Proceedings of the 13th European Wave and Tidal Energy Conference 1-6 Sept 2019, Naples, Italy

Recent Developments at the U.S. Navy Wave Energy Test Site

Patrick Cross, Krishnakumar Rajagopalan, Andrew Druetzler, Alex Argyros, James Joslin, Even Hjetland, Andrew Stewart

Abstract—**The U.S. Navy's Wave Energy Test Site (WETS) in Hawaii has hosted two wave energy conversion (WEC) devices since its June 2015 commissioning – the Fred. Olsen BOLT Lifesaver and the Northwest Energy Innovations (NWEI) Azura – each for two deployments. Several additional devices will be tested in the coming years, beginning with the Ocean Energy device in summer 2019. The Hawaii Natural Energy Institute (HNEI) provides research and logistics support to WETS. We will provide an overview of three major activities that we have recently undertaken in this capacity. First, we will discuss results from a project in which modifications were made to the hull and float of the Azura, aimed at improving power performance for a second WETS deployment. Second, HNEI undertook a redeployment of Lifesaver beginning in October 2018, with the dual intent of achieving improvements in reliability and power performance, while also conducting an important demonstration of the use of wave power for non-grid applications. HNEI partnered with the University of Washington to integrate their Adaptable Monitoring Package (AMP) into the hull of BOLT Lifesaver. Included for this deployment was a subsea inductive charging capability from WiBotic, Inc.. These systems are powered entirely by electricity generated by the Lifesaver itself. Finally, HNEI has undertaken design improvements for the deeper berth moorings at WETS, with principal engineering guidance from DNV GL. This has included extensive numerical analysis of strength and fatigue aimed at establishing moorings that can persist for as long as possible. The resulting design will be discussed.**

Keywords— **Alternative markets, autonomous systems, Hawaii, moorings, Wave Energy Test Site.**

Fig. 1. Fred. Olsen, Ltd. Lifesaver WEC, at WETS 60m berth in January 2017.

I. INTRODUCTION

THE Hawaii Natural Energy Institute (HNEI) has been providing research and logistics support to U.S. Department of Energy (DOE) and U.S. Navy objectives at the Navy's Wave Energy Test Site (WETS) for the past several years. During this time, two commercial wave energy converter (WEC) developers have deployed their devices at the site – Northwest Energy Innovations (NWEI) and Fred. Olsen, Ltd. The latter device is shown in Figure 1. The NWEI Azura device was deployed at the WETS 30m berth from June 2015 to December 2016, and the Fred. Olsen Lifesaver at the 60m berth from March 2016 to April 2017. These were the first two of approximately eight WECs currently expected to conduct open ocean tests at WETS over the next few years. In both cases, HNEI utilized Navy funds from the Naval Facilities Engineering Command (NAVFAC) to pursue various design changes aimed at improving power performance and survivability. In the case of the Lifesaver, the project included a unique demonstration of the ability of a non-grid-connected WEC

ID: 1575, Track: Wave Device Development and Testing. This work was supported by the Naval Facilities Engineering Command, under NAVSEA contract N00024-08-D-6323/0016, through the Applied Research Laboratory - University of Hawaii.

P. Cross and K. Rajagopalan are with the Hawaii Natural Energy Institute, 1680 East West Road, POST-109, Honolulu, HI 96822 U.S.A. (e-mail: pscross@hawaii.edu, krishnak@hawaii.edu). A. Druetzler is with the Applied Research Lab at the University of Hawaii, 2800 Woodlawn Dr., Honolulu, HI 96822 U.S.A. (e-mail: adruetzl@hawaii.edu).

A. Argyros is with DNV GL/Noble Denton Marine Services, 30 Stamford Street, London, SE1 9LQ. (e-mail: alex.argyros@dnvgl.com).

A. Stewart and J. Joslin are with the Applied Physics Laboratory at the University of Washington, 1013 NE 40th St., Seattle, WA 98105 U.S.A. (e-mail: andy@apl.uw.edu, jbjoslin@apl.washington.edu).

E. Hjetland is with Bolt Sea Power of Fred.Olsen Ltd, Tollbugata 1B, Oslo, Norway (e-mail: evh@fredolsen.com).

to provide power for an onboard environmental monitoring suite and a subsea inductive charging capability. Both redeployments have now been completed and will be discussed in Sections II and III.

Moorings were installed for the Navy in September 2014 for the two deeper berths (60 and 80m water depths) after completion of an extensive environmental assessment. In recent years, it became apparent that certain design improvements were needed to ensure sufficient longevity of these moorings to allow them to host upcoming WEC deployments. HNEI was thus tasked with overseeing a thorough design analysis for Navy and with conducting needed improvements. Sound and Sea Technology (SST) was contracted to lead the design effort, with substantial numerical engineering analysis provided by DNV GL. An exhaustive strength and fatigue analysis was conducted, examining all mooring components, including main chain, joining links, surface floats, and a "no-WEC hawser" system to ensure the moorings are kept in tension when a WEC is not attached. The thought processes and resulting design choices will be discussed in Section IV. For clarity throughout the paper, the layout of the three WETS berths is shown in Figure 2.

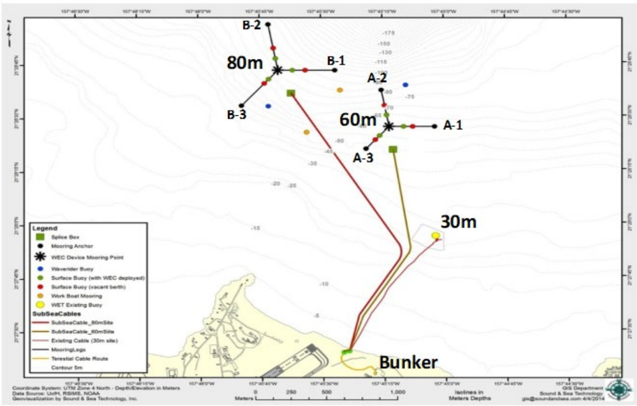

Fig. 2. WETS layout, including designators for the three legs of each of the deep berths, which are referenced in Section IV.

II. Azura Modification and Redeployment

The NWEI Azura was deployed at the WETS 30m test berth between June 2015 and December 2016. While the device performed quite well in terms of survivability (very little intervention needed over the 18-month deployment), its power performance was less than expected. In turn, HNEI funded NWEI to perform modifications to the device and conduct a second deployment in hopes of improving upon the power results. First, a heave plate was added at the base of the device to improve the motion of the float relative to the spar/hull. Second, the float itself was increased in width, such that it no longer fit between the two vertical spars, and extended out from the spars for a greater moment arm. Both modifications were expected to better align device response to the prevailing wave conditions at WETS. The two float shapes are shown in Figure 3.

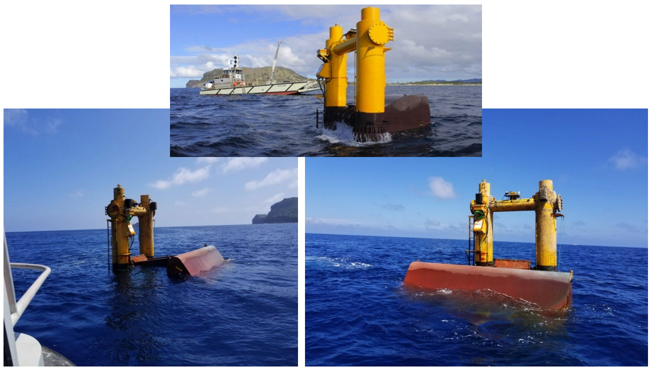

Fig. 3. Baseline (top) and modified (bottom) Azura floats as deployed at WETS. Not visible is the roughly elliptical heave plate added to the base of the modified device.

The modified Azura was deployed at WETS from February to August 2018. Qualitatively, the device motions appeared to change similarly to what was predicted – greater spar stability relative to the float, improved float motion, and less heave of the WEC. Upon analysis of device motions after the deployment [1], this observation was borne out. That is, the hydrodynamic response to the device modifications resulted in motion changes quite similar to those modelled. However, a corresponding improvement in power production was not realized. Extensive analysis of modelled versus observed device motions was carried out by Rajagopalan, et al. [1], with the fundamental conclusion being that the device PTO, which was unchanged between deployments, was unable to adequately respond to the increased torque, and rapid changes in torque, of the modified device. This suggests that changes to PTO properties could result in substantial improvements in power performance for the Azura. NWEI has taken these findings into account in a project they are currently undertaking for the U.S. Department of Energy for a full-scale WEC to be tested at WETS within the next few years. A full treatment of the motion analysis is contained in these proceedings in [1].

III. BOLT Lifesaver Redeployment

During the initial WETS deployment of the Fred. Olsen Lifesaver WEC (see Figure 1), a number of issues related to the moorings were encountered. This device hosts three power take-off (PTO) systems, which consist of direct-drive winches with taut connections to the seabed. In the event of failures of these PTO moorings, the device is also kept on station with a three-leg primary mooring system connected to the WETS mooring hardware. This dual mooring approach is illustrated in Figure 4. In one instance, failures in the primary mooring hawsers resulted in additional stresses on the PTO risers and subsequent failures there, before the primary hawsers could be replaced and the PTOs brought back into operation. The initial motivation for the redeployment discussed here was to address issues related to these mooring systems – for

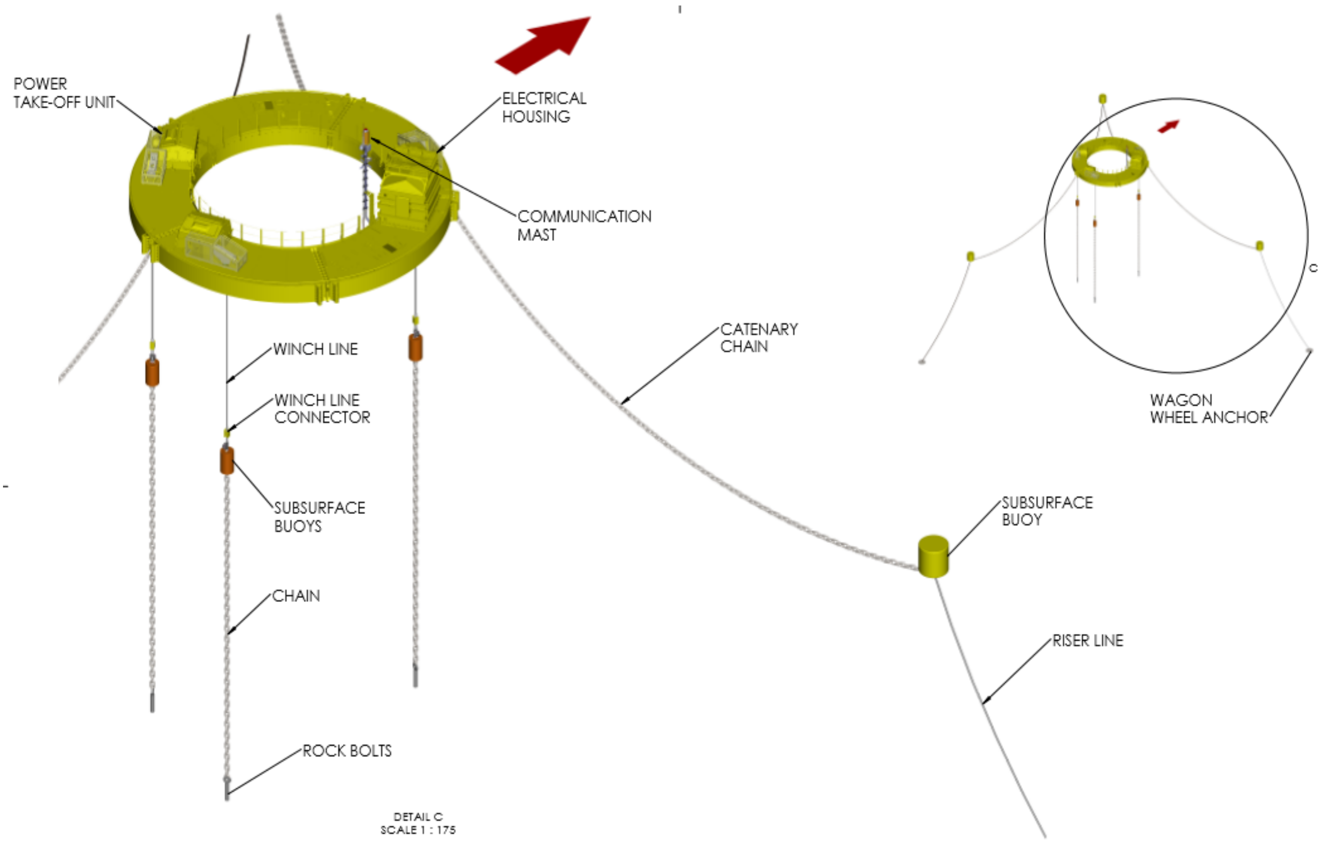

Fig. 4. Mooring systems used during Fred. Olsen, Ltd. BOLT Lifesaver deployment at WETS from October 2018 to March 2019. Note: chain shown in the figure was replaced with VETS-333 nylon line for the hawsers and with Aramid fibre lines in the PTO risers

both greater reliability and improved power performance. During the course of project planning, however, it was decided that the project would also incorporate an important global first by utilizing WEC-generated electricity to power a subsea environmental monitoring suite developed at the University of Washington. This system, the Adaptable Monitoring Package (AMP), consists of active and passive acoustic systems as well as optical cameras illuminated by strobe lights, all controlled by sophisticated onboard processing. For this deployment, the AMP also incorporated an inductive subsea charging capability as a demonstration of relevance to the future charging of unmanned undersea vehicles. As this deployment is unique at WETS in that the WEC is not cabled to shore, all power for the AMP systems was provided by the Lifesaver and onboard battery systems.

1) Lifesaver Mooring System Modifications

To improve on the reliability of the mooring system of the Lifesaver, while also enhancing power performance, HNEI undertook a redesign of both the primary mooring to the Navy-installed anchors at the 30m test berth and the PTO moorings. In this second WETS deployment, the Lifesaver was shifted from the 60m to the 30m berth – primarily to ensure the former's availability for the upcoming Ocean Energy deployment. The key difference between these two berths is that while the deeper berths are characterized by a sandy bottom, the 30m berth consists of a rock seabed with a thin veneer of sand and very sparse coral coverage. The 60m deployment required the use of large gravity anchors for the PTOs, which mandated the use of an expensive heavy-lift vessel. A second issue encountered during the first deployment was the excessive elasticity of the PTO riser lines. As analysed by Fred. Olsen, this had a significantly negative impact on power performance, as riser stretch reduced PTO winch rotation. Finally, there were reliability issues associated with chafing of the thimbles on the hawser lines that kept the Lifesaver connected to the Navy 60m berth moorings, which in one case resulted in a failure of a hawser and associated displacement of the WEC from its central position on the mooring. This appears to have resulted in failures in at least one of the three PTO winch lines.

To address these issues, HNEI worked with Fred. Olsen and Sea Engineering, Inc., with mooring analysis support from DNV GL, to redesign both the primary/storm moorings and the PTO moorings. First, we took advantage of the rocky bottom at the 30m berth to employ a rock bolt anchor system. This eliminated the need for heavy-lift vessels and had minimal impact on the seabed, which proved advantageous in the permitting process. Second, new PTO risers with substantially reduced elasticity (67mm Selantic Subsea Tether SX-82-20000, Aramid fiber by Cortland) were procured. Finally, 63.5mm VETS-333 nylon hawsers, fitted with appropriate roll/circular thimbles to address chafing issues, were used to attach the WEC to the 30m berth subsurface floats.

Another design intent for the second deployment was to reduce the amount of pretension in the storm mooring system to allow for greater freedom of WEC movement relative to the first deployment. Hawser lengths were thus selected to minimize the degree to which the primary/storm moorings restricted Lifesaver's response to the waves (pretension of about 160kg), while ensuring that the storm mooring had sufficient strength to keep the WEC on station in 100-year storm conditions.

The full results of these changes are currently being analysed. However, a few key findings can be reported at this writing. First, the new storm moorings were robust throughout the deployment, including through two consecutive winter storm events with Hs peaking around 5m. The nylon hawsers with roll/circular thimbles appear to have been an effective system for maintaining the device on station. Second, the reduced pretension in the storm moorings and the reduced elasticity of the PTO riser lines did not produce the improvement in power performance expected. Preliminary analysis indicates reduced PTO winch rotation in the same wave climate. Ongoing analysis seeks to understand whether this is from reduced global device motion, or from elasticity in the risers. Device motion data from the deployment will be analysed in an attempt to explain these results and to guide a subsequent deployment of Lifesaver.

2) Integration of Adaptable Monitoring Package

Fig. 5. Fred. Olsen Lifesaver with Wave Adaptable Monitoring Package (WAMP) installed. WAMP is in lowered (operational) position, with support structure to right of white electronics housing.

During the first Lifesaver deployment at WETS, generated power was burned off as heat at sea. This deployment was unique at WETS in that it was not cabled to shore. (Other past and planned WEC deployments will all be connected to the Oahu power grid via cables to shore.) While developing the mooring concept for the second deployment, HNEI worked with the University of Washington (UW) to plan the integration of their Adaptable Monitoring Package (AMP) with the Lifesaver, with the intent of obtaining the power it needed for operation from the WEC itself. Since the Lifesaver hull is fitted with five PTO wells, but only three are occupied for the WETS deployments, the remaining two were available to host the hardware of the AMP sensor package. The UW team worked to develop an AMP that could be mounted above this PTO well and, when in operational position, be lowered through the hull. A housing was developed to sit on the deck of the Lifesaver and enclose all associated electronics and onboard processing. The AMP system, mounted on Lifesaver and deployed at WETS, is shown in Figure 5.

As configured for this deployment, the Wave AMP, or WAMP, consisted of active and passive sonar systems, as well as optical systems supported by strobe lighting – all of which is controlled by onboard processing. The system is designed to monitor marine life activity in the presence of marine energy converters as an important form of monitoring potential impacts of these devices on the environments in which they are deployed. Incorporated into the system for this deployment was a subsea inductive charging capability developed by Seattle-based WiBotic, Inc. This served as a demonstration of the potential for wave energy converters to provide an offshore recharge capability for autonomous systems.

From system start on 13 October 2018 until 28 January 2019, the AMP was powered on for more than 84% of the time. (It is estimated that less than 1% uptime would be achieved over this period on batteries alone.) Approximately 1,152 kWh was received by the AMP from the Lifesaver during that time, with a supplementary 100 kWh from a solar panel mounted on top of the AMP electronics enclosure. Power to the AMP was off for more than one minute due to low wave production on 120 occasions, although during 83 of those the onboard battery bank, charged by WEC production, was able to supply the necessary draw of roughly 600W. Thus, only 37 instances of the AMP needing to power down were experienced over this 3.5 month period – all fairly brief. Lifesaver power production, along with power consumed by WEC auxiliary systems and by WAMP, are shown in Figure 6. A detailed description of the AMP system, its integration with the Lifesaver, and its operation at WETS is contained in these proceedings in Joslin, et al. [2].

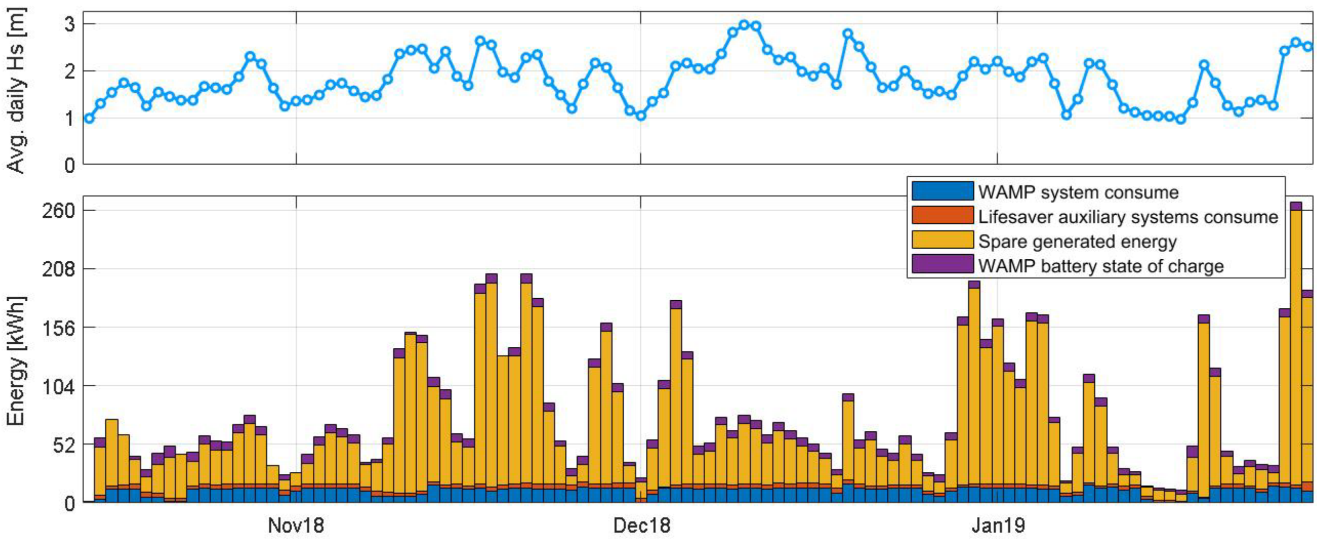

Fig. 6. Average daily wave height and Lifesaver power production for the WETS deployment, showing WAMP and auxiliary power consumption. (Note: key variables are included in this plot, in addition to wave heights. These include number of PTOs operational (1-3) and the degree to which the PTOs are loaded. In the early weeks of the deployment, PTO loading was kept relatively low, then ramped up. Some periods of PTO downtime occurred as well, although at least one was operational at all times.)

IV. WETS Deep Berth Mooring Design

Following an extensive permitting process undertaken by the U.S. Navy (Naval Facilities Engineering Command – NAVFAC), two new deeper berths were installed at WETS in September 2014 to complement the existing berth at 30m water depth. While the 30m berth hardware provided by the Navy consists only of an anchoring system (risers, subsurface floats, and WEC hawsers provided by project developers), it was determined that in order to reduce the high costs to developers associated with mooring systems, the Navy would provide a three-leg mooring system to which developers would connect. Specifically, each leg of the new berths, at 60m and 80m water depths, would consist of a large drag embedment anchor (unlike the 30m berth, the deeper berths are characterized by sufficiently thick sand deposits), connected to a surface float with 70mm chain, forming a chain catenary. Five concrete sinker weights, attached to the main chain with sinker shackles and short chain segments, would provide additional weight to the system as protection against anchor uplift in storm conditions.

Due in part to extended periods with no WEC attached to these moorings, wear began to be experienced such that it was deemed prudent to undertake a design reanalysis to ensure that sound moorings would be available to upcoming WEC developers. Navy tasked HNEI with overseeing this design effort, and HNEI in turn contracted with the team of Sound and Sea Technology (SST) and DNV GL to conduct a thorough strength and fatigue analysis of the systems, and install any recommended upgrades. That analysis is now largely complete, and upgrades are planned during 2019.

1) Design Considerations

While the original design appears to have been adequate in terms of strength, the predominant finding from the new analysis is that fatigue, in the highly dynamic environment of WETS, is the primary driver of mooring system and component selection. With the key design constraints of 1) 100-year storm survivability (Hs = 6.5m, Tp = 14.4s), 2) minimum fatigue life of 10 years in working seas (1.6 – 4.5m), and 3) retain as much of the original hardware as possible, the system was analysed in two basic configurations – with a large WEC installed and with no WEC installed. The "worst case" WEC was assumed to be the very large oscillating water column OE35 device from Ocean Energy USA LLC. This device will be deployed at the WETS 60m berth in summer 2019. This is the largest device currently expected at WETS, and was used as the worst case design WEC for both berths in the modelling process. When no WEC is attached, a "no-WEC hawser" system will be employed to ensure the system is kept in sufficient pretension to reduce the wear and fatigue seen previously in the main chain, thus minimizing the wear (by reducing interlink collisions) and extending the life of the main chain system. These configurations are shown in Figure 7.

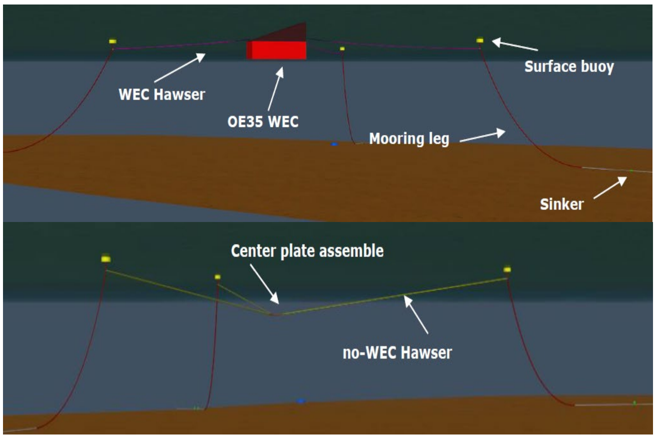

Fig. 7. Deep berth mooring configurations with a large WEC deployed (top) and no WEC deployed (bottom).

The functional requirement of the berths is to provide station keeping of the WEC within an offset envelope defined by the limits of the power umbilical. Therefore, some pretension is typically required to provide initial restoring stiffness. Consequently, the hawsers have a horizontal profile to minimize the influence of the mooring system on the WEC wave frequency motions and power take-off. The ultimate improved design solution was to produce a mooring system with stiffness characteristics that were as close as possible to the original design, so as not to impact planning and design already underway by near-term WEC developers such as Ocean Energy and Columbia Power. At the same time, the mooring analysis was required to meet the requirements of the applicable design standard(s) for offshore mooring [3, 4].

2) Resultant Deep Berth Mooring Design

The resulting mooring system design for the 60m and 80m berths is very similar, and as such we focus on the 60m berth. The resulting design is shown in Figure 8 for the easternmost (most loaded) line (designated as A-1 in Figure 2). It is composed of a Bruce FFTS Mk4 drag anchor and 70mm marine grade chain from that anchor through the outer two of the original five concrete sinkers. These anchors and 70mm chain, as well as the two outer sinkers on each leg, are retained from the original 2014 system. The sinkers should only be lifted in extreme 100-year return period conditions. Where possible, without disturbing the placement of the anchor, Kenter joining links within the 70mm section are replaced by suitably sized LTM D-shackles. This grounded 70mm chain section connects to new 102mm chain via a suitably sized LTM H-link. The larger chain then extends to a tri-plate beneath new surface floats, the connection to which is described in the next section. The D-shackles, tri-plates, main 102mm chain, H-links, and Bruce anchors are shown in Figures 9a and 9b.

Mooring strength and fatigue analysis were performed with and without the Ocean Energy OE35 WEC. For the WEC-connected condition, the analyses were performed for a pretension range of 50kN – 75kN, such that the analyses account for manufacturing uncertainty of hawser components and also are not over-optimized to a level that may be difficult to reproduce in the offshore environment. For the no-WEC hawser arrangement a nominal 45kN pretension (±10% sensitivity) was selected to give a balance between reducing fatigue damage (higher pretension means higher mean load in a stiffening system and therefore larger tension variation for a given offset) and avoiding excessively slack lines and line snatching.

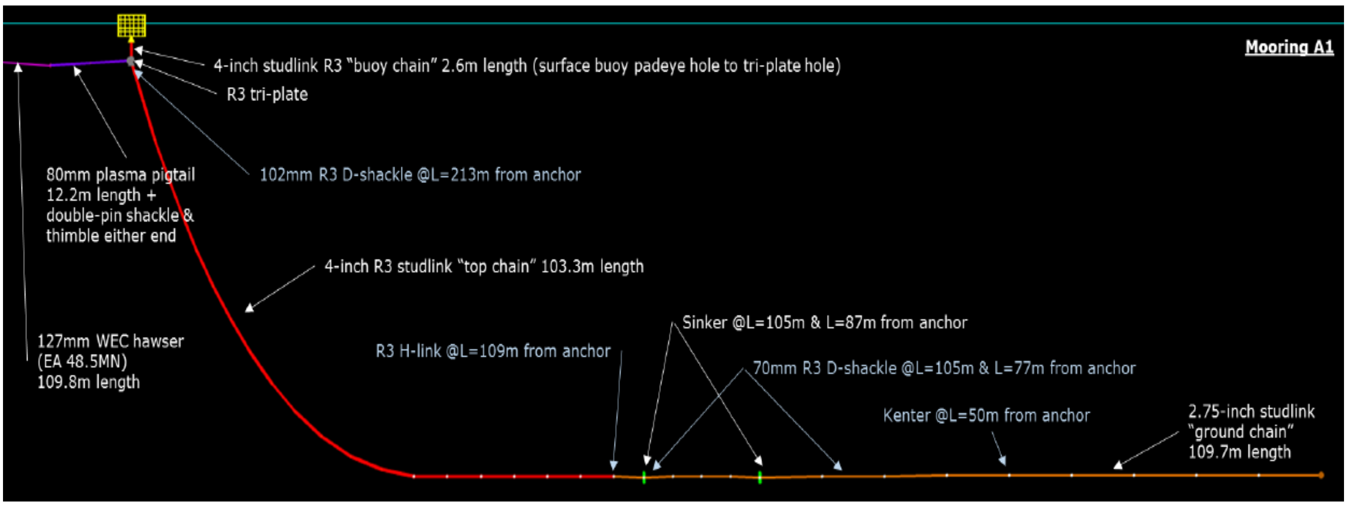

Fig. 8. Mooring A (60m berth) leg A-1, which is the easternmost (most loaded) leg of the mooring. The location of the A-1 leg is shown in Figure 2.

Fig. 9a. WETS 60m berth mooring components, including (top) 102mm D-shackles used beneath the surface float and as joining links between shots of chain, and (bottom) tri-plates which join surface float chains to main chain and WEC or no-WEC hawser systems.

3) Connection of Surface Floats to Main Chain

A key distinction between the shallow and deep WETS berths is that the deep berths utilize large surface buoys, while the shallow water site utilizes smaller subsurface buoys. A significant design challenge that resulted from these large surface buoys' dynamic response in high occurrence sea states is that rolling motion causes out-of-plane bending of the surface buoy padeye and connector. The surface buoy padeye is free to rotate about the pin of the connector in the pitch direction, but it cannot rotate in the roll direction, as shown in Figure 10. Roll is defined as rotation perpendicular to the line heading. Rotation in roll imparts bending in the connector and the padeye. The Crosby "bow" shackle used originally to make connection to the padeye was found to have unacceptably low bending fatigue life. For this reason, the re-designed surface buoys utilize a U-link which is a much stockier component and provides adequate stress distribution of the bending loads. The buoy chain makeup was modified from a 5-studlink arrangement to one with two end links and two D-shackles, in order to align the buoy in the correct orientation and reduce the risk of chain studs working loose. This configuration is shown in Figure 10. Two of the floats, and a representative U-link, are shown in Figure 11.

Fig. 9b. WETS 60m berth mooring components (continued), including (top) main 102mm chain, (center) H-links, which join new 102mm chain to existing 70mm chain, and (bottom) existing Bruce anchors.

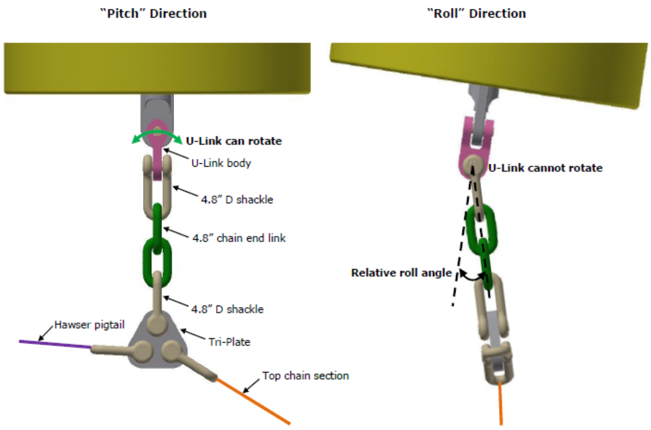

Fig. 10. WETS deep berth surface float connection design, incorporating U-links (shown in purple) to address issues with bending fatigue.

A linear elastic finite element analysis was performed; an Inventor model of each component was created, and the components were assembled together in a straight tension configuration. The model was run with a constant 400kN tension applied at four angles: 0.0°, 2.5°, 5.0° and 7.5°. The stress vs roll angle curve was found to be linear. The location of maximum hotspot stresses for each component is shown in Figure 12. From the linearity trend established earlier, the maximum principal stress for each component is found as a function of angle and tension. The OrcaFlex tension and angle time histories are used to derive the combined B-T stress time history at hotspots, and this is used to calculate the combined B-T fatigue life. Using this methodology, the approach illustrated in Figure 10 was found to substantially improve overall fatigue life and thus guided the design of the deep berth surface float padeye/connector system that will be installed in 2019.

V. Conclusions

Three major activities undertaken at WETS over the past two years are described. First, hull and float modifications to the NWEI Azura device were performed in an attempt to improve power performance during a second deployment at the 30m test berth, which was carried out between February and August of 2018. The device continued to exhibit excellent survivability/reliability, as demonstrated in its first deployment, but improvements to power performance were not realized. As documented more thoroughly in Rajagopalan, et al. [1], it appears that although device motion improvements were observed, similar to expectations from modelling, the device PTO was not capable of adapting to the higher torque, and rapid changes in torque, experienced by the modified prototype device.

Second, the Fred. Olsen, Ltd. Lifesaver WEC was also deployed for a second time at WETS, beginning in October 2018. In this deployment, changes were made to the dual mooring strategy of the device – including both a PTO mooring and a storm mooring – in an attempt to improve upon reliability and power performance. Also, a sophisticated environmental sensing suite, which also incorporated a subsea charging capability – developed by the University of Washington – was integrated into the Lifesaver hull for this deployment. This system received the ~600W of power it needed to maintain operation from electricity generated by the WEC itself. This important global first serves as a demonstration of the use of WEC power for various offshore, non-grid-connected applications, such as ocean observation and autonomous vehicle recharge.

Fig. 11. WETS 60m berth mooring components, including (top) surface floats and (bottom) a representative U-link, which is attached to the buoy padeye and to a 102mm D-shackle (as shown in Fig. 10).

Finally, a major design effort was undertaken to re-examine the WETS deep berth mooring systems to ensure readiness for planned deployments of large WEC systems in the near future. A key finding of this effort was that fatigue analysis, in addition to overall system strength in 100-year storm conditions, was critical to component selection. The dynamic nature of the wave regime at WETS is such that cyclic loading on system components must be carefully understood to ensure adequate fatigue life is obtained. This resulted in the selection of larger chain and associated joining links, as well as the implementation of a "no-WEC hawser" system to ensure that the systems are kept in adequate pretension when a wave energy converter is not connected. An unexpected challenge that emerged in the design process was overcoming bending fatigue analysed in the surface float padeye/connector configuration. This was ultimately overcome with the use of a large U-link at the buoy padeye, which in turn connects to a D-shackle, two open links, a second D-shackle, and to the tri-plate which connects to the main chain and to the hawser (either a no-WEC hawser or a WEC device hawser). These changes will be implemented during 2019.

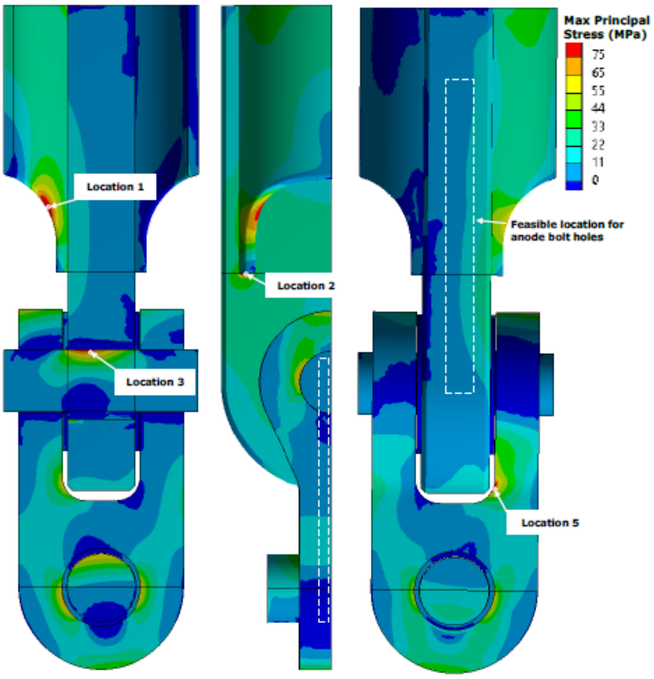

Fig. 12. Maximum Principal Stress Plots for surface buoy padeye/U-link connection with 7.5° load angle and 400kN tension.

ACKNOWLEDGEMENTS

Funding for this work comes primarily from the Naval Facilities Engineering Command under NAVSEA contracts N00024-08-D-6323/0016 and N00024-08-D-6323/0033, and from the U.S. Department of Energy's Waterpower Technologies Office under grant DE-FG36-08GO18180. Navy funds come to the Hawaii Natural Energy Institute via the Applied Physics Laboratory at the University of Hawaii.

In addition to the organizations included here as co-authors (UW, DNV GL, Fred. Olsen, Ltd.), critical data and interpretive contributions were made by Northwest Energy Innovations for the Azura effort, and all at-sea operations discussed here, as well as planning for those operations, would not be possible without our key research partner Sea Engineering, Inc. of Honolulu. The deep berth mooring design effort was conducted under contract to Sound and Sea Technology, which in turn contracted DNV GL.

REFERENCES

[1] K. Rajagopalan, P. Cross, B. Ling, T. Lettenmaier, "AZURA WEC Power Performance - A preliminary comparison of trial data and numerical modelling results", presented at the European Wave and Tidal Energy Conference, Naples, Italy, September, 2019.

[2] J. Joslin, E. Cotter, P. Murphy, P. Gibbs, R. Cavagnaro, C. Crisp, A. Stewart, B. Polagye, P. Cross, E. Hjetland, A. Rocheleau, B. Waters, "The wave-powered adaptable monitoring package: hardware design, installation, and deployment", presented at the European Wave and Tidal Energy Conference, Naples, Italy, September, 2019.

[3] DNVGL-ST-0119, Floating wind turbine structures, 2018.

[4] ISO19901-7, Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units, 2013.