

EARLY RESEARCH EFFORTS AT THE NAVY'S WAVE ENERGY TEST SITE

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INTRODUCTION AND BACKGROUND

The United States' first grid-connected wave energy test site is being developed off the coast of the island of Oahu, in Hawaii. The site, known as the Hawaii Wave Energy Test Site (WETS), is located on the windward (east) side of the island at Marine Corps Base Hawaii (MCBH), at Kaneohe, as shown in Figure 1. The site infrastructure is being built by the US Naval Facilities Engineering Command (NAVFAC) as a means of examining the potential of wave energy to address the energy goals of the Navy. Through a cooperative effort between the Navy and the US Department of Energy (DOE), the site will host companies seeking to test their pre-commercial wave energy conversion (WEC) devices in an operational setting and advance their device technology readiness level. Now fully permitted and consisting of three berths, at water depths of 30m (in place), 60m, and 80m (cabled to shore in spring 2015), all within about 2 km of shore, the site will be capable of hosting point absorber and oscillating water column WEC devices up to a peak power of 1 MW.

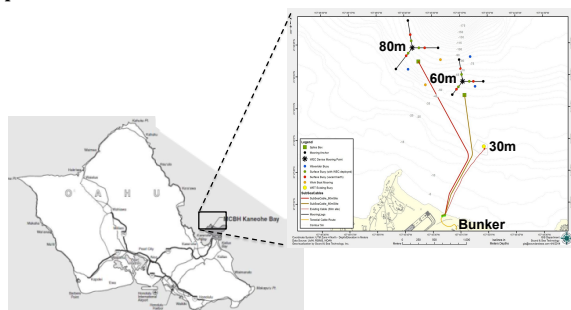


FIGURE 1. LOCATION OF THE WAVE ENERGY TEST SITE (WETS) OFF OAHU, SHOWING THE CONFIGURATION OF THE THREE TEST BERTHS.

Companies interested in testing their devices at WETS will compete for federal funds to do so through either a DOE Funding Opportunity Announcement or a Navy Broad Agency Announcement. A pair of developers for each of the two deep berths has been identified through these processes to date, with anticipated deployments in 2015 through mid-2018. Additional funding opportunities are anticipated. Near-term WEC deployments expected at this writing include Northwest Energy Innovations (NWEI) Azura in April/May 2015 and Fred.Olsen Energy Lifesaver in June 2015. Columbia Power Technologies StingRay, Ocean Energy, USA oscillating water column device, and NWEI's grid-scale device will follow in subsequent years at dates to be determined in consultation with DOE and the Navy.

The Hawaii Natural Energy Institute (HNEI), at the University of Hawaii at Manoa (UH), is supporting NAVFAC and DOE testing at WETS in three key areas: 1) environmental impact monitoring, 2) independent WEC device performance analysis, and 3) development of operational and maintenance protocols. Environmental monitoring will consist of ongoing measurements of device acoustic signature, device and power cable electromagnetic fields (EMF), and possible changes in device/mooring-induced sediment transport, seawater chemistry, and the ecological environment. HNEI will independently assess device performance through robust wave environment measurements using Waverider buoys and an ADCP, daily wave forecast modeling, comprehensive device power output monitoring and analysis, and regular diver and ROV inspections of the deployed devices and associated mooring and cabling infrastructure. An

additional HNEI effort is aimed at utilizing the data from WETS to advance geophysical fluid dynamics-based models of device performance to guide design improvements.

A key focus at WETS is on reducing the considerable costs to developers associated with at-sea testing of WEC devices. The regular device and mooring inspections mentioned above are an important aspect of this. Additionally, HNEI plans to contract with a local ocean engineering company to provide a site-dedicated support vessel, outfitted with dive and ROV facilities, an A-frame, and workspaces for use by WEC developers and UH scientists/engineers. To reduce mobilization costs and shorten emergency response time, this platform will be kept at a state marina within an hour's transit from the site. Further, a limited amount of emergency maintenance response will be provided to tenants at WETS, furthering HNEI's ability to fully document device reliability issues and develop operational and maintenance protocols for DOE and the Navy. Developers will remain responsible for major emergency responses, as well as WEC device deployment and recovery.

SITE CHARACTERIZATION FINDINGS

Prior to funding companies to test at the new deep berths at WETS, the Navy undertook an environmental assessment (EA). That process was completed in early 2014 with a finding of no significant impact, and the associated NEPA hold on specified in-water activities has been released. HNEI provided direct support to the process in the form of bathymetric and sediment profiling of the site to guide site design, including cable routing, anchor selection and placement, and wave environment characterization through analysis of Waverider buoy data, wave forecast modeling, wave hindcast database development, and weather/current data.

The ocean bottom in the vicinity of WETS is a combination of rock, sand, and coral. Based on the bottom data collected by HNEI, the site designers (Sound and Sea Technology [1], for the Navy) were able to identify suitable areas of thick sand to support the emplacement of drag embedment anchors for the moorings at 60m and 80m. The data were also used to identify cable paths that would minimize any impact on local coral ecosystems, resulting in the site layout shown in Figure 1. A representative leg of the resulting mooring design is shown in Figure 2, while a plot of the bathymetry and bottom composition, with yellow and red areas depicting thicker deposits of sand, is shown in Figure 3.

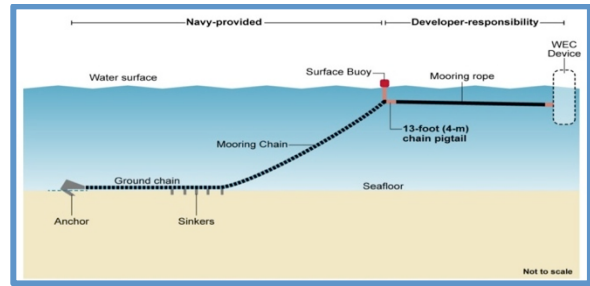


FIGURE 2. ONE LEG OF THE THREE-POINT MOORING SYSTEM UTILIZED AT WETS.

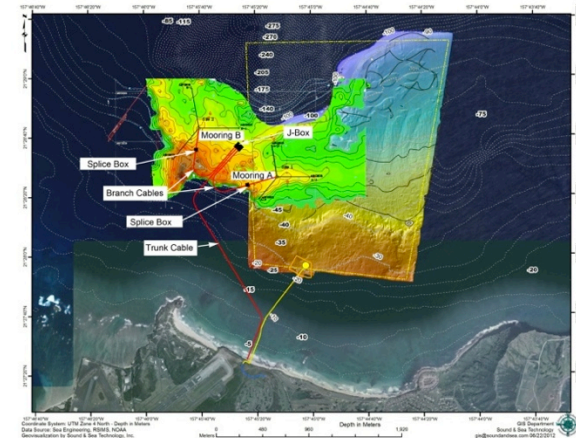


FIGURE 3. WETS BOTTOM PROFILE, SHOWING PLACEMENT OF NEW DEEP MOORINGS IN AREAS OF THICKER SAND DEPOSITS.

While other areas of the world have higher mean and peak wave conditions than those experienced at WETS, the site is well suited as a location to host wave energy testing. The wave environment is characterized by a long-term annual average power flux of 11-18 kW/m, with a significant number of daily averages exceeding 30 kW/m each year, and regular occurrence of much higher hourly averages. A predominance of trade wind driven waves occurs throughout the year, with occasional long-period swells, especially from the north in winter. Despite this reliable wave energy, relatively quiet periods are likely throughout the year, providing good year round access to WEC devices.

A 34-year hindcast database was recently created at the University of Hawaii for sites around the Hawaiian Islands. The hindcast methodology, as described in Stopa, et al. [2] and Li & Cheung [3], incorporates high-resolution meteorological forcing in WAVEWATCH III® and SWAN wave models, customized with the coastline and bathymetry of Hawaii. From this analysis, monthly averages of significant wave height and wave power at WETS are shown in Figure 4. Hourly averages in two individual years, 1985 and 1995, were plotted to represent the range of conditions possible at WETS, as shown in

Figures 5 and 6, respectively. Note the peak wave power of 167 kW/m in 1985 (the highest peak in any year in the database) and 88 kW/m in 1995 (the lowest peak in any year). These events corresponded to significant wave heights of 5.7m and 3.5m, respectively. Finally, measured significant wave heights from the Kaneohe Bay Waverider buoy, since its deployment in October 2012, are plotted in Figure 7. It is clear from these plots that while WETS has a lower annual mean wave power than some other existing and proposed wave energy test and deployment sites, WEC developers must be prepared for monthly mean wave power flux of 20 kW/m, with peak months over 50kW/m, and significant wave heights exceeding 5m, occasionally occurring in fall/winter months.

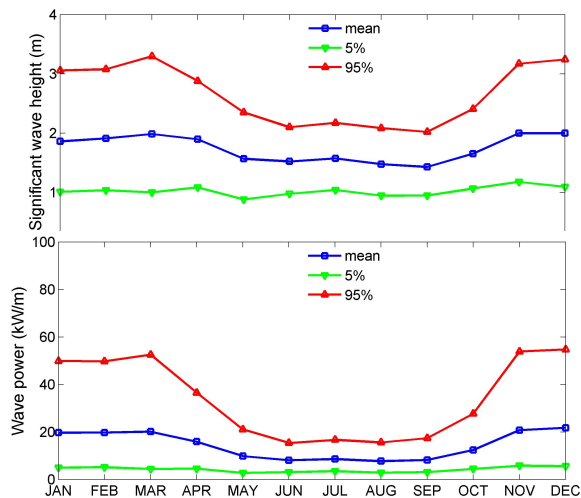


FIGURE 4. MONTHLY AVERAGES OF SIGNIFICANT WAVE HEIGHT (TOP) AND WAVE POWER (BOTTOM) AT WETS.

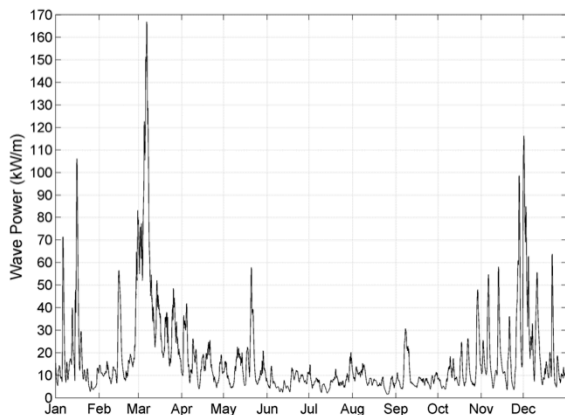


FIGURE 5. HOURLY AVERAGED WAVE POWER AT WETS DURING 1985.

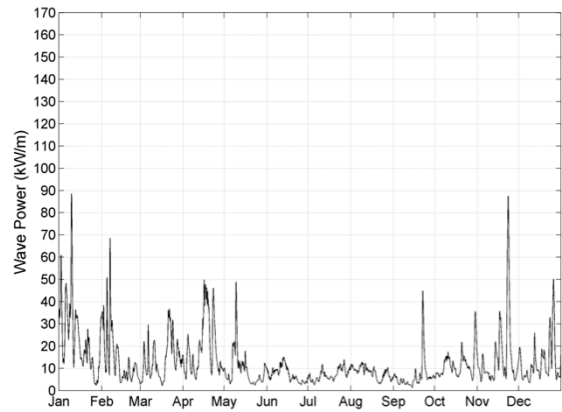


FIGURE 6. HOURLY AVERAGED WAVE POWER AT WETS DURING 1995.

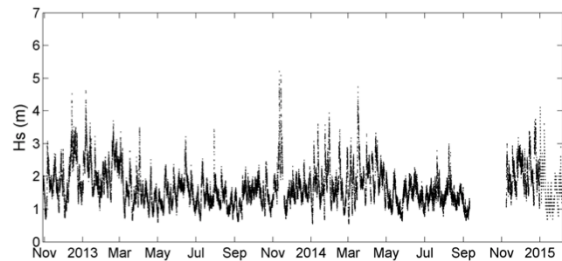


FIGURE 7. SIGNIFICANT WAVE HEIGHT AT THE KANEOHE BAY WAVERIDER BUOY, FROM DEPLOYMENT IN OCTOBER 2012 TO JANUARY 2015.

PLANNED HNEI RESEARCH SUPPORT AT WETS

HNEI research in support of DOE and Navy-funded WEC testing at WETS will consist of work in three categories: 1) environmental impacts, 2) device performance monitoring and analysis, and 3) operational and maintenance protocol development.

Environmental Impact Measurements

Environmental data collection and analysis will consist of the following: 1) WEC device acoustic signatures, 2) WEC device and submarine power cable electromagnetic fields (EMF), 3) sediment transport, 4) ecological surveys, 5) water chemistry, and 6) marine species monitoring.

Acoustic data will be collected in proximity to deployed WECs on a nearly continuous basis, utilizing an autonomous single hydrophone station associated with each WETS berth. The UH-developed system, acoustic monitoring package – single channel, or AMP-1, is shown in Figure 8. The stations are capable of deployments of up to three months duration (depending on duty cycles and sampling frequency), at which time they will be recovered and redeployed with refreshed batteries and data storage. The positively buoyant systems are designed to keep the hydrophone acoustically decoupled from the bottom and away from the worst of the noise associated with

snapping shrimp prevalent in Hawaiian waters. The devices will be capable of resolving sounds in the frequency range of 20 Hz to 100 kHz. Additional acoustic data will be collected in collaboration with colleagues at the University of Washington, who will periodically deploy a free-drifting device with a hydrophone suspended 1.5m below the surface. All acoustic data will be processed with the primary objective of deriving relevant source levels of sounds coming from the WEC devices and their associated moorings, while also comparing those emissions with ambient noise and other acoustic signals in the area. Variability due to weather conditions, seasonal changes in ambient noise, and other factors will be examined. To obtain ambient conditions prior to WEC deployments, an initial AMP-1 deployment was begun in late January 2015. Preliminary results from this deployment are expected to be available at the time of the 2015 Marine Energy Technology Symposium.



FIGURE 8. UH-DEVELOPED AMP-1 HYDROPHONE STATION.

In collaboration with researchers at Oregon State University, a developmental effort will be undertaken at WETS to gather EMF emission data in association with the devices and their associated submarine power cables. Data will be compared to ambient conditions and other EMF sources in the area. Particular attention will be paid to EMF emissions as a function of the method of power transmission to shore.

The sediment distribution shown in Figure 3 will be periodically reexamined to determine whether the presence of the moorings, or of the devices themselves, has a measurable impact on sediment distribution over time. A combination of core samples and fixed measurement staffs will be used for this purpose. This effort will focus on the new deep berths, as the bottom at the 30m berth consists of limestone only.

Diver surveys begun during past Navy testing with Ocean Power Technologies at the 30m berth will resume under HNEI oversight, utilizing the protocol developed by Navy biologists. The purpose of these surveys will continue to be to monitor the evolution of the local ecology at the site, including fish types and populations, marine growth, and other biological changes over time. During each of these surveys, water samples will be collected at bottom, mid, and upper portions of the water column. These samples will be analyzed

for chemical composition to ascertain any changes over time that may be due to the presence of WEC devices under test.

Although not specifically an HNEI research objective, trained marine species observers will periodically be employed at WETS, per Navy requirements, to monitor and mitigate any impacts on marine mammals (primarily humpback whales and monk seals) and sea turtles. Specifically, observers will be deployed aboard vessels engaged in deployment of WEC devices, and will visually monitor activity at the site from shore on a quarterly basis.

To support HNEI analysis of environmental impacts, developers will be expected to provide daily logs of device operational status in 30-minute intervals.

Device Performance Analysis

HNEI will conduct a multifaceted approach to independent WEC device performance monitoring and analysis. In order to ensure accurate and robust measurement of wave conditions during testing, three Waverider buoys will be deployed. The first of these was deployed in October 2012. Two additional Waveriders will be deployed in mid-2015 to ensure redundancy and provide additional data points in support of testing at the deep berths. Data records from these buoys, with a sampling frequency of 1.28 Hz, are available in 30-minute intervals. Additionally, an up-looking ADCP will be deployed by NREL in conjunction with the upcoming deployment (February/March 2015) of the NWEI device at the 30m berth (sampling frequency of 1 Hz or higher, 30-minute data records). Other ADCPs are possible in the future, in conjunction with deployments at the deep berths.

Wave data from WETS will continue to augment the 34-year hindcast database, which will be available to developers planning WETS testing. Also available to developers (and publicly) is a daily 7.5-day wave forecast. This model, run at UH and forced with high-resolution meteorological inputs, will have the advantage of being calibrated with abundant wave data from the site and should prove valuable for both operational planning and interpretation of performance results.

HNEI will coordinate regular inspections, conducted by marine engineering partner, Sea Engineering, Inc., to assess the durability of both mooring infrastructure and deployed WEC devices. These will be conducted by divers at the 30m berth and with an ROV at the deep berths. In addition to the obvious benefits to both sponsors and developers of conducting such inspections to identify any problems early, HNEI will also be

ideally positioned to analyze the findings and develop maintenance and operational protocols associated with the devices under test.

Essential to success of the test site is an independent analysis of power output. HNEI will utilize wave input and power output data to develop power matrices for each device, in addition to any data collection efforts conducted by the WEC developers. Over the period of a WEC deployment, given the wide range of wave conditions expected at WETS (significant wave height and wave period), increasingly robust plots of device electricity generation as a function of wave input will be achieved, as shown conceptually in Figure 9. To support this independent analysis, WEC developers will provide HNEI with time history records of power output (sampling frequency of 1 Hz or higher, 30-minute intervals) at the generator terminal and at the utility connection.

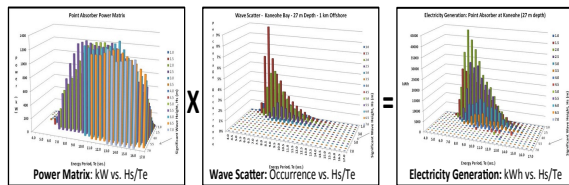


FIGURE 9. ELECTRICITY GENERATION MATRICES WILL BE DEVELOPED OVER TIME FOR EACH DEVICE UNDER TEST.

Another component of device performance research at UH is device and array numerical modeling. In-house and commercially available geophysical fluid dynamics models are being developed/adapted in an effort to more thoroughly understand the performance of the devices under test and provide insights into design alterations that may improve that performance. Additionally, wave array modeling, utilizing such tools as WAMIT, is ongoing, and will benefit from data sets available as a result of testing at WETS. Proximity to the site and the close relationship that UH researchers will enjoy with WEC developers, as well as the unique role HNEI will have as independent performance analysts, will present a unique opportunity to combine theoretical and practical approaches to contribute to the global advancement of wave energy commercial readiness.

Operational Protocol Development

As mentioned previously, HNEI will work with a local marine engineering company, Sea Engineering, Inc., to provide a site-dedicated support vessel. The vessel will be moored a short distance away from the site and provide an important measure of emergency response as well as a critical element in routine support of at-sea

WETS activities, including diver and ROV inspections and maintenance, and HNEI research activities. While this vessel will provide an important asset to facilitate testing at WETS and reduce costs to be borne by developers, it will also allow HNEI to document activities at the site and build an experience base for the development of operational and maintenance (both routine and emergent) protocols.

CONCLUSIONS

Following an extended period of design, environmental permitting, and research planning, the U.S. Navy's Hawaii Wave Energy Test Site is now shifting into its operational phase. Northwest Energy Innovations will soon deploy their device at the existing 30m berth (deployment and early highlights available by the time of the conference) and two additional deeper-water berths will begin hosting WEC developers in 2015. The Hawaii Natural Energy Institute and the University of Hawaii will continue to directly support Navy and DOE objectives at the site and undertake a number of essential research tasks, thus uniquely positioning the institute to make important contributions to the state of readiness of wave energy to address Navy, State of Hawaii, U.S., and global renewable energy needs.

ACKNOWLEDGEMENTS

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