}}$ (s)
IWS 1	0.123	0.0012	10.7	0.254	1.48	0.008
IWS 2	0.139	0.0029	17.7	0.665	1.90	0.007
IWS 3	0.273	0.0022	82.0	0.975	2.27	0.006
IWS 4	0.109	0.0003	14.2	0.222	2.43	0.024
IWS 5	0.319	0.0027	159.8	4.42	3.04	0.032
IWS 6	0.166	0.0015	46.0	1.39	3.19	0.035
LIWS 1	0.392	0.0052	216.5	6.68	2.83	0.011
LIWS 2	0.371	0.0019	157.1	1.411	2.41	0.003
RWS 1	0.138	0.0004	18.5	0.178	1.98	0.016
RWS 2	0.101	0.0010	12.4	0.347	2.43	0.028

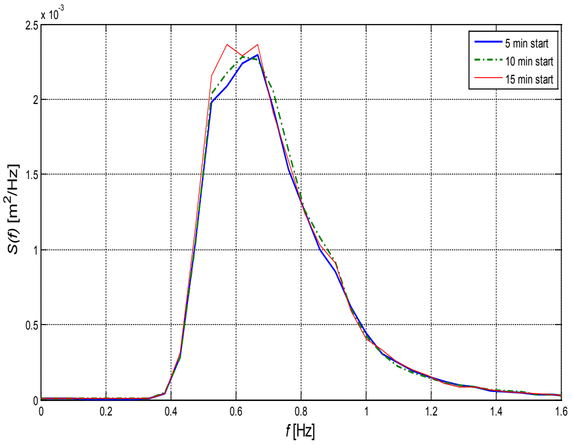

Fig. 16. The wave spectra for the IWS 1 for the three 25 minute window data sets with start times staggered by 5 minutes.

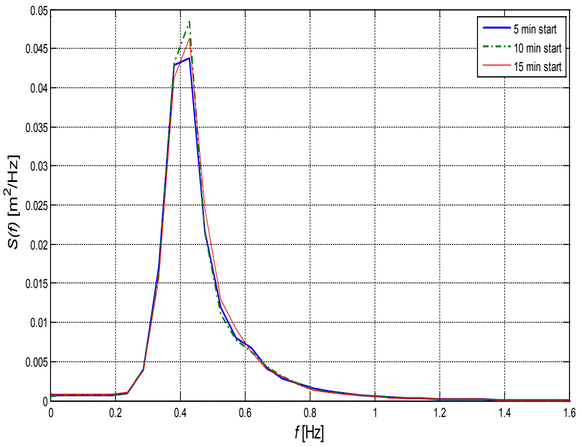

Fig. 17. The wave spectra for the LIWS 2 for the three 25 minute window data sets with start times staggered by 5 minutes.

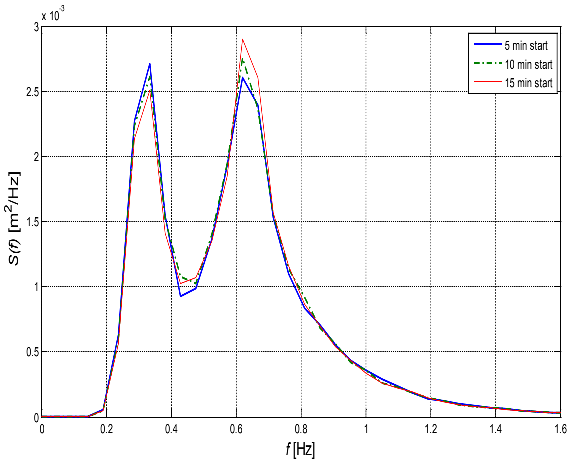

Fig. 18. The wave spectra for the RWS 1 for the three 25 minute window data sets with start times staggered by 5 minutes.

C. Data Acquisition, Sensors and Data Quality Assurance

The measurements used to judge the teams consisted of wave height, mooring loads, PTO variables and device motion. The wave measurements were provided by sets of acoustic and capacitive wave sensors located upstream of the WEC test station at 0 deg and -70 deg. A National Instruments Compact RIO (primary cRIO) data acquisition system was used to sample the PTO and mooring load sensor at 100 Hz. A natural point tracking system (NPTS) was used to track the motion of each body in the WECs at 100 Hz. The wave probes were on separate cRIO systems. The primary cRIO interfaced with the NPTS and the wave DAQs to ensure tight data synchronization (Fig. 19). Data streams were fed from the primary cRIO to the team if they needed the data to support their control. The Prize recommended that each team have sensors with a NIST (or equivalent) traceable calibration. For sensors without NIST traceable calibration, the Prize asked team to have third party calibrations performed to ensure sensor accuracy. During the first week of testing, the Prize performed spot checks on every team provided sensor to ensure calibration certificate validity and third party calibrations were accurate.

Given that each team had only one week to deploy, test, and recover, and that the test schedule was tight, it was critical to ensure that all sensors were performing properly and to identify any issues as they occurred, instead of waiting for post-processing. This methodology allowed issues to be addressed as they were identified so tests could be repeated as needed; thus, each team had the best possible opportunity to complete all test runs with a full suite of working sensors.

Data were recorded on the Carderock DAS for each test then, at the end of the run, data were recorded to an optical disc and given to the data analyst. The Carderock DAS was able to display time series of all individual channels and the calculated power, in engineering units, in real time (Fig. 19). Between each run, the data analyst processed the data and performed a quality assurance review. The QA consisted of several checks: 1) all channels were automatically checked to identify NaNs, repeated values, and empty data streams, 2) the time stamp was reviewed to ensure measurement continuity and that the DAS did not freeze or skip measurements (Fig. 20), 3) wave time series were reviewed against threshold values and wave statistics ($\overline{H_S}$ $\bar{J}$, and T_E) and spectra were compared with the theoretical and baseline (calibration) spectra (Fig. 21), 4) kinematic, dynamic, and calculated power time series were reviewed against threshold values for all PTOs (Fig. 22), 5) mooring load time series were reviewed against threshold values for all PTOs and peak values were identified for the HPQ calculation (Fig. 23 and Fig. 24), 6) time series of PTO travel were reviewed against end stop thresholds and peak values were identified for the HPQ calculation and 7) the time horizontal motions of the primary body were reviewed and peak values were identified for the HPQ calculation. Prior to proceeding to the next test, results were reviewed by the team, the Prize test lead, the data analyst and a prize administrator.

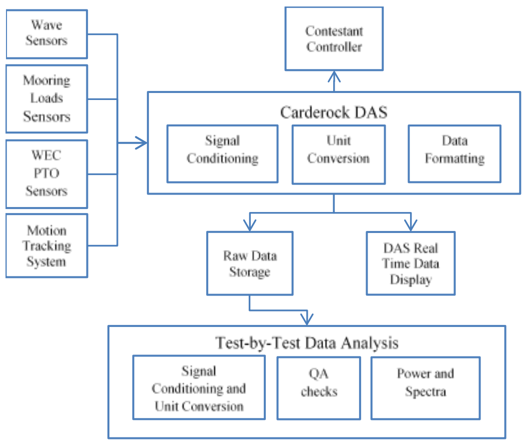

Fig. 19. Schematic showing the data flow from the sensors through the data acquisition system and to the processing and quality assurance that was provided between tests.

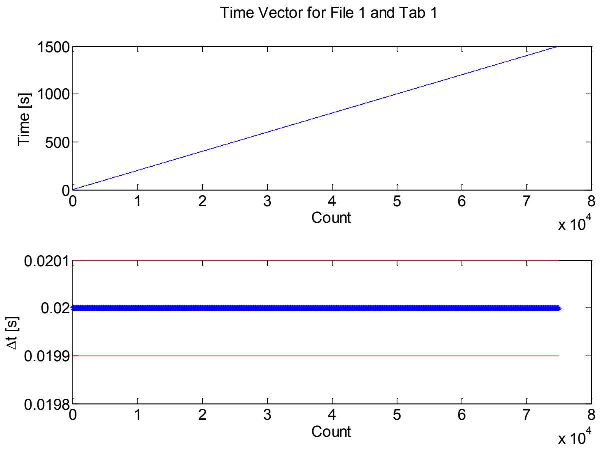

Fig. 20. Time series of the time and discrete time difference used to evaluate the stability of the DAS

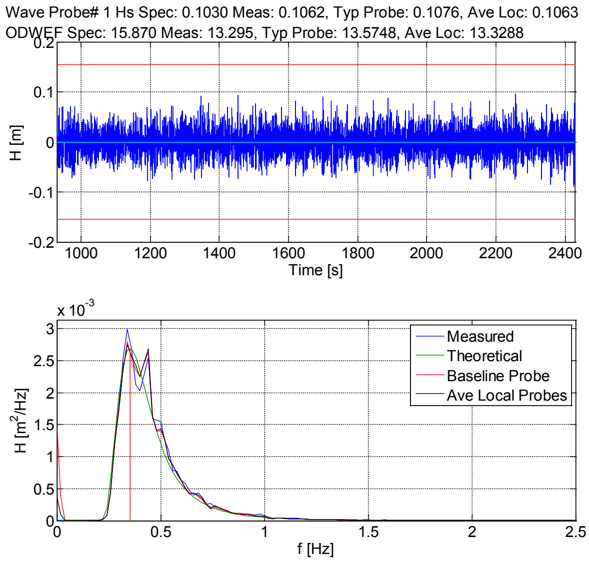

Fig. 21. Time series of the significant wave height and measured, theoretical and baseline probe spectra of the significant wave height. The red bars in the top figure represent the low and high not-to-exceed (threshold) values and the light blue line represents the expected mean.

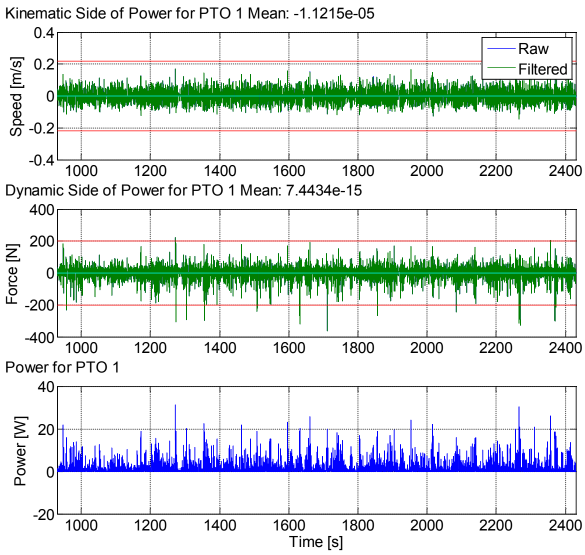

Fig. 22. Time series of the kinematic, dynamic and net power for one PTO. The red bars in the top figure represent the low and high not-to-exceed (threshold) values and the light blue line represents the expected mean.

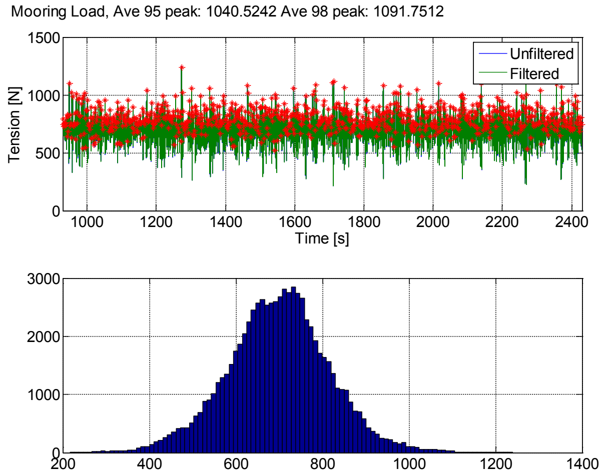

Fig. 23. Time series (top graph) of the mooring load for one mooring line. The red starts are the detected peaks and the bottom graph is the histogram of mooring load peaks

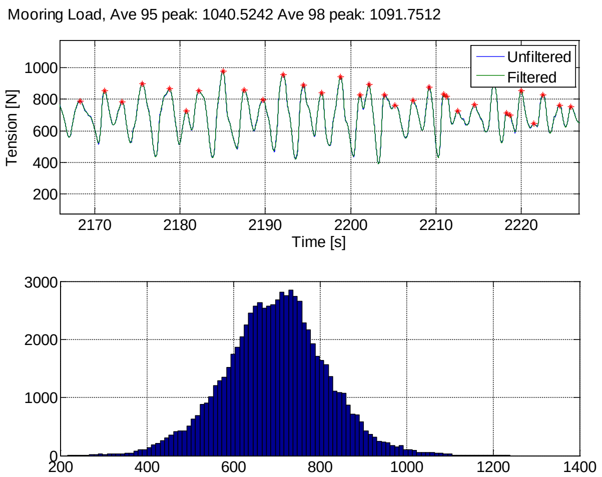

Fig. 24. Zoomed in figure of the time series (top graph) of the mooring load for one mooring line. The red starts are the detected peaks and the bottom graph is the histogram of mooring load peaks

IV. Discussion and Conclusions

This paper provides an overview of the 1:50 and 1:20 scale testing of the DOE's Wave Energy Prize. For the purpose of the prize, a rigorous testing program was established with a necessary incremental flow from concept to 1:20 scale testing to ensure maximum likeliness of success – in the end, all 20 semi-finalists and all 9 finalists were able to test, and most were able to complete all waves and acquire full sets of data. Rigorous testing and data review ensured high quality data which provided a very high confidence in the measurements used for the ACE and HPQ calculations. The scores of the top four teams are shown in Fig. 26.

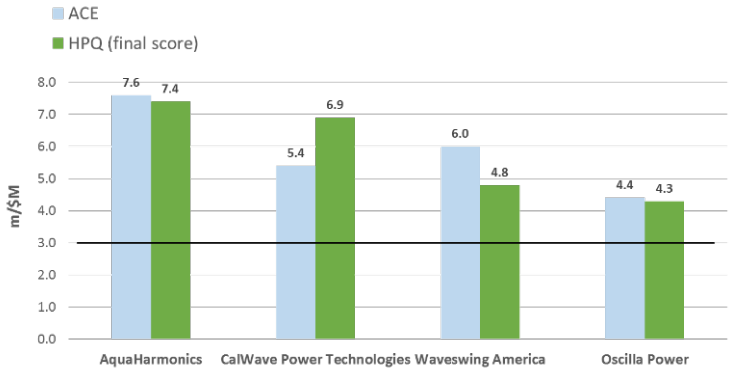

Fig. 25. The ACE and HPQ scores of the top 4 teams that exceeded the base ACE value of 3 m/$M.

A few lessons learned from the tank testing programs are:

- Select high-quality sensors and data acquisition components. Testing is expensive and investing in good measurement hardware reduces failures and gives high confidence in the measurements
- Fully test all hardware and software in the exact configuration it will be used. Do this well before testing to ensure sufficient time to solve any issues.
- Meet regularly with the teams, test leads, data analysts, and project leads to plan all details of testing (assembly, transition to tank, testing, and removal disassembly).
- Performing test readiness reviews are critical to set intermediate milestones and to ensure that everyone (teams, test facilities, data analysts, and administrators) are ready for testing.
- Real-time data QA is critical (even for non-Prize tests) to identify and fix any issues while tests can still be repeated. This proved critical – in several instances sensor failure or device performance issues were identified and quickly fixed.

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Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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