Test Plan:

Full Power Testing of a 20kW Wave Energy Device at the WETS 30m Site

2015

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Prepared by:

Northwest Energy Innovations, LLC

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1. Introduction

Northwest Energy Innovations (NWEI), Naval Facilities Engineering Command's Expeditionary Warfare Center (NAVFAC/EXWC), University of Hawaii's Hawaii National Marine Renewable Energy Center (HINMREC) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) are working collaboratively to deploy and test NWEI's half-scale multi-mode wave energy converter (NWEI Device). These tests will take place at the 30-meter berth of US Navy's Wave Energy Test Site (WETS 30m Site) at the Kaneohe Marine Corps Base Hawaiʻi (MCBH) on the windward (northeast) coast of the island of Oʻahu. The site is located northeast of Heei'a Kea Small Boat Harbor and is within the security zone of MCBH. The WETS 30m Site was engineered and installed as part of a previous wave energy program. As described in the Site Report[1] (Appendix A), it is grid connected to MCBH through a cable which begins at the control room in Battery French and terminates offshore at the 30m Site.

Primary project structures include the NWEI Device, anchors and mooring system, the HINMREC Waverider buoy, and an NREL acoustic wave and current profiler (AWAC). An existing 1 km long cable to shore will be used to transmit power from the NWEI Device to shore. Existing NAVFAC shore facilities and interconnect equipment provided by NWEI will be used to provide grid interconnection. An umbilical cable provided by NWEI will be used to connect the NWEI Device to a subsea junction box at the seaward side of the subsea cable. NREL instrumentation, along with onboard NWEI Device instrumentation systems, will be used to collect operating data during the testing. Communications between the NWEI Device and shore will be through fiber optics in the subsea cable and umbilical. The NWEI Device will be deployed at the WETS 30m Site for a period of up to 12 months.

2. Objectives

- Verify correct operation of the modified power takeoff hydraulics
- Collect data in order to validate analytical tools.
- Collect data to characterize device performance while operating in a range of sea conditions with different control settings. This data will be used to determine the control inputs that optimize power output as well as to provide HINMREC data records required to estimate the device power matrix (i.e., power output as function of wave parameters: significant wave height and energy period).
- Collect data that will allow for the future development of an adaptive control method that will automatically adjust control settings to maximize output power in all sea states.
- Collect data to validate mooring calculations.

[1] 30-meter Site Report, NAVFAC, November 10 2013

3. Roles of Personnel

The roles and contact information for personnel from the different organizations that will be involved in the project during the deployment period is listed in the table below.

Person	Responsibility	Contact
Steven Kopf, NWEI	NWEI project management	skopf@nwenergyinnovations.com C: 484-459-8200
Justin Klure, NWEI	NWEI project management	jklure@nwenergyinnovations.com C: 503-475-2999
Terry Lettenmaier, Consultant to NWEI	NWEI test engineering	lett@peak.org C: 541-961-5833
Bruce Yamashita, Consultant to NWEI	NWEI communications engineering support	Brucesheri@aol.com C: 808-285-1574
Derek Shotbolt, Energy Hydraulics Ltd	Device engineering and fabrication	Derek.Shotbolt@ehltd.co.nz O: 06467552400 C: 06427445606
Eric Nelson, NREL	NREL test engineering	Eric.Nelson@nrel.gov C: 303-887 8752
Arlinda Huskey, NREL	NREL project management	Arlinda.Huskey@nrel.gov C: 303-384-6987
Dr. Luis Vega, University of Hawaii/HINMREC	HINMREC contact	luisvega@hawaii.edu O: 808-956-2335 C: 808-221-5267
Alex Devisser, NAVFAC	NAVFAC contact	alexandra.devisser@navy.mil O: 805-982-6070
Andrew Rocheleau, Sea Engineering	Deployment & ocean engineering support	arocheleau@seaengineering.com 808-259-7966

4. SCHEDULE

A rough schedule that shows the anticipated timing and durations of the significant tasks leading to deployment is shown below.

October 30, 2014	Onshore grid interconnection equipment installed and tested at low power
November 4, 2014	PowerPod arrives in Honolulu and ready for final assembly
February 2015	Final assembly complete and ready for deployment
March 2015	Device deployed
March-April 2015	Commissioning and initial testing
March 2016	Device removed

5. Test Article Description

The NWEI Device that will be deployed at WETS is a half-scale multi-mode, point absorber wave energy convertor based on the WET-NZ design. The NWEI Device is now known commercially as Azura.

5.1. General Arrangement

The NWEI Device produces power as a result of the relative motion between the Hull and Float. As the wave forces the Hull to surge and the Float to rotate, the eccentric crankshaft drives two hydraulic pistons. Hydraulic pressure (4,000 to 5,000 psi) is accumulated and through a series of valves and controls, is used to drive a hydraulic motor, which is connected to the generator. With the exception of the hydraulic cylinders, all of the hydraulics, generator, and controls are located within the watertight PowerPod. The PowerPod was originally built in New Zealand. Following the Oregon ocean testing from August 2012 to October 2012, it was shipped back to New Zealand to be modified and factory tested by Energy Hydraulics Ltd. These modifications are complete and the PowerPod will be shipped to Honolulu for additional testing and integration with the Hull. The major components of the NWEI Device are shown below in Figure 2. Note that Figure 2 provides an accurate representation of the device that will be deployed at WETS. All other figures in this document may show images of a circular float, which was used in the previous ocean testing of the device. Figure 7 provides a photograph of the float that will be deployed at WETS.

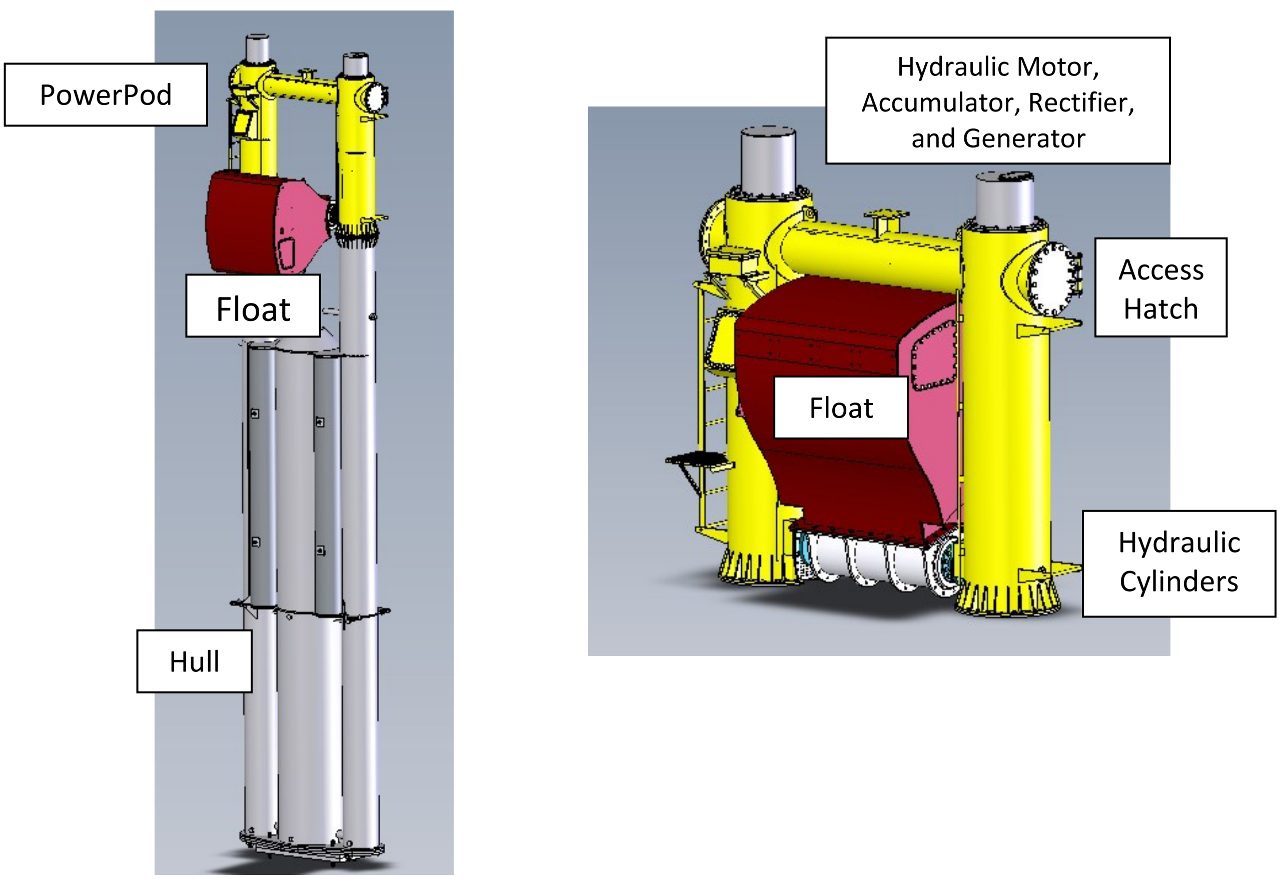

Figure 1: Primary Components of NWEI Device

5.2. Hull

Figure 2 shows the Hull before attachment to the PowerPod in preparation for the August 2012 deployment in Oregon. The flanges in the foreground are the mating point of the PowerPod. An airline runs from the top of the hull to the lower ballast tanks. The three mooring lines are attached about mid-draft of the Hull and the float pin is used to secure the float during transport (Figure 3). Dimensions and specifications of the PowerPod are shown in Section 5.8.

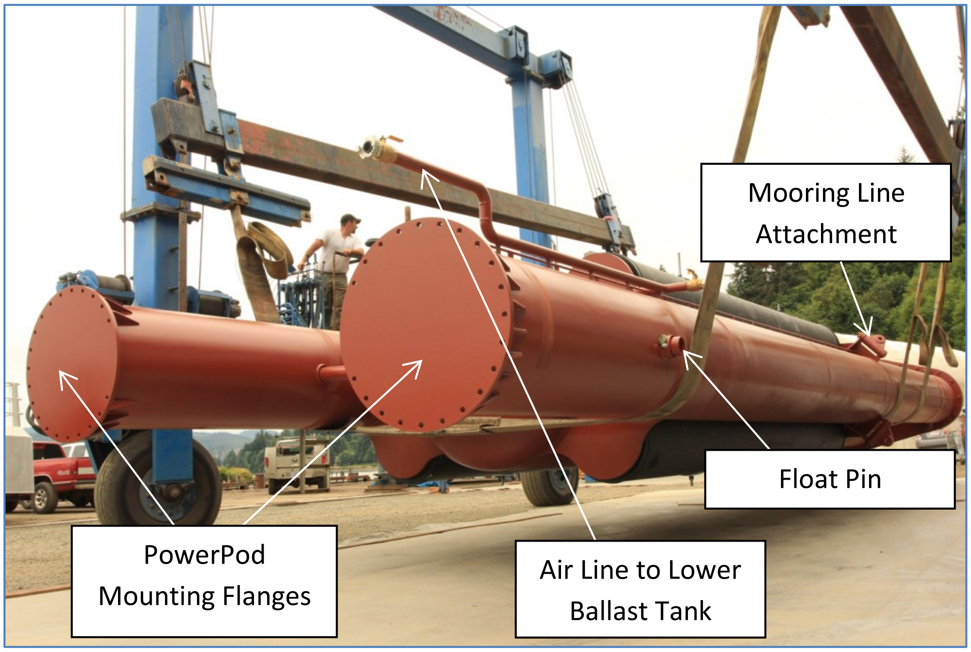

Figure 2 - Hull prior to integration with the PowerPod

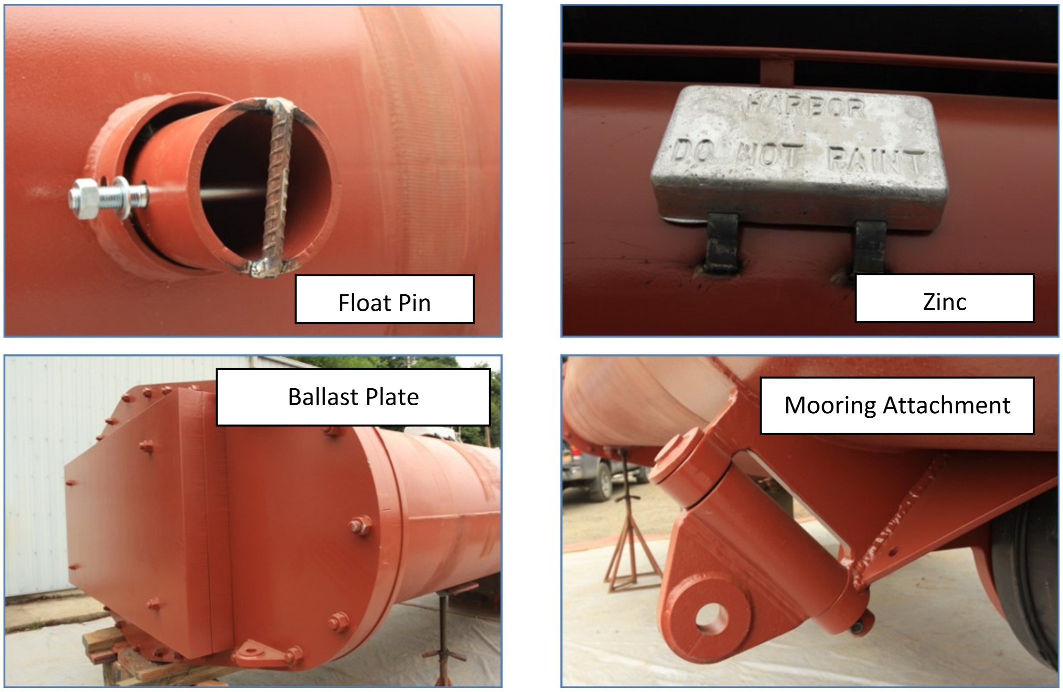

Figure 3 - Additional Hull Details

5.3. PowerPod

Figure 4 below shows a detailed view of the PowerPod (with the float removed) and its associated components. The hydraulic cylinders which are driven by the eccentric shaft are located in the lower legs of the PowerPod in a flooded compartment (Figure 5). High pressure flow lines penetrate the bulkhead between the dry and wet portions of the PowerPod. All other components of the power take-off system are located in the upper horizontal member of the PowerPod. Hatches on the vertical members of the PowerPod provide access to the hydraulic system (Figure 6). However, it is not expected that any repairs, inspection or maintenance will be conducted at sea; as such, these hatches will remain closed during the deployment. Following the 2012 Oregon ocean testing, the PowerPod was modified by Energy Hydraulics Limited in New Plymouth, New Zealand and will be shipped to Honolulu, HI for additional dry testing and integration with the Hull. Modifications included a removable teardrop shaped float (Figure 7), replacing the cylindrical shape float used in Oregon. The PowerPod is shipped in a vertical position (Figure 8) and then is oriented horizontally for integration with the Hull (Figure 9). Dimensions and specifications of the PowerPod are shown in Section 5.8.

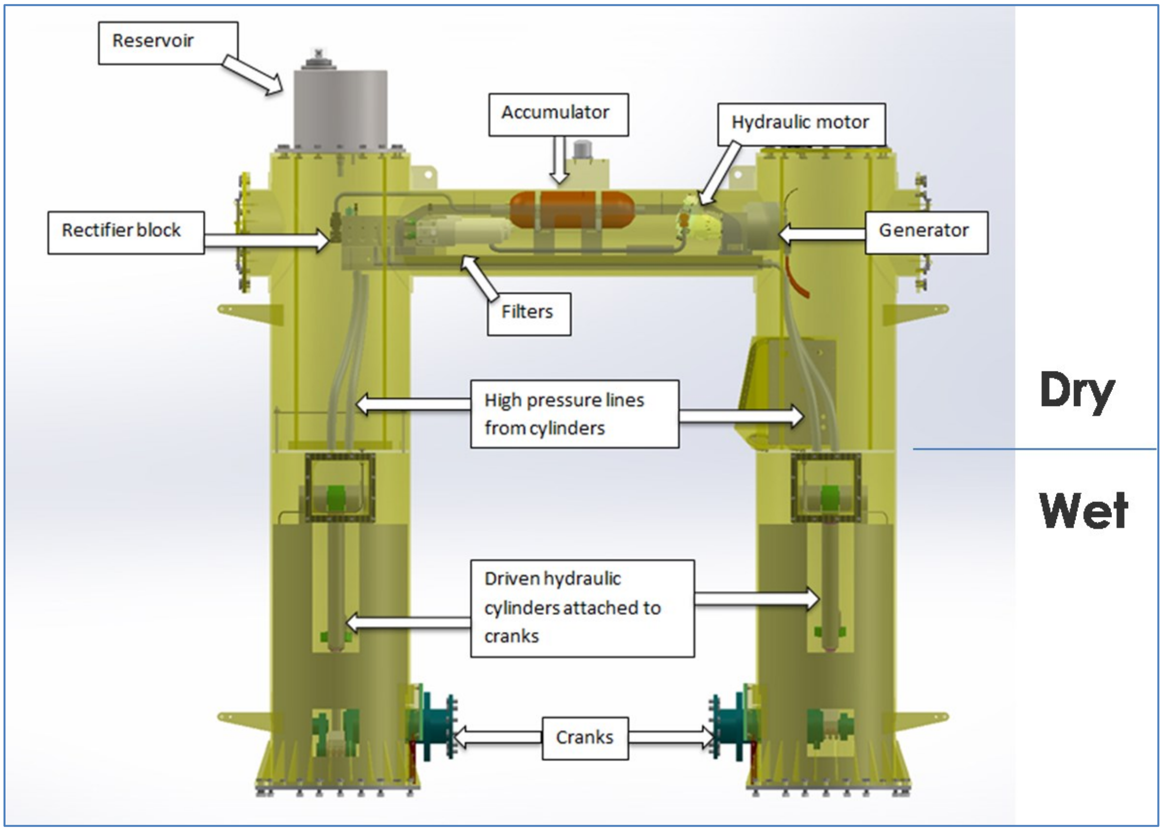

Figure 4 - PowerPod Layout (Float removed)

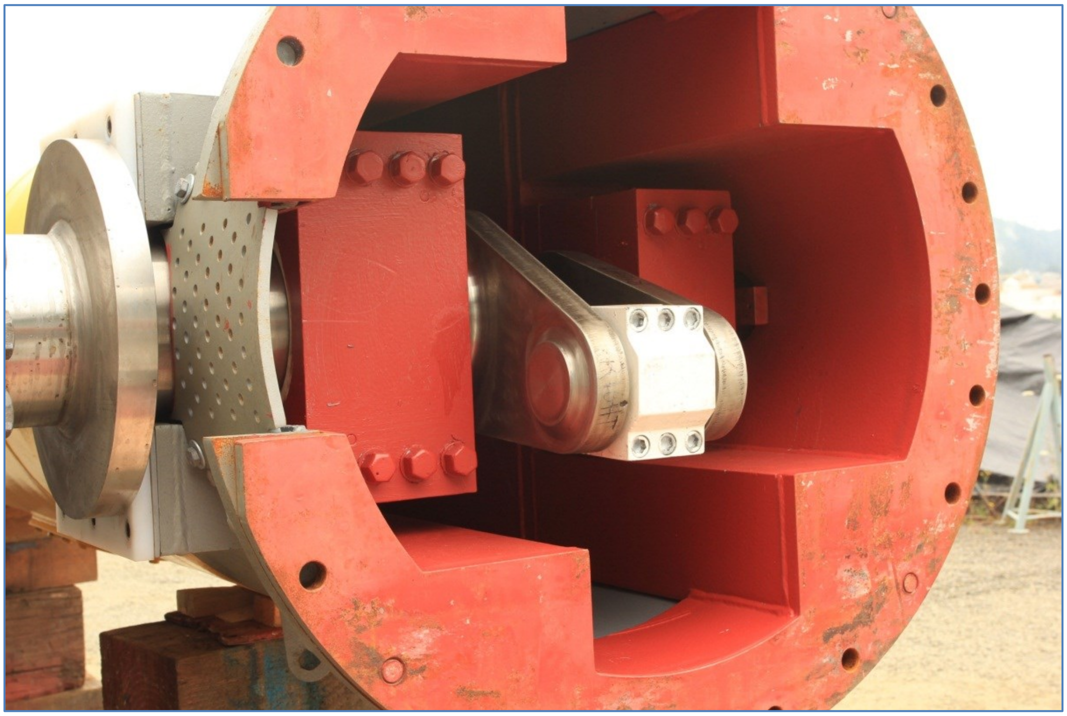

Figure 5 - Lower leg of PowerPod showing eccentric crank and hydraulic cylinder attachment (white block)

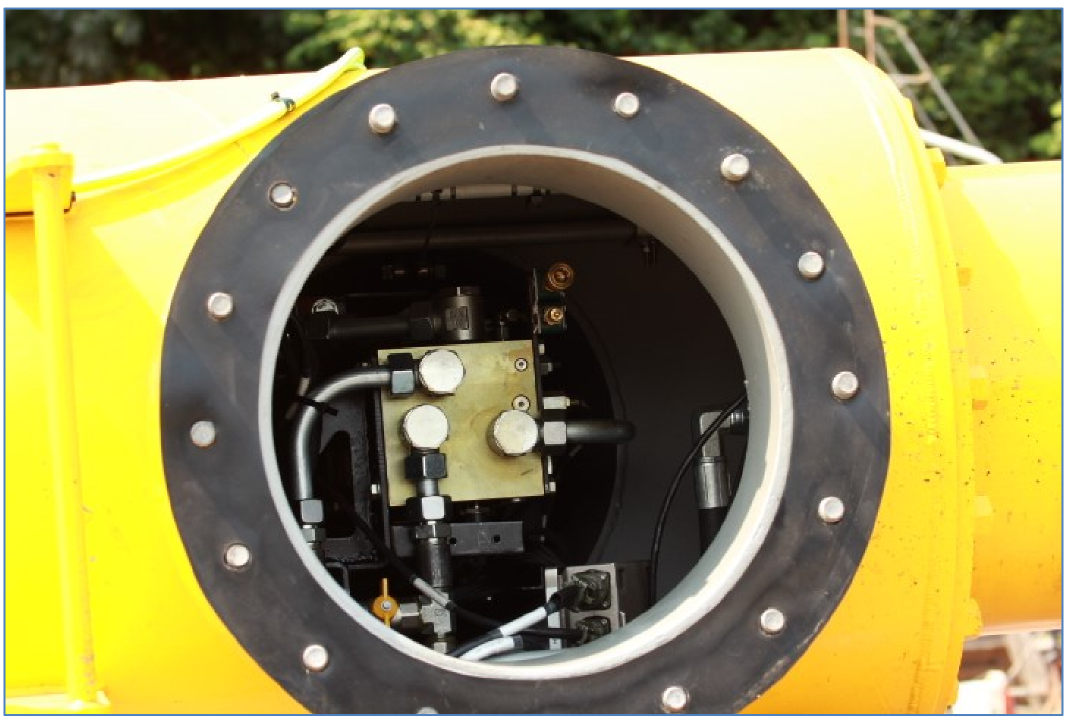

Figure 6 - The hatch provides access to the hydraulic components in upper portion of the PowerPod

Figure 7 - PowerPod ready to ship to Honolulu and Teardrop Float

Figure 8 - PowerPod being mated to Hull prior to Oregon deployment. Float has subsequently been modified to teardrop shape.

5.4. Hydraulic

The hydraulic system consists of two cylinders located in the lower, free flooded portion of the vertical legs of the PowerPod (Figure 10). The accumulator, rectifier and hydraulic motor are located in the upper, watertight, horizontal member of the PowerPod (Figure 11). Figure 12 shows a schematic of the hydraulic system. The NWEI Device contains approximately 60 liters (15.9 gallons) of ELF Elfolna DS 46 hydraulic fluid. The Material Safety Data Sheet is attached as Appendix F.

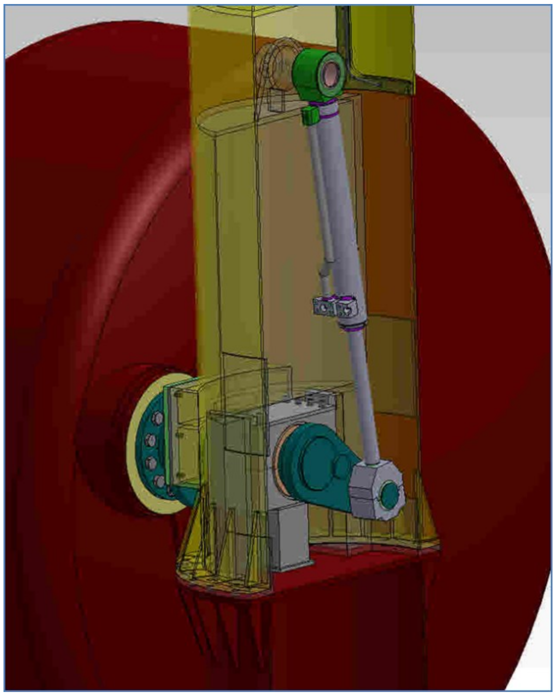

Figure 9 - Hydraulic Piston Attached to Crankshaft

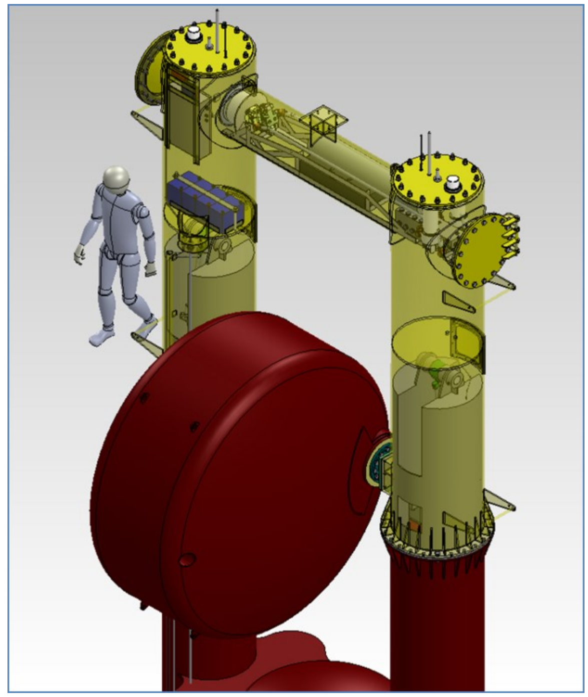

Figure 10 - Hydraulic Motor Located In Upper Portion of the PowerPod

A schematic showing major components of the hydraulic system is shown in Figure 11. Two double-acting cylinders are driven by the float. The outputs of these cylinders are both rectified; the common rectified output is used to drive a variable displacement hydraulic motor. The hydraulic motor is coupled to the electrical generator, as described in Section 5.5. The displacement of the motor is controlled to keep its speed constant whenever possible. An accumulator is included to provide a small amount of storage and provide motor flow when the float velocity goes to zero, which occurs briefly twice per ocean wave cycle.

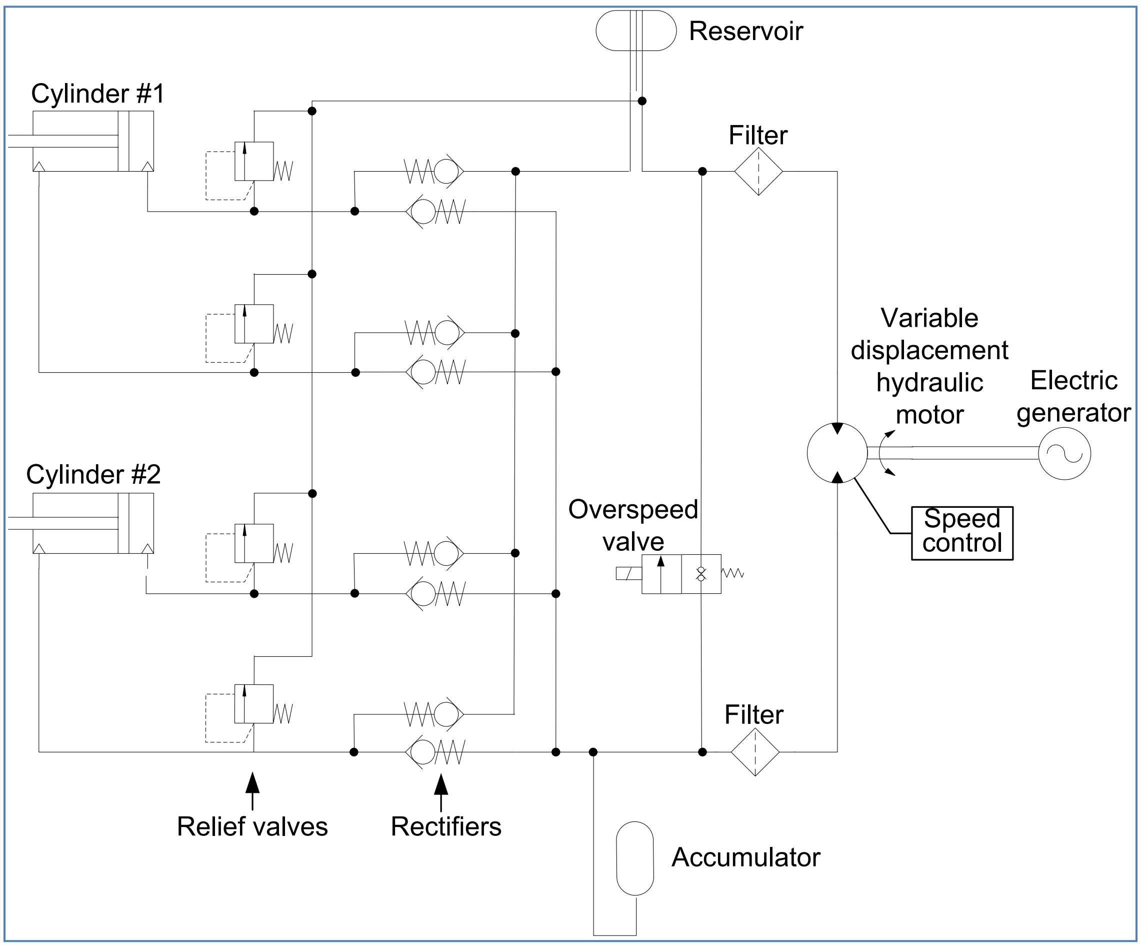

Figure 11: Hydraulic System Schematic

5.5. Electrical

The NWEI Device electrical power system is shown in Figure 12. A UQM 380 permanent magnet generator that has the specifications listed in Table 1 is driven by a hydraulic motor which is part of the PTO hydraulic system that is described in the previous section. The three phase ac generator output connects to a three phase boost transformer through three contactors that can be opened from shore when fault conditions are detected or the system is disabled. The boost transformer doubles the generator voltage to decrease current and losses in the subsea cable. The transformer output is connected to a three phase diode rectifier module that converts the ac generator output to dc voltage. The rectified generator output can range from 0 – 575 Vdc depending on generator speed and electrical load. The dc output of the generator is connected to the generator control and interconnect equipment on shore (see Section 7.1) through the umbilical, subsea, and terrestrial cables. This onshore equipment includes a dump load system that increases electrical load when necessary to limit voltage to the 575 Vdc maximum.

A third conductor in the subsea cable will be used to provide 200-400 Vdc ancillary power by using the negative dc power conductor as a return; this voltage will fluctuate due to cable resistance and generator current flowing in that conductor. A wide voltage range, isolated dc-dc power supply will convert this voltage to 24 Vdc in order to power data and control systems on board the device.

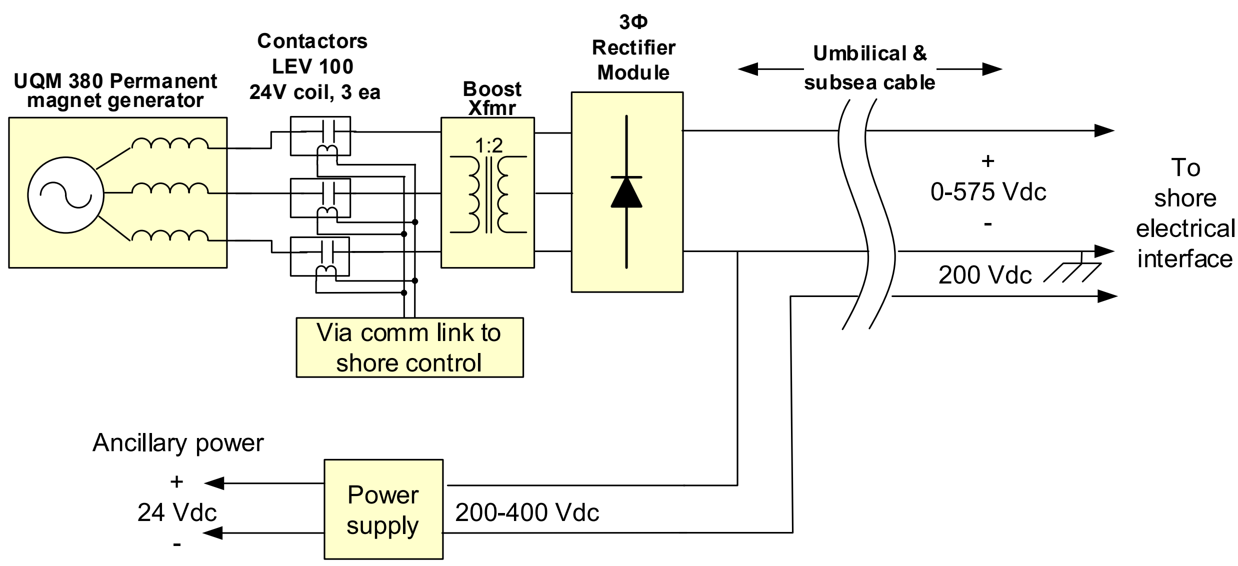

Figure 12: NWEI Device onboard electrical power system

Table 1: Electrical Generator Specifications

Manufacturer	UQM Technologies
Model	380
Type	3 phase, permanent magnet synchronous generator
Back emf	Sinusoidal
Pole pairs	9
Inductance	225 µHy/phase
Voltage constant	55 Vrms line-neutral/1000 rpm
Phase connection	Wye connected with neutral isolated

5.6. Umbilical Cable

The umbilical cable connects the NWEI Device to the Subsea Cable as shown in Figure 13. The umbilical cable is connected to the NWEI Device at the dry box (Figure 14) which is located near the top of the PowerPod. The cable then runs down the side of the PowerPod and Hull and is attached to the bend restrictor and the strength terminator located just below the mooring attachment points (Figure 15). Once the cable leaves the device, the cable is fitted with flotation which creates a lazy-S shape. This provides strain relief as the cable moves as a result of wind, waves, and current. The umbilical cable is attached to the seabed via the Transition Plate or T-Plate as shown in Figure 16. The T-Plate is rock bolted to the seabed.

From the T-Plate, the umbilical cable is connected to the subsea cable at a subsea junction box. The junction box is a waterproof, oil filled housing where the electrical and data fiber connections are made. These connections are made on the installation vessel, and then the junction box is lowered to the seabed. A diagram of the subsea junction box is shown in Figure 17. This junction box has been custom designed for NWEI to interface with the existing penetrator and ODI connector that terminate the power and fiber optics in the subsea cable. An Acoustic Wave and Current Profiler (AWAC) will be mounted nearby the junction box. The AWAC connector cable has separate entry into the junction box. Details of the T-Plate and T-Pod can be found in Section 8.2 of the Site Report (Appendix A). Detailed information about the umbilical cable, bend restrictor, and strength terminator is included in Appendix B. Locations of the subsea junction box and T-Plate are shown in Section 5 of the Mooring Analysis (Appendix D).

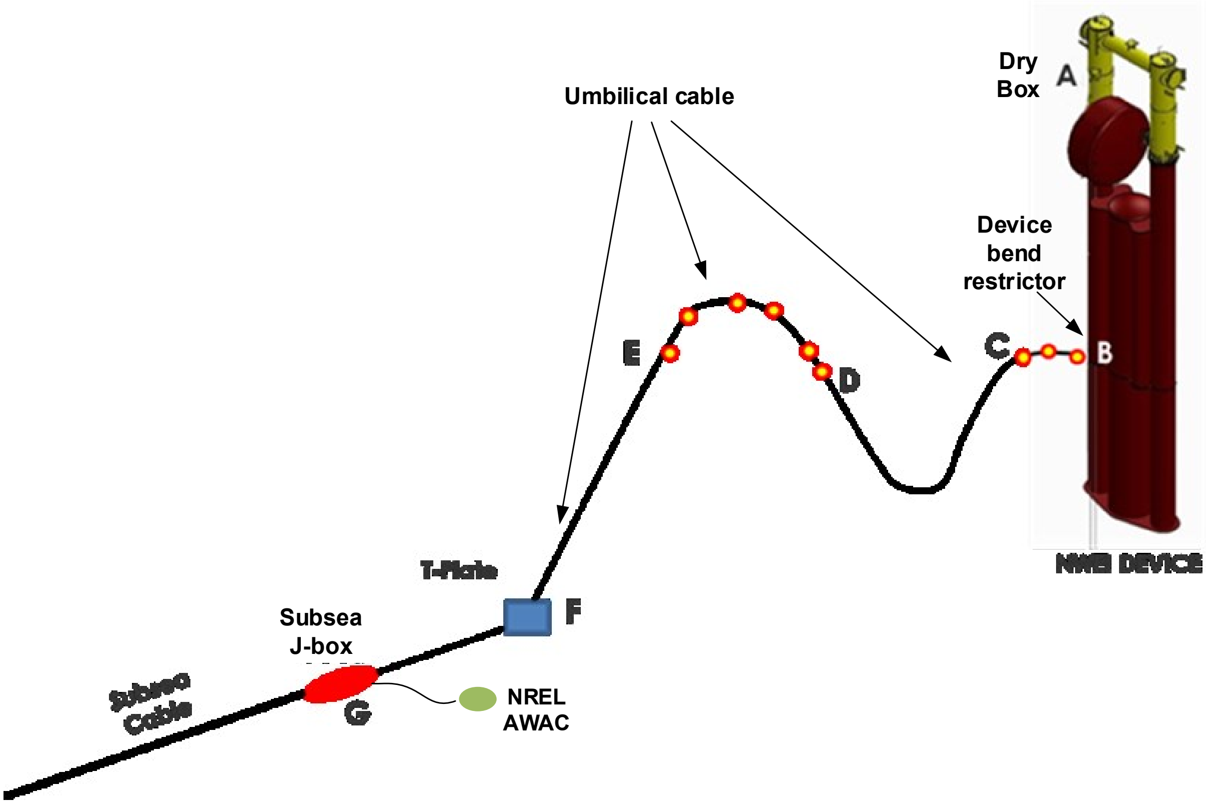

Figure 13 - Umbilical Cable General Arrangement

Figure 14 - Top View of PowerPod Showing the Dry Box

Figure 15 - Bend Restrictor and Strength Terminator

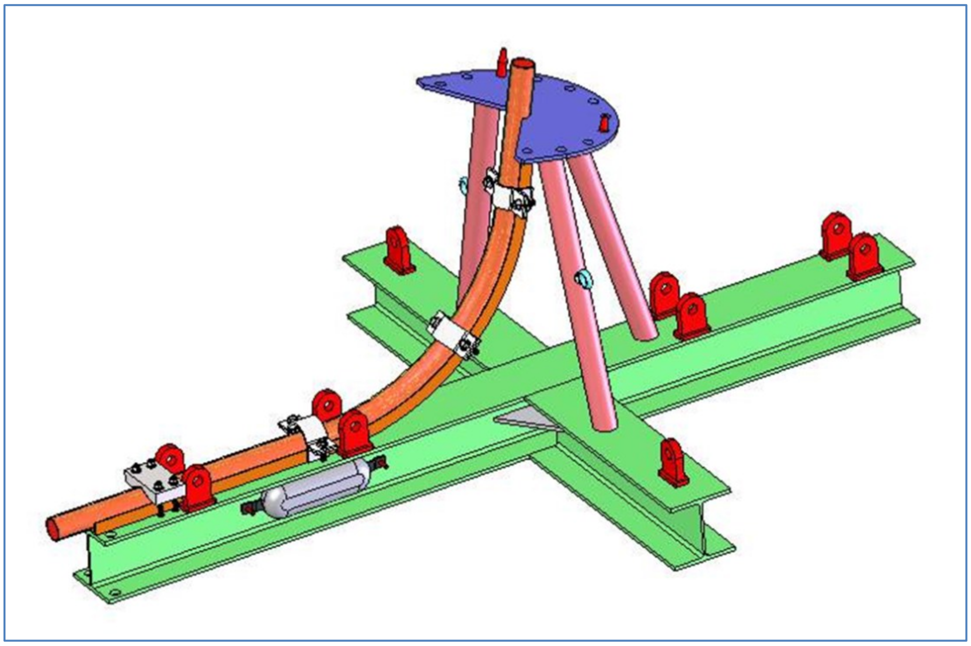

Figure 16 - Transition Frame (T-Frame)

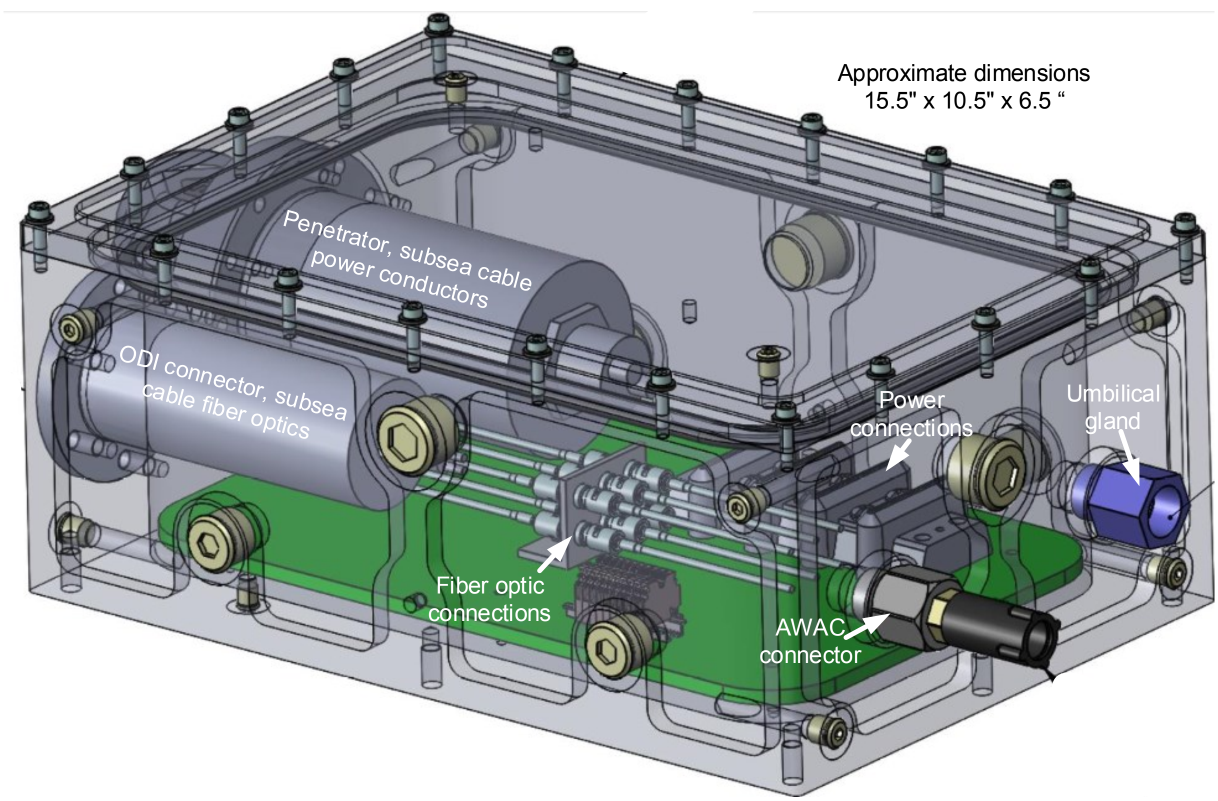

Figure 17 – Subsea Junction Box

5.7. Mooring

The NWEI Device will be connected to the existing anchors, as shown below and as described in Section 8.2 of the Site Report (Appendix A). Complete drawings and analysis of the NWEI Device mooring system are shown in Appendices C and D.

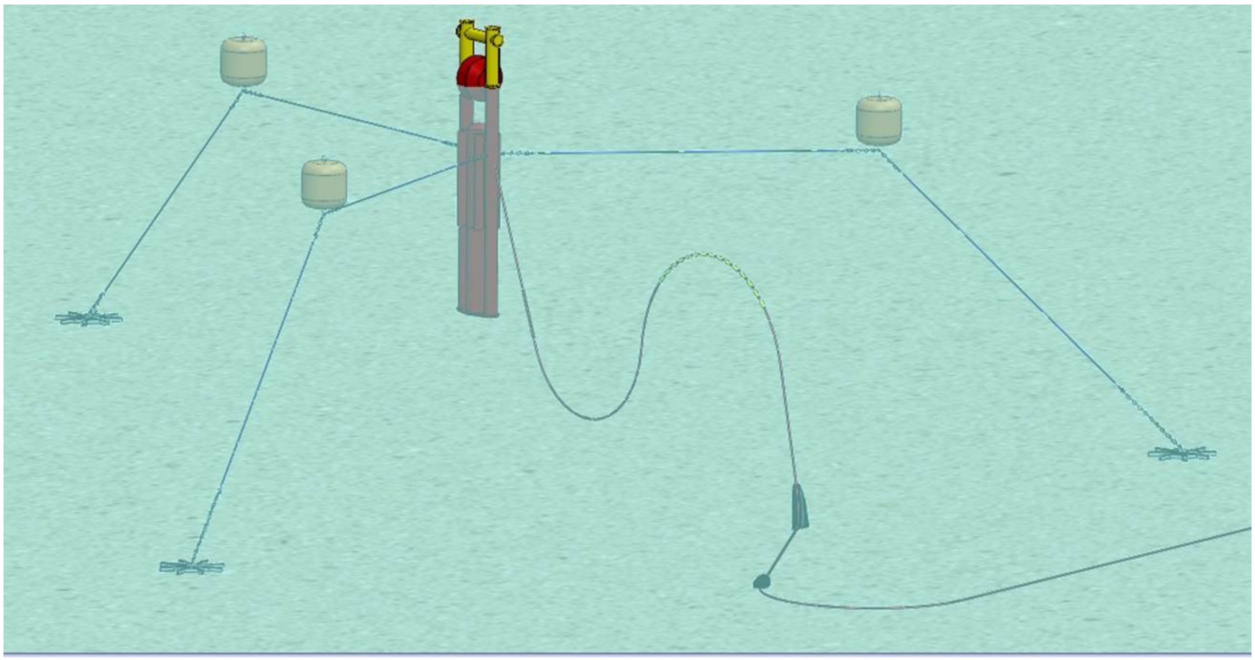

Figure 18: Mooring System Schematic

5.8. Specifications

Characteristic	Dimension	Unit
Height Above Waterline		
Draft Below Waterline	14.50	meters
Total Height	3.67	meters
Float Diameter	2.40	meters
Hull Width	3.79	meters
Hull Depth	1.53	meters
Center Hull Tube Outside Diameter	1.52	meters
Center Hull Tube Wall Thickness	12.70	millimeters
Center Hull Tube Outside Diameter	0.81	meters
Center Hull Tube Wall Thickness	9.53	millimeters
PowerPod Vertical Tube Outside Diameter	0.81	meters
PowerPod Vertical Tube Wall Thickness	9.53	millimeters
Wet Mass of Hull	50.00	metric tons
Wet Mass of Float	4.00	metric tons

6. Test Site

The test site is located in 30 m depth berth at the Wave Energy Test Site (WETS) in Kaneohe Marine Corps Base Hawai‘i (KMCBH) on the windward (northeast) coast of the island of O‘ahu; see Figure 19 for the specific location. This site has an existing cable to shore that was previously used for testing three of Ocean Power Technologies’ (OPT) WEC devices. OPT deployed its first WEC at this site in June 2004. The site is managed by NAVFAC.

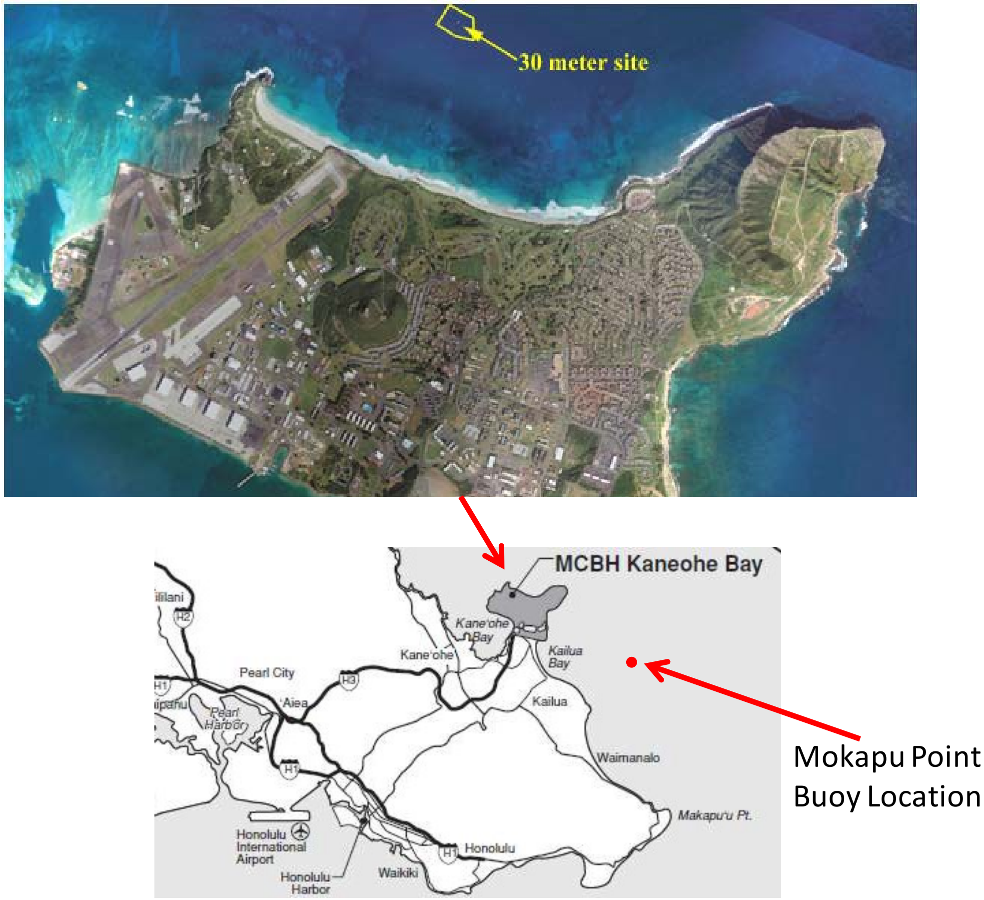

Figure 19: Test Site Location

6.1. Wave Climate

The best source of wave climate information for the test site is recorded by the Kaneohe Bay Waverider buoy operated by the University of Hawaii. It is located at 81 m depth about 1 km away from the 30 m berth at WETS. For data from this buoy refer to National Data Buoy Center (NDBC) Station 51207, Kaneohe Bay, HI:

http://www.ndbc.noaa.gov/station_page.php?station=512027

7. Test Setup

7.1. Grid Interconnection and Generator Control

See Figure 20 for a diagram of the NWEI grid interconnection system, which also controls the NWEI electrical generator. The output of the generator on board the NWEI device is boosted in voltage using a transformer, then rectified to produce a dc voltage for transmission to shore as described in Section 5.5. The dc output from the device will be connected through umbilical, undersea, and terrestrial cables to NWEI grid interconnect equipment to be installed inside Building 614. This equipment will include three inverters with 6 kW peak power capability each that will operate in parallel to convert the 0-575 Vdc to 208 Vac, 60 Hz for interconnection to the utility grid. Each inverter will be an off-the-shelf PowerOne PVI-6000 model inverter that is UL-1741 approved. The three parallel inverters will provide a total power conversion capability of 18 kW. The three inverters will each be connected via single phase isolation transformers to single phase 208 V switchgear in Building 614.

The three parallel inverters will control the output power of the generator on board the NWEI device per a power command by adjusting their dc input voltages to control generator current. The three inverters will be operated so that they share power equally. The inverter power command is produced by the NWEI onboard control system, which is integrated with the NWEI offshore cRIO DAS described in Section 7.4. Commands from the onboard control will be transmitted to shore via fiber optics, and an onshore NWEI cRIO controller will be used to interface with the three inverters.

A dump load system consisting of a dump loadbank and an IGBT switch will be used to limit maximum dc voltage. The IGBT switch, controlled by the onshore NWEI cRIO controller, will be turned on when voltage exceeds 550 Vdc in order to limit maximum voltage by connecting in the large electrical load provided by the dump loadbank.

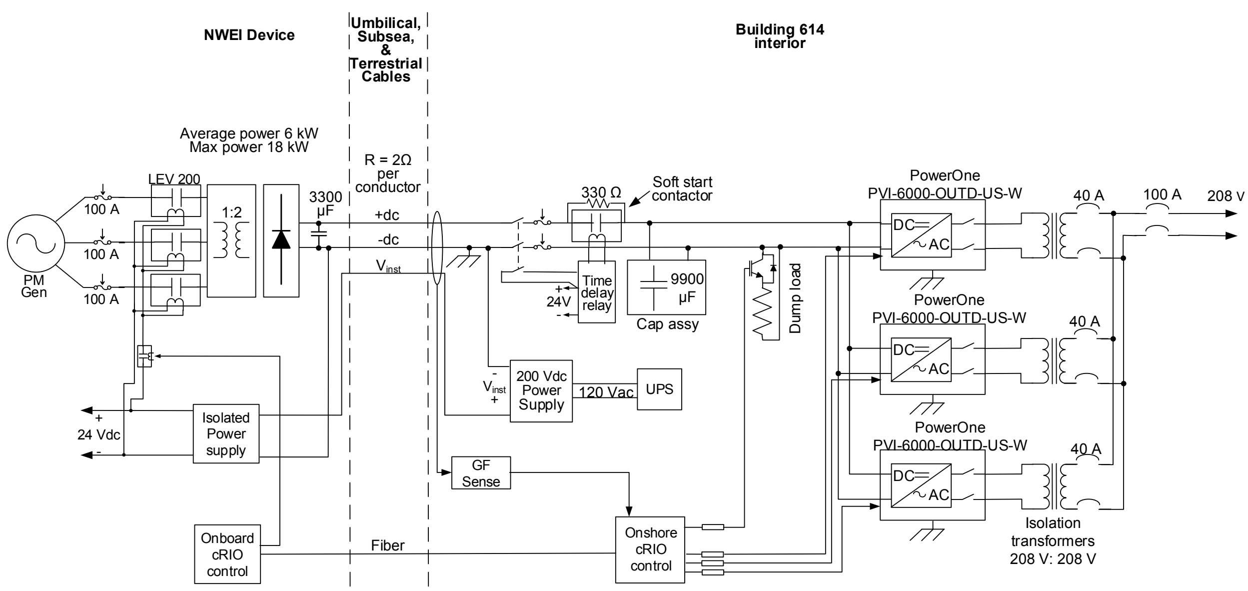

Figure 20: NWEI Grid Interconnection and Generator Control

7.2. Subsea, Terrestrial, and Umbilical Cables

Three cables will be used to connect the NWEI Device to the interior of building 614 as shown Figure 21: 1) an umbilical cable (to be supplied by NWEI) between the NWEI Device and the a subsea junction box; 2) an existing subsea cable between the junction box and on-shore cable vault (located approximately 40 m above high tide line); and 3) a terrestrial cable between the cable vault and Building 614. Lengths, conductor sizes, and resistances for each cable are listed in Table 2. Refer to Appendix B for a drawing of the umbilical cable. Refer to the Thirty-Meter Site Report for detailed information about the subsea cable and some information about the terrestrial cable. The total resistance of the three cables is approximately 2 Ω per conductor.

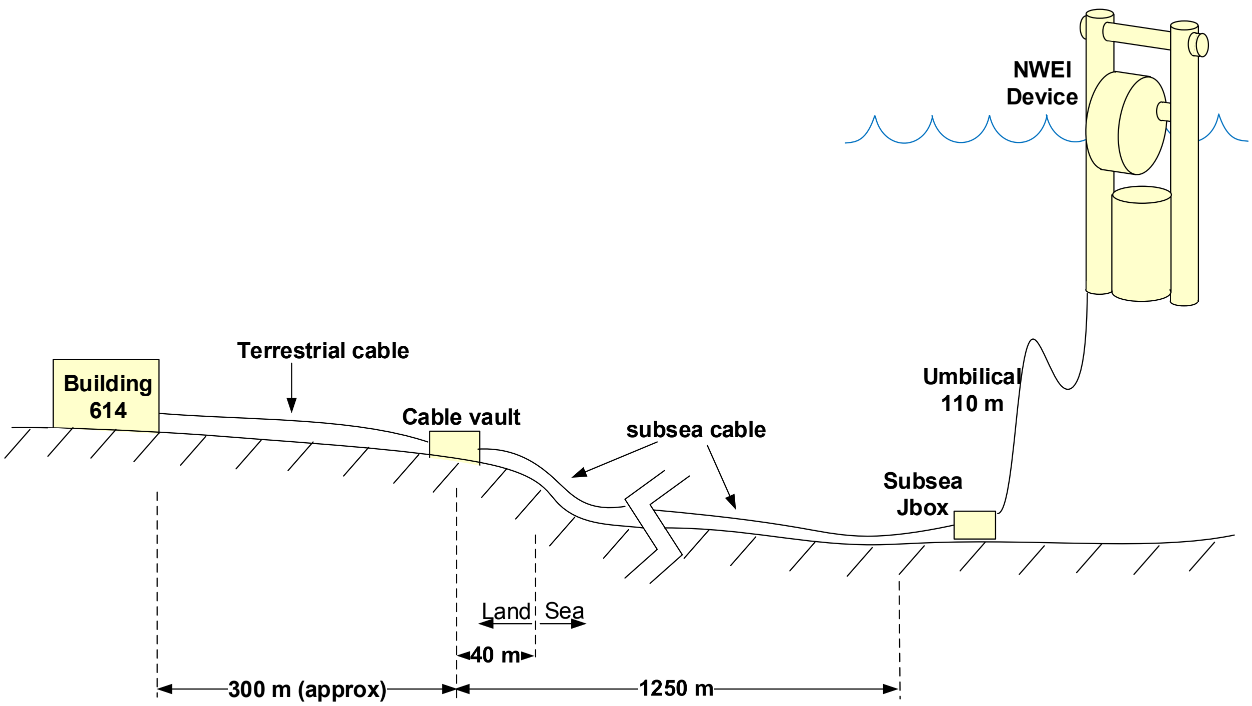

Figure 21: Cables between NWEI Device and building 614

Table 2: Cable Specifications

Cable	Umbilical	Subsea	Terrestrial
Length	110	1250 m	300 m (approx)
Power conductors	6 AWG	3 x 16 mm² (6 AWG)	6 AWG
Electrical resistance	0.15 Ω	1.49 Ω	0.42 Ω
Optical fibers	6x single mode	4x single mode	≥4 single mode

7.3. Data Acquisition and Instrumentation

The different data acquisition systems (DAS) that will be used to record data during the NWEI Device tests are listed in Table 3. Two instrumentation systems will be installed on the device: 1) NWEI offshore cRIO DAS inside the PowerPod that monitors internal PTO function; and 2) an externally mounted NREL cRIO DAS that monitors additional sensors. In addition, NREL will install a Nortek Acoustic Wave and Current profiler near the subsea junction box, on the seafloor near the device. All offshore data will be recorded and stored in each DAS itself and will also be transmitted to shore and stored on an NREL PC. In addition, wave data from a HINMREC waverider buoy and wind data from a NOAA Aviation Weather Center will be downloaded from web sites to the NREL PC. Refer to Appendix E for specific information for the NREL data systems, and Appendix G for a channel list for the NWEI cRIO DAS.

Table 3: Data Acquisition & Instrumentation Systems

System	Owner	DAS	Time synch	Primary data
NWEI offshore cRIO DAS	NWEI	NI cRIO[3]	GPS	Power, hydraulic pressures & flows, float position, & other NWEI Device internal measurements
NREL cRIO DAS	NREL	NI cRIO[2]	GPS	Power, Mooring force, 6 degree motion, GPS compass, depth, & measurements from NWEI device DAS
AWAC	NREL	Self contained	Via NREL cRIO	Wave & current
Waverider buoy	HINMREC	Via internet, NREL PC		Wave data
Wind data		www.aviationweather.gov/adds/metars/		Wind speed and direction
NWEI Inverter	NWEI	NREL PC	Via PC time	Inverter voltage, current, power
NWEI onshore cRIO DAS	NWEI	NI cRIO[3]	Offshore cRIO synch	Inverter voltage and current
Shore camera	NWEI	NREL PC	Via PC time	Device video

Communications between the device and shore are through fiber optics in the umbilical, subsea, and terrestrial cable as shown in Figure 22. An Ethernet to fiber converter on the device and on shore will

[2] National Instruments Compact RIO

provide two Gigabit Ethernet channels between the device and shore over a single fiber; one of these two channels will be a spare. AWAC data will be separately transmitted to shore via a serial over fiber link. Limited communications are also possible between the offshore equipment and shore via a 3G cellular link with an NREL installed router. An NREL desktop PC will be used as the user interface for all data systems. This computer will be operated remotely via remote desktop from outside building 614 during the deployment.

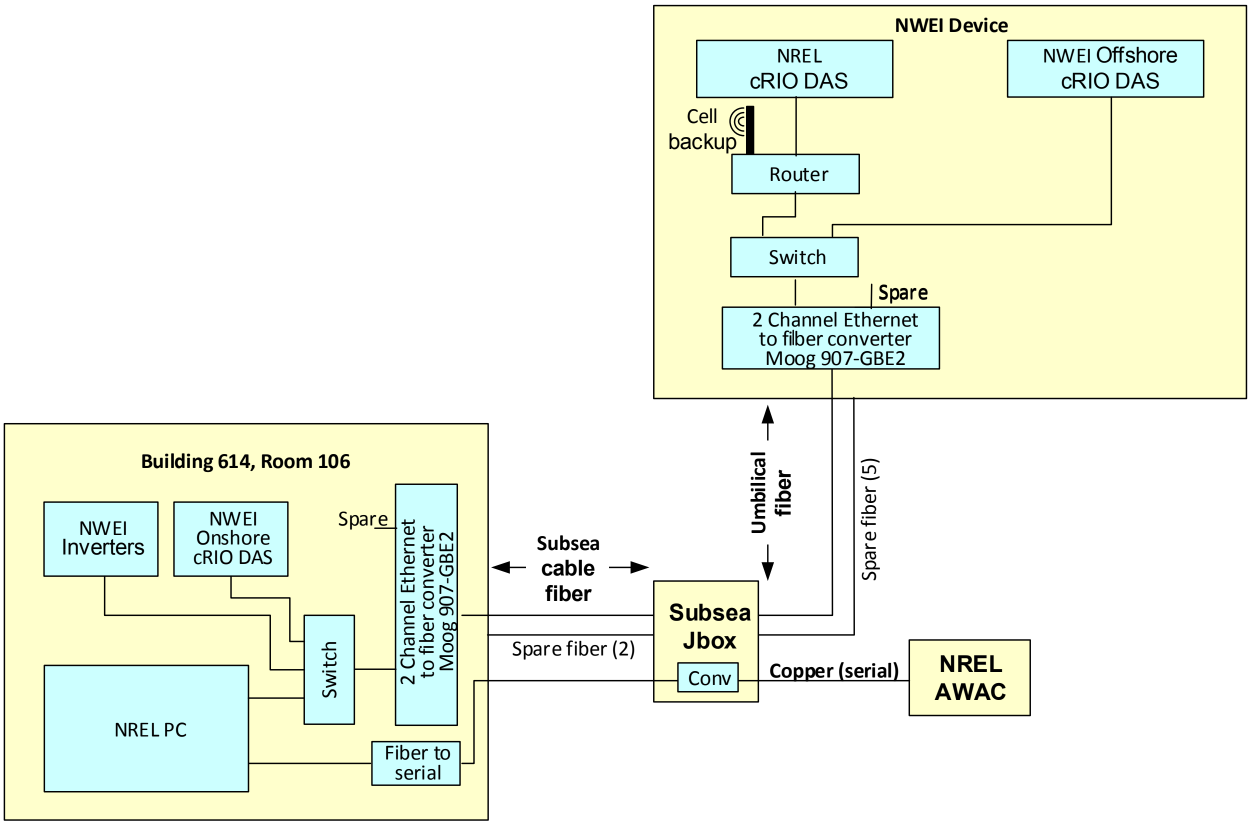

Figure 22: Data Acquisition & Instrumentation System Communications

8. Ocean Test Procedures

The following procedures will be used to test the NWEI device during the deployment period.

8.1. System commissioning and operational checks

The first one to two months of the deployment will be dedicated to commissioning and operational checks of the complete NWEI system, including the device itself and the NWEI grid interconnection and control equipment installed in building 614. Modifications will be made to the NWEI control software as necessary during this time to improve system performance. This phase of testing will include the following:

1. Verification of valid data collection from all sensors, for the data systems listed in Table 3.
2. Verification of inverter overvoltage protection via the dump load system described in Section 7.1.
3. Testing of NWEI control system shutdown during fault events such as loss of communications and loss of inverter grid connection.
4. Testing of onboard control power hold up by the NWEI UPS during simulated loss of building 614 grid power.
5. Verification of equal current sharing between the three parallel PowerOne inverters during normal operation.
6. Testing inverter overvoltage protection via inverter control; this is a slower system that increases inverter current at higher voltages to reduce dump load use.
7. Determining the minimum resistance setting that gives stable inverter control.
8. Testing with constant motor displacement and constant inverter resistance control under different sea conditions. Effectiveness of damping control with this method will be determined and the ability to limit peak voltage fluctuations with the dump load system will be verified.
9. Testing proportional-integral (PI) control of hydraulic motor displacement with constant inverter resistance control under different sea conditions. Effectiveness of damping control with this method will be determined and the ability to limit peak voltage fluctuations with the dump load system will be verified.

8.2. Characterization of performance with different control methods and parameter settings

These are the primary tests that will be performed during the deployment. During these tests, NWEI device power output and wave spectra data will be recorded while the device is operated with different control methods and parameter settings. Wave spectra data will be collected for each one hour period. The host computer that is the user interface for the NWEI onboard control system will be programmed to repeatedly cycle the onboard control between alternate control parameter settings every hour, so that a large set of data can be accumulated for the device operating in different sea conditions with different parameters. This data will be periodically analyzed to determine the most effective control parameters for different sea conditions. Data from all DAS listed in Table 3 will be recorded during these tests. These tests will be repeated for different control methods.

The goal of the NWEI control system is to operate the device with constant hydraulic resistance (force/velocity) applied to the float through the hydraulic cylinders in the PTO. The results of NWEI PowerPod dry tests at EHL, performed in July-August of 2014, indicate that PI control of hydraulic motor displacement provides the best approximation of constant damping with the NWEI system. This method will be tested along with an alternate, simpler method of operating with fixed hydraulic motor displacement. When using either control method, data will be collected with different parameter settings that will be chosen so that device operation will best approximate constant damping with the five different values of hydraulic resistance listed in Table 4. These values of hydraulic resistance were used for simulations of the device performed by IRL.

Table 4 Constant hydraulic resistance settings

Control Setting	Hydraulic resistance (Ns/m)
1	1.25×10^6
2	2.5×10^6
3	5×10^6
4	1×10^7
5	2×10^7

The goal of these tests will be to record at least three hours of output power data for each alternate control method and each parameter setting described above, for each significant wave height (Hm0) - energy period (Te) bin listed in the power matrix shown in Table 5. Note that due to Froude scaling, significant output power isn't expected from the half-scale device for periods longer than 10 s so these bins are not listed in Table 5, however, data will be recorded for the different hydraulic resistance settings in those longer wave periods as well when they exist.

Table 5 Power Matrix

Significant Wave Height H_{m0} (m)	Energy Period T_e (s)																	
	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19
0.5-1.0																		
1.0-1.5																		
1.5-2.0																		
2.0-2.5																		
2.5-3.0																		
3.0-3.5																		
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4.0-4.5																		
4.5-5.0																		
5.0-5.5																		
5.5-6.0																		
6.0-6.5																		
6.5-7.0																		
7.0-7.5																		
7.5-8.0																		

8.3. Collect power performance data

After the best control method is determined along with the optimum control settings for different sea conditions per the previous section, the device will be operated further with that control method to assess device power performance. Data recorded under these conditions will be provided to HINMREC for their independent assessment of device performance. During these tests, the host computer will be configured to automatically adjust the device control parameters to optimum settings for current wave conditions. This will be done by using ocean wave data collected during the previous hour and setting control parameters to the optimum values for those wave conditions during the following hour, using optimum settings determined during earlier testing. This will approximate the operation that would occur with an adaptive control able to continuously adjust settings to optimum values in order to maximize power output. Data from all DAS listed in Table 3 will be recorded with the device operating in this manner for an extended period of time. The wave and device output power data from this test will be used by HINMREC to assess power performance of the device.

8.4. Ballasting tests

During the deployment, the effect of changes in ballasting on device performance will also be measured. These tests will be conducted as follows:

- Tests will be performed in seas with medium wave heights having H_{m0} between approximately 1.0 m and 2.0 m, and near optimum energy periods for the device.
- Device control settings will be fixed at the value that gives the best performance for the sea conditions, based on Section 8.2 results.
- Data sets of at least an hour will be collected for different ballasting levels applied to the device. Data from all DAS listed in Table 3 will be recorded during these tests.

8.5. Mooring load measurements

Mooring load measurements will be included in the data recorded during the control characterization tests described in Sections 8.2; no additional tests are required to collect this data.

GLOSSARY OF TERMS & ACRONYMS

1:2 scale	The ½ ("half") scale NWEI Device, constructed and deployed at the NNMREC ocean test site in 2012 under the TRL 5/6 program. Also used to describe the first generation, 1:2 scale NWEI Device tested in New Zealand under the MEDF program.
1.5:1 scale	The currently projected size of a commercial scale WET-NZ device and the recommended scale of a TRL7/8 pre-commercial device.
AC	Alternating Current
ADCP	Acoustic Doppler Current Profiler
Active float *(or float)*	The surface floating body component of the NWEI Device, which is pivoted via a PTO shaft
DAS	Data Acquisition System
DC	Direct Current
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EMF	Electromagnetic Field
Full Scale Device	Reference dimensional scaling (defining linear dimension s=1) used by the project team to represent a projected NWEI Device that will perform in the full ocean wave environment, with nominal Hs up to 5m and Te up to 15 seconds. A power rating for a commercial-scale device based on a specific sea state (Hs, Te and spectrum), has not yet been developed, but will be below the peak power output of the device, likely between 250 kW and 1 MW.
half-scale	Refers to the "half-scale" terminology used to define scale in the WET-NZ development, which is based on an early estimate of a nominal full-scale device with a Power Take Off peak power output of approximately 200 kW, in a Hs = 5 m sea. Subsequent analysis of wave tank model testing and computer simulations suggest that a commercial-scale point absorber-like device can be larger, with a float area approaching 60 m2 and a weight in the order of 130 tons or more. See also "1:2 scale"
HINMREC	Hawaii National Marine Renewable Energy Center
Hull *(or reactive body)*	The largely immersed vertical body of the NWEI Device which provides the pivot-bearing support and reaction forces for the PTO
IRL	Industrial Research Limited, a New Zealand Crown Research Institute and co-founder of the WET-NZ consortium

kW Kilowatt, unit of power equivalent to 1 x 103 Watts

MHK Marine and Hydrokinetic (*i.e.,* ocean wave, ocean thermal, tidal current and current technologies)

NREL National Renewable Energy Laboratory, a U.S. DOE Laboratory

NWEI Northwest Energy Innovations, a wholly-owned subsidiary of Pacific Energy Ventures formed for the specific purpose of advancing the WET-NZ design in the U.S.

PEV Pacific Energy Ventures, a consulting and business development firm specializing in strategic marketing, project management, and governmental affairs in the renewable energy sector

PTO Power Take Off, the system for converting mechanical energy to electrical energy

SCADA System Control and Data Acquisition, a component of the NWEI Device system. There are two on the 1:2 scale NWEI Device, referred to as the "Orange" and "Black" boxes.

TC 114 Technical Committee 114, the International Electrotechnical Commission's Technical Committee responsible for International Standards for marine energy conversion systems

TRL Technology Readiness Level, a scale utilized by the public and private sector to track technology development phases. The scale begins at the concept level (TRL 1) and progresses to successful operation of actual equipment in the full operation environment (TRL 9).

WEC wave energy converter

Appendix A – 30m Site Report

Thirty-Meter Test Site Characteristics

Wave Energy Test Site (WETS)
Engineering Services Support

Contract N62583-09-D-0064
Task Order 052
CDRL A018
Rev 01
Prepared for
Naval Facilities Engineering Service Center
Contract No. N62583-09-D-0064
15 November 2012

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1.0 INTRODUCTION

1.1 Background

Emerging renewable and alternative energy sources are crucial to Navy objectives for reducing dependence on fossil fuel, reducing “carbon footprint” with respect to global climate change and developing energy independence for Navy, Marine Corps, and selected other coastal facilities around the world.

Continuing developments in renewable ocean energy industry indicate that the availability of pre-permitted test sites for the several technologies is crucial to development, demonstration, and implementation of viable ROE systems. Efforts to assess and pursue ocean renewable energy demonstration projects at Naval and Marine Corps bases situated in geographic areas favorable to specific renewable energy technologies require test facilities that provide conditions representative of those areas. The Navy and USMC are in a unique position to facilitate the development of these test sites at selected locations.

The NAVFAC Engineering Service Center has undertaken a project to develop an expanded wave energy test facility that will leverage the unique position of Marine Corp Base Hawaii Kaneohe (MCBH-K). The expanded test facility will develop two deep-water sites for testing large wave energy devices and incorporate an existing shallow water site located about one kilometer off shore in a water depth of 30 meters.

The infrastructure for the existing 30 meter site was developed and installed between 2000 and 2003. It was used to test various wave energy devices developed by Ocean Power Technology (OPT) between 2003 and 2012. With the completion of the OPT testing and removal of their wave energy device in July of 2012, the test site has become available for testing devices from other wave energy developers.

1.2 Scope

This report provides a summary of the site characteristics and as-built designs of the power transmission, mooring components, and onshore facilities for the existing thirty-meter test site.

2.0 SITE DESCRIPTION

2.1 Location

Marine Corps Base Hawai’i – Kane’ohe (MCBH-K) is located on the east coast of Oahu. The general location is shown in Figure 1. The base is located on the windward side of O’ahu approximately 12 miles northeast of Honolulu and occupies the Mokapu Peninsula, which connects to the mainland near the cities of Kane’ohe and Kailua. The main access to the base is by either State Highway 3 (H-3) or by Mokapu Road. Honolulu and Pearl Harbor are reached by using Likelike Highway and/or Highways H-1 and H-2. MCBH Kane’ohe Bay has a 7,500-foot runway and supporting taxiways which, in addition to normal air operations, are used for access to the outer island training areas. The base also has a 600-foot fuel pier and waterfront area, used for loading tank landing ships (LST's) and small boats for transporting equipment off-island.

MCBH is located at 21°26′37″N 157°44′56″W / 21.44361°N 157.74889°W (21.443580, -157.748883).

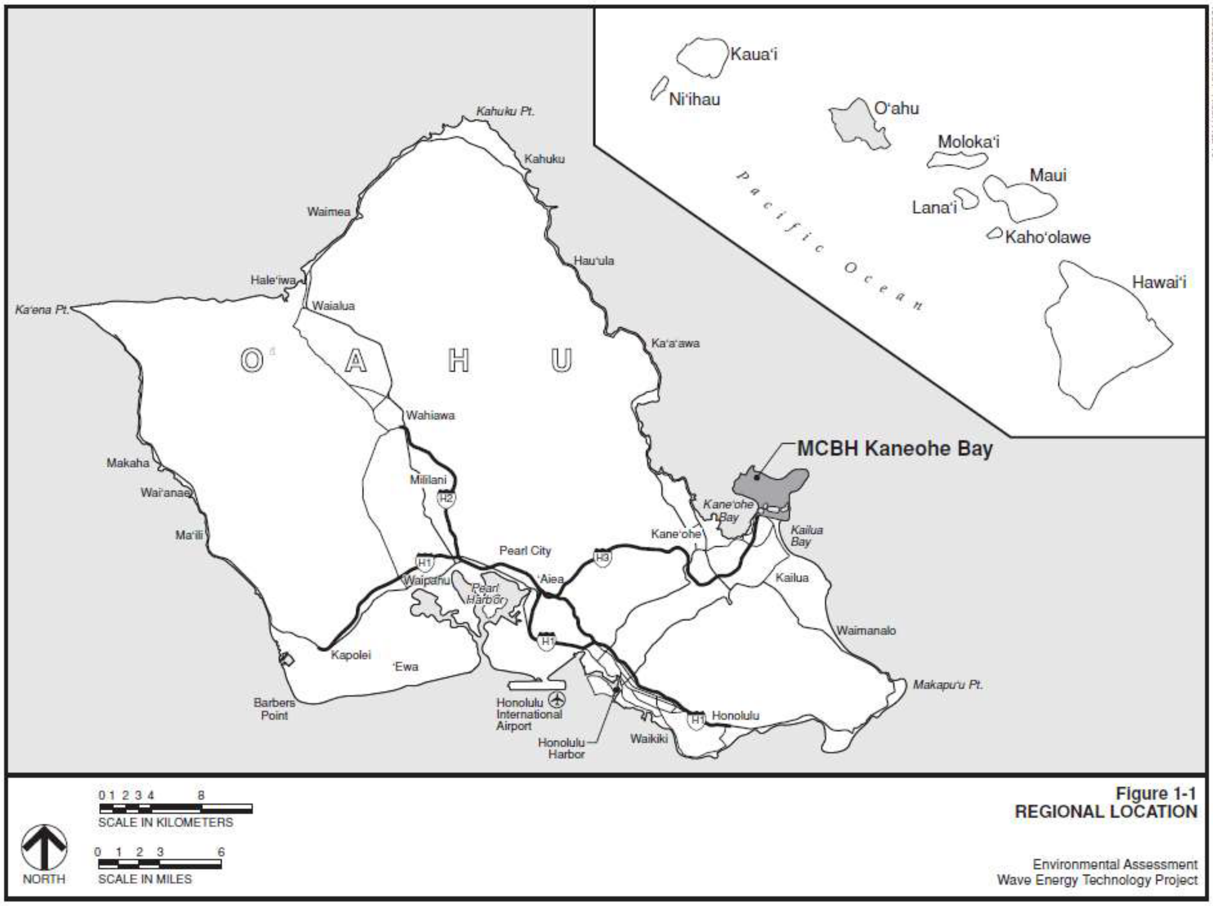


Figure 1- Location of MCBH on the East Coast of O'ahu, HI

Geographically, the Mokapu Peninsula is a large, generally flat plain oriented north-south, having two steep "parasitic" volcanic cones near the north shoreline. The majority of level land has been developed for runways, hangars, operational and support facilities, and military housing. A large portion of the remaining level land is tidal lowlands and ponds, which are protected for wildlife conservation. Figure 2 shows a satellite view of the base and environs.

Figure 2 - Marine Corps Base Hawai'i – Kane'ohe (MCBH-K)

2.2 Geology

2.2.1 Geology of the Hawaiian Islands

The Hawaiian Island chain lies nearly at the center of the world's largest ocean basin, thousands of miles from any tectonic plate boundary. Geologically, the islands owe their origin to the presence of a 'hot spot,' a small plume of abnormally hot molten rock pushing up through the Earth's mantle. Because of its persistence in situ over nearly 60 M years, the spot seems to be firmly rooted in the Earth's interior. As the Pacific Plate moves slowly northwestward at a rate of several centimeters per year, the hot spot punches up through the plate. Fluid basaltic lava extrudes onto the sea floor and gradually builds a "shield" volcano, which continues to grow until the movement of the Pacific Plate carries it past the source of magma. Over millions of years, this process has produced a series of volcanoes, one after another in assembly-line fashion. The result is a chain of volcanic islands (the Hawaiian Archipelago) that consists of eight major islands and 124 islets stretching from the Big Island of Hawai'i along a northwest line for 1,500 miles toward Japan and the Aleutian Islands of Alaska. In total, the islands spread across an area of 6,459 square miles.

2.2.2 Geology and Geomorphology of O’ahu, the Ko‘olau Volcano and Kane’ohe Bay

The island of O’ahu is the third largest in the Hawaiian chain, with an area of 1574 km2, and lies in the eastern Pacific Ocean at approximately 21°30'N and 158°00'W. The bulk of the island consists of the heavily eroded remnants of two shield volcanoes formed over the Hawaiian hotspot: Wai’anae Volcano in the west, and Ko’olau Volcano in the east.

The area near Kane’ohe Bay was once part of the crater floor but was filled in with lavas and rock debris over a million years ago. The bay we see now is not directly related to a volcanic crater. Hawaiiloa and Ulupao Craters on Mokapu Peninsula are late-stage eruptive features, formed when the Hawaiian hot spot had nearly cut off the vents to Ko’olau Volcano. Like the more famous Diamond Head and Koko Head craters, Ulupao and Hawaiiloa are primarily cinder cones from small vents, made of interbedded volcanic ash, pumice and cooler lavas (and thus thicker, and able to sustain much steeper slopes than the hotter basalts). These two peaks are the first of a series of more than 40 similar cinder cones that cross the island of O’ahu.

2.2.3 Seafloor Geology

At the 30-meter site, the 100-foot contour is approximately 3,400 feet off the runway. The bottom between the 100 and 50-foot contours slopes upward at a rate of rise of 1V on 18H. From the 50-foot contour to the 20-foot contour the slope decreases to 1V on 65H.

Diver tows were made by Sea Engineering Inc. to determine the bottom conditions in both of these areas. Divers were towed behind the boat, using hand held planning boards to control depth. Differential GPS was used to navigate and record position during the tows. The dotted lines on Figure 3 show the tow tracks.

The bottom at the Site is described in Table 1:

Table 1 – Seafloor Characteristics from Shore to 100 foot Water Depth

Water Depth	Description
100’	Flat bottom, hard limestone, with scattered sand veneer
100’ to 90’	Flat bottom, limestone with scattered thin sand patches
90’ to 40’	Bottom slopes steadily upward, averaging 1V on 25 H. In the deeper part of this area, bottom is flat limestone with little vertical relief. Irregularities increase slightly with distance inshore, with some potholing and minor vertical relief.
40’ to 30’	Bottom varies - there is flat bottom with minor vertical relief in some parts of this depth zone, very irregular bottom in other areas (see description of 30’ to 20’ area, below).
30’ to 20’	This is an area of very irregular bottom over a 600 feet wide zone, with numerous ledges and overhangs. Large slabs of limestone bottom are undercut and many have slumped into deeper pockets of the bottom. Vertical relief is 5 to 6 feet.
20’ to 0’	Sand patches interspersed with flat scoured limestone. Protruding basalt ridges just offshore (photo 1).

Figure 4 and Figure 5 show typical conditions at the 100-foot water depth. The bottom is flat limestone, with little vertical relief. There is scattered sand in some of the small depressions in the limestone. No large sand deposits were observed during the diving, but it is possible that sand deposits are present in the general area. The relatively flat, featureless limestone bottom continues up the slope. The bottom irregularity increases somewhat at the 50 to 60-foot depth, but not enough to preclude a cable route. Figure 6 and Figure 7 show typical conditions in this area. The scattered coral and limestone outcrops forming the irregularities can be avoided during cable placement. The bottom becomes more irregular between the 20 and 30-foot depth contours, as shown in Figure 8 and Figure 9. A cable route in this area will have to cross small ledges and surge channels, however, the route through this zone will be optimized to avoid as many of these features as possible. This zone is approximately 600 feet wide. Inshore of the 20-foot contour, the limestone bottom gradually gives way to a thin sand deposit with scattered outcrops of scoured limestone.

Figure 10 shows a view looking toward the runway. Figure 11 thru Figure 13 show the shoreline conditions at the proposed landing site. The backshore around the runway is undeveloped, and access is restricted. However, winches and other equipment required for a cable landing can be easily mobilized to the shoreline at the site.

2.2.4 Summary

In general, inspection of the bathymetric records indicates that bottom conditions throughout the study area are relatively even from the 100-foot depth inshore to the 30 to 40-foot depth. Bottom irregularity and increased vertical relief was a common feature of all records between the 20 and 30-foot depth, and in some areas this zone extended out to the 40-foot depth.

In many areas around the Oahu, an old sea level stand is defined by a steep ledge at the 40 to 70-foot depth. This ledge can be the main obstacle to cable routing. However, this ledge was not observed in any of the survey work completed for this project. There is a steeper slope in these depths, but the bottom is relatively even.

Sand channels connecting beach areas to deeper offshore deposits offer ideal cable routes, but we found no evidence of such channels in the project area. The vertical aerial photograph of the area confirms this. Therefore, any cable route will have to cross the zone of higher vertical relief in the 20 to 30 foot water depths. Minimizing the amount of irregular bottom to be crossed will be an important factor in the final route selection.

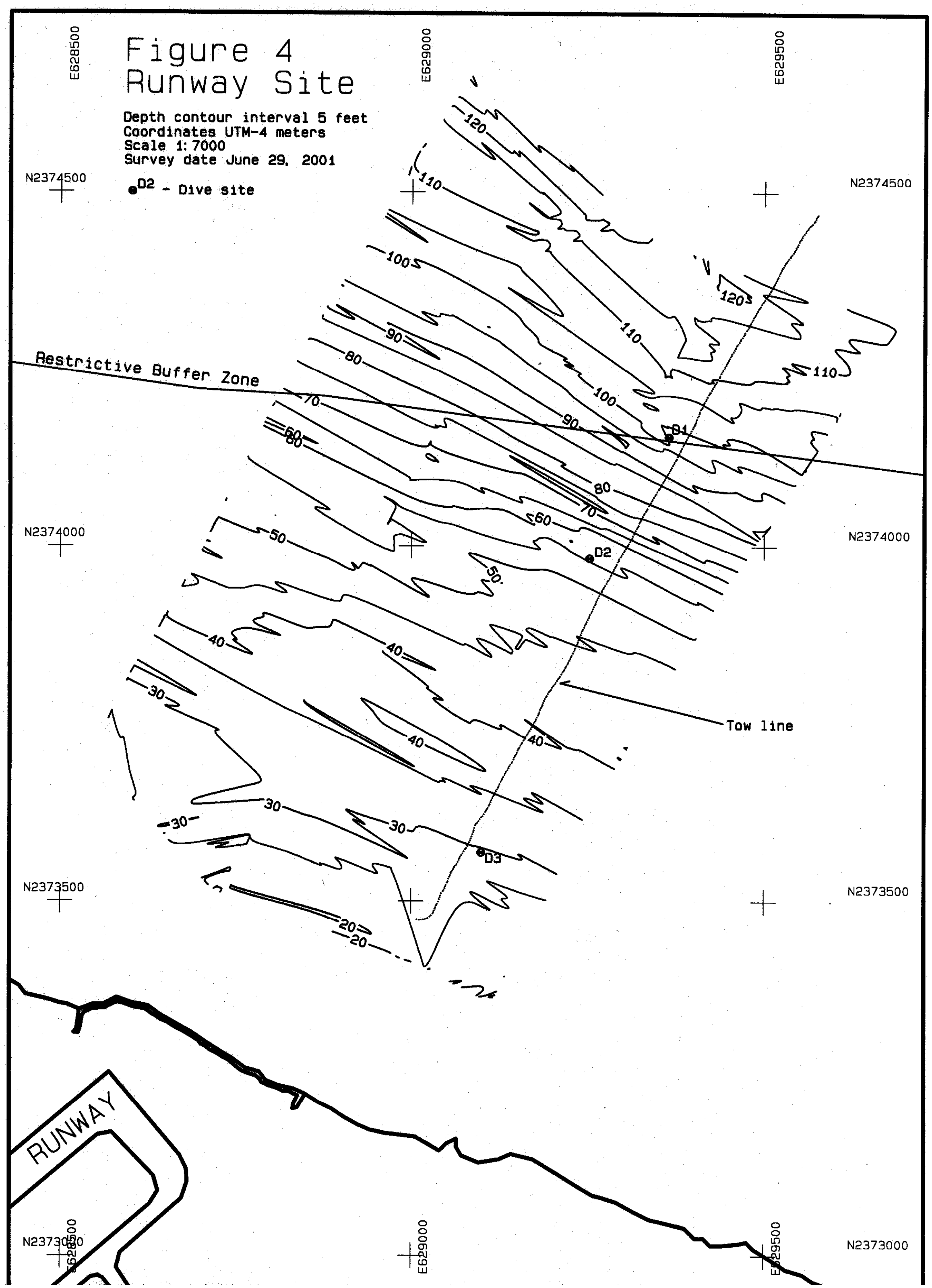


Figure 3 –West Site

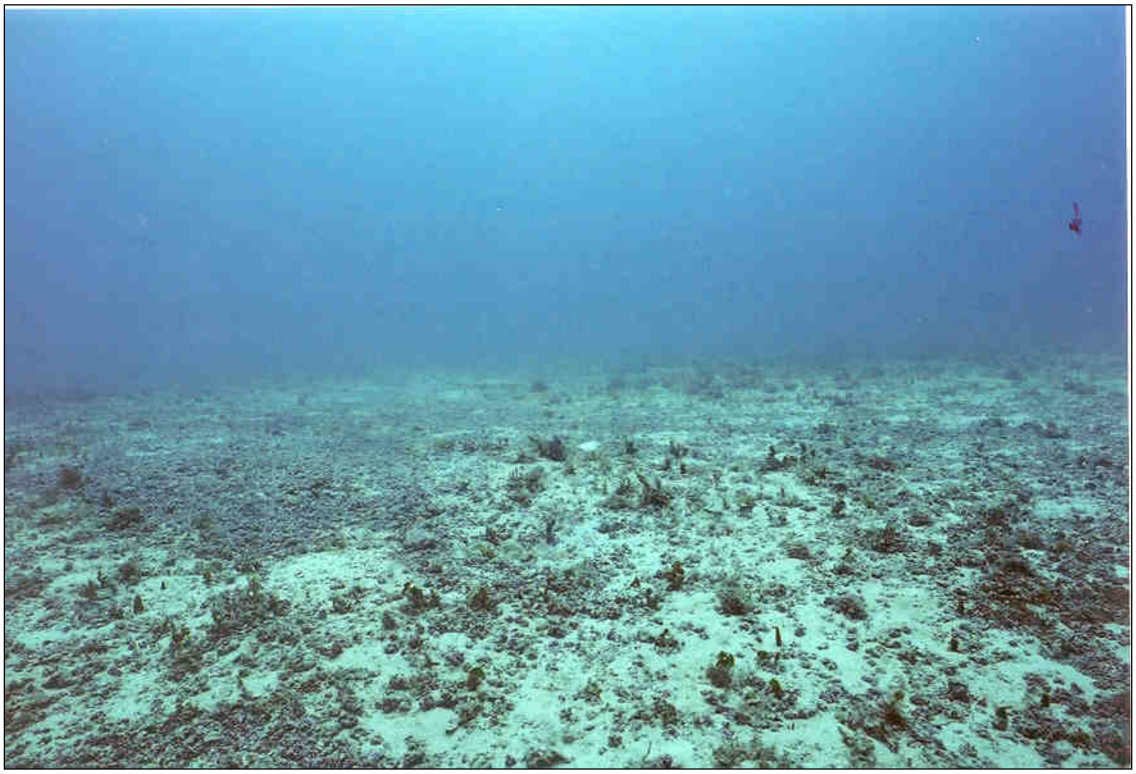


Figure 4. Typical Conditions at Dive Site 1, 100-Foot Water Depth

Figure 5 - Typical Conditions at Dive Site 1, 100-Foot Water Depth

Figure 6 - Typical Conditions at Dive Site 2, 55-Foot Water Depth

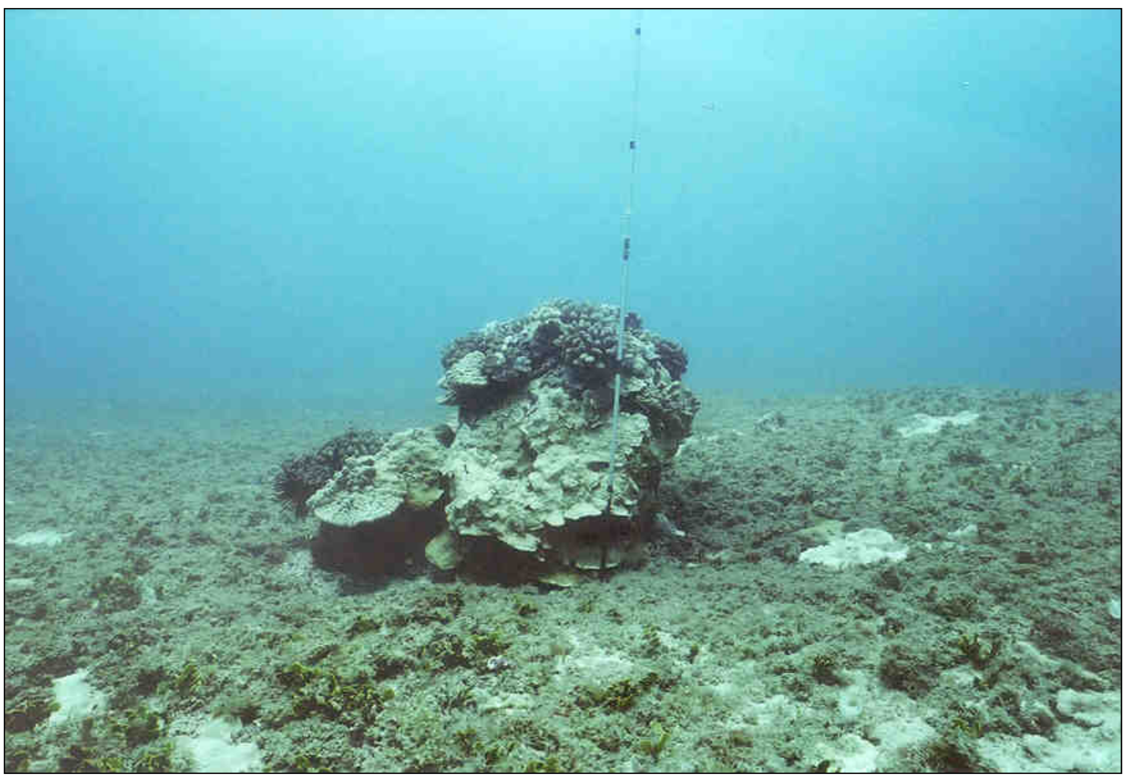


Figure 7 - Typical Conditions at Dive Site 2, 55-Foot Water Depth

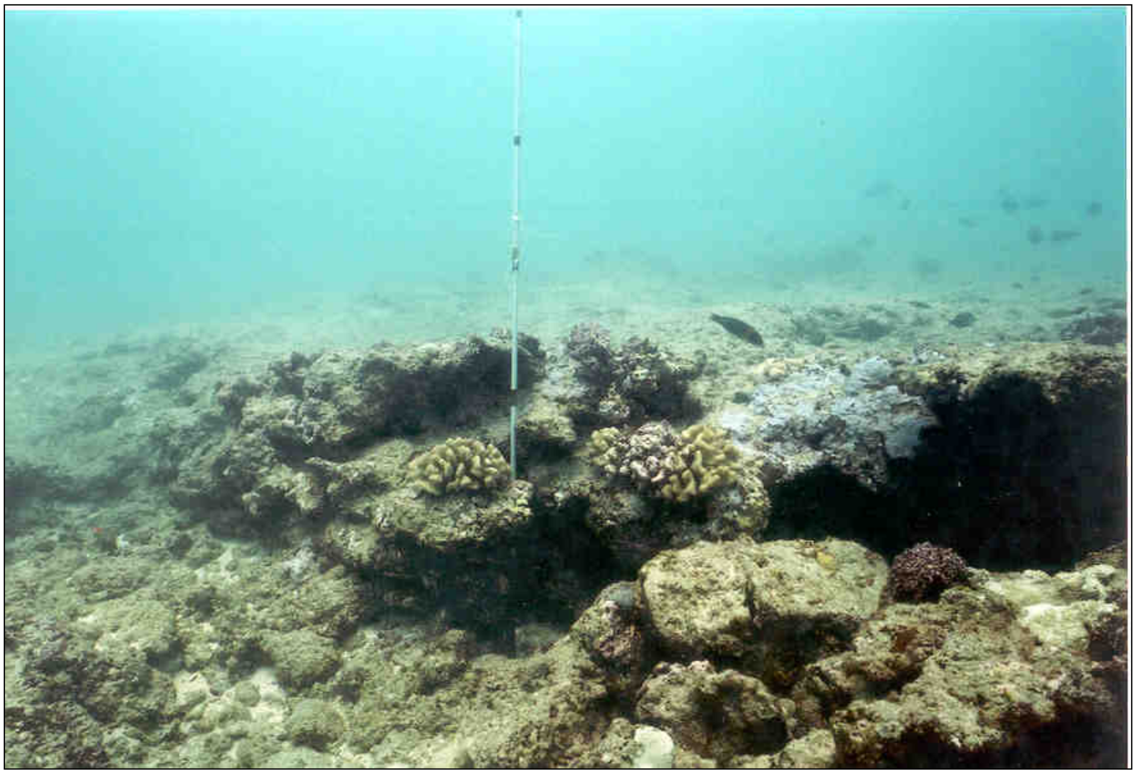


Figure 8 - Typical Conditions at Dive Site 3, 30-Foot Water Depth

Figure 9 - Typical Conditions at Dive Site 3, 30-Foot Water Depth

Figure 10 - Shoreline at Runway Landing Site

Figure 11 - Shoreline View, Looking Toward Runway Landing Site

Figure 12 - Offshore View, Runway Landing Site

Figure 13 - View Looking Shoreward From Top of Rocks, Runway Landing Site

3.0 PHYSICAL ENVIRONMENTAL FACTORS

3.1 Climatology

3.1.1 Regional Climate

The Hawaiian Islands are located at the northern edge of the Tropic Zone, where the climate is generally mild throughout the year. During the summer months, average temperatures range from approximately 32°C (90 F) during the day to 23 C (73 F) at night. Average temperatures during the winter and early spring months range from daytime highs of about 26 C (79 F) to nighttime lows of 15 C (59 F). Average relative humidity varies between 50 percent in the afternoon to over 90 percent at night.

The frequency of trade winds varies greatly in the Hawaiian Islands. The islands may experience extended periods of no winds followed by days of constant trade winds. In general, the Trades are more persistent in the summer months than during the winter season. Northeasterly trade winds prevail over O'ahu throughout most of the year and comprise "onshore flow" wind conditions at MCBH Kane'ohe. On the open seas, trade winds average less than 25 kilometers per hour (15 mph) and are slightly stronger in summer than in winter.

Moderate to strong southerly winds associated with weak frontal passages and "Kona" low pressure systems occur periodically during the winter months and often blow offshore at MCBH. Morning upslope (onshore) flow toward the Ko'olau Range and evening offshore flow are a reflection of local land-sea breeze effects and may temporarily enhance or weaken trade winds.

3.1.2 Climate of Kane'ohe MCBH

The following statistics are recorded for the former Kane'ohe Marine Corps Air Station (KMCAS), Kane'ohe, Hawaii, now known as MCBH Kane'ohe:

KMCAS weather station call sign: 911760 (PHNG)
Latitude: 21°27.00'N
Longitude: 157°46.00'W
Altitude: 5 m above MSL

Based upon information from the NOAA U.S. Daily Climate Normals 1971-2000, the climate at Kane'ohe MCAS, now Marine Corps Base Hawai'i (MCBH), is typically warm, with partly to mostly cloudy days and light to moderate winds. The average daily high temperature is 81.5°F, the average low is 72°F and the annual average temperature is 76.5°F. Relative humidity ranges from 42 to 96% with a daily average of 80%; rainfall averages just under 40 inches per year, peaking twice, in February and November. The atmospheric pressure typically ranges from 1006 to 1024 mb with 3 or 4 winter storms bringing trough (weakened cold front) lines across the Hawaiian chain for a brief period of lower pressure. The average (local) wind direction is from the SW at 11 knots (affected by local topography), with an average annual maximum wind of 36 knots from the ENE during strong trade wind periods. In the offshore areas the trade winds will dominate.

3.1.3 Winds

International Station Meteorological Climate Summary (ISMCS) (1996) jointly produced by Fleet Numerical Meteorology and Oceanography Detachment, National Climatic Data Center, and USAFETAC OL-A provides annual and monthly summaries of winds based on hourly observations and monthly peak gusts measured at Kaneohe Bay Marine Corps Air Station (MCAS). The weather station is located at 21^{o} 27'north and 157^{o}47'west.

The wind summaries are presented in Appendix A and the peak gusts are given later in the section of extreme wind conditions. The summaries are based on wind data collected during the period between 1945 and 1995. The winds are two minute averages taken hourly for a 24-hour day.

Tables A-1 to A-13, in Appendix A, give the percent frequency distributions for winds at the weather station. Table A-1 gives the annual distribution and Tables A-2 to A-13 give the monthly distributions. Annually over 70 percent of winds were tradewiinds from the northeast through east-southeast clockwise with an average speed of approximately 10 knots (5 m/s). The easterly tradewinds were most frequent in summer months. The gust winds are discussed later in this report.

3.1.4 Waves

The general Hawaiian wave climate can be described by four primary wave types: northeast tradewind waves, North Pacific swell, south swell and Kona storm waves. The project area is sheltered from south swell and Kona storm waves by the island of Oahu itself.

Northeast tradewind waves may be presented in Hawaiian waters throughout the year, but are most frequent in summer months, when they usually dominate the Hawaiian wave climate. They result from the strong and steady tradewinds blowing from the northeast quadrant over long fetches of open ocean. Typical deepwater tradewind waves have periods of 5 to 8 seconds and height of 1 to 3 m.

North Pacific swell is produced by severe winter storms in the Aleutian area of the North Pacific and by mid-latitude low-pressure systems. North swell may arrive in Hawaiian waters throughout the year, but it is largest and most frequent during the winter months of October through March. The North Pacific swell approaches from the sector west through north, with periods of 13 to 20 seconds and typical deepwater heights of 1.5 to 3 m. The site is partially sheltered from the approach of North Pacific swell, and only the more northerly of these swells arrive at the site.

In addition to the two primary wave types, infrequent tropical cyclones may generate large waves, which can impact any coastal area of Hawaii.

The Scripps Institution of Oceanography deployed a wave buoy 4.5 miles southeast of Mokapu Point, Oahu (Figure 14) and has been measuring waves since August 9, 2000. The buoy is located at 21^{o}24.9' north and 157^{o}40.7' west at the water depth of 100 meters. This buoy provides wave data directly applicable to the project site, since the exposure at the two sites is the same. For our analysis, we used the data collected for the 10-month period between August 2000 and June 2001.

Tables A-14 to A-25, in Appendix A give the percent frequency distributions for waves measured at the buoy location. The wave height is a spectrally based significant wave height, which is derived from the zeroth moment of the reported energy spectrum; i.e., $H_{m0} = 4(m_0)^{1/2}$. This spectrally based wave height is approximately equal to the statistically defined significant wave height in deepwater, which is an average of top one-thirds of wave heights. However, as wave shapes deform in shallow water, the statistical significant wave heights exceed the spectrally based wave heights. The wave period is associated with the highest energy in the reported spectrum.

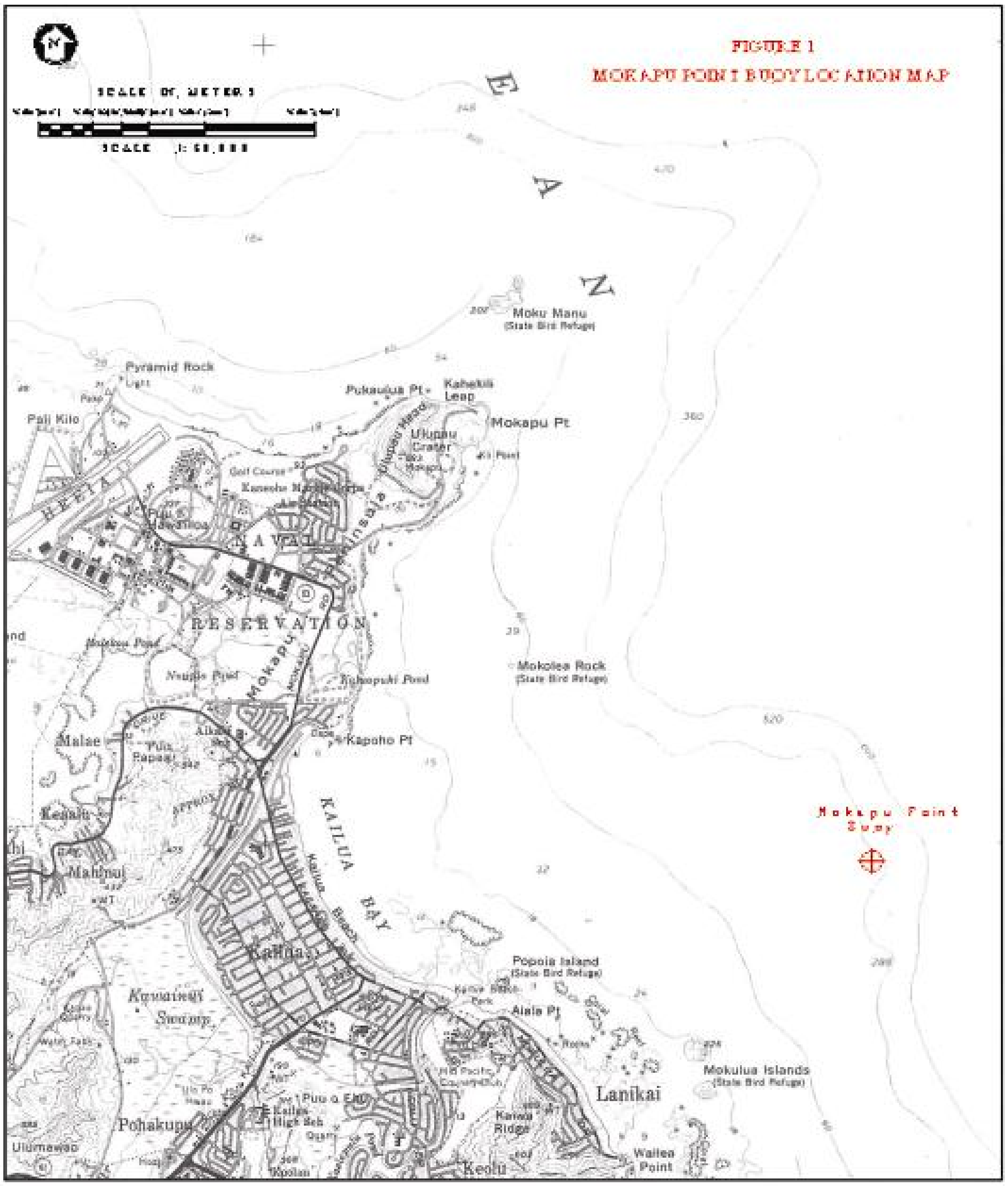


Figure 14 – Mokapu Point Buoy Location

Table A-14 gives the annual distribution and Tables A-15 to A-25 give the monthly distributions. During the 10-month duration, wave periods ranged from 4.0 to 22.2 seconds. The largest wave height was 4.5 m recorded in August. Approximately 90 percent of waves had a wave period less than 12 seconds, indicating almost 90 percent of reported waves were wind waves and only 10 percent were swell.

The wave data at the measurement location was transformed to a water depth of 30 m by applying wave shoaling, which is based on linear wave theory. Since the exact proposed buoy location is not known, refraction and diffraction effects were not included in this analysis. The results are presented in Tables A-26 to A-37. Table A-26 gives the annual distribution and Tables A-27 to A-37 give the monthly distributions. The information in Tables A-13 to A-25 can be considered representative of typical prevailing wave conditions at the site. The largest significant wave height at the 30 m water depth for the ten-month period was calculated to be 4.2 m. The recording duration covered by the data did not include a severe storm or a major hurricane. Hurricane waves are discussed later in this report. The largest waves occurred in February and August with wave periods ranging from 8 to 10 seconds. In general, larger and longer period waves were recorded in the winter months than in the summer months.

The predominant directions and frequency of occurance of significant wave heights is shown in the wave rose diagram presented in Figure 15.

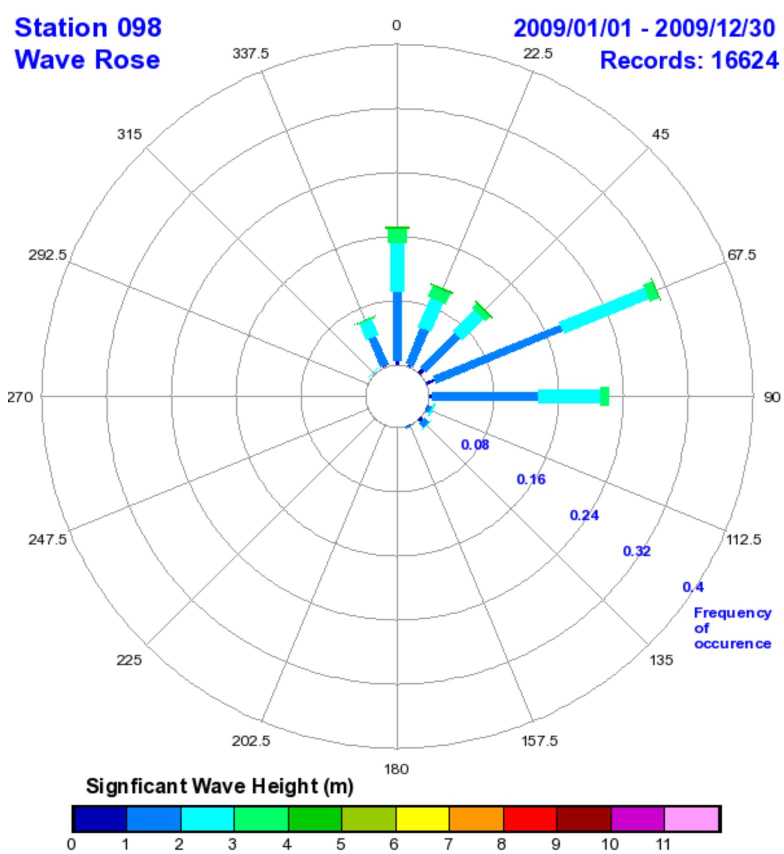


Figure 15 - Swell and Sea Predominant Directions (Mokapu Waverider)

4.0 EXTREME CONDITIONS

4.1 Tsunamis

The Hawaiian Islands have a history of destructive tsunamis. Since 1819, twenty-two severe tsunamis have occurred, with wave heights ranging from 4 to 60 feet. The resultant tsunami wave height at the Hawaii coastline during a given occurrence varies greatly from location to location. The height is affected by a number of factors including offshore bathymetry, coastal configuration and exposure to the generating area. In 1978, M&E Pacific, Inc. prepared a manual for determining tsunami wave elevations along the coastline of Hawaii for various frequencies of occurrence. This manual has become the accepted standard, and the methods they developed have been used to develop the Flood Insurance Rate Maps for the state. The manual has a table of predicted tsunami elevations for statewide locations for a 10-year return period and a method to calculate tsunami heights for return period greater than 20 years. The predicted 10-year height for the project area is 2.5 feet above mean sea level, at a point 200 feet inland of the coastline. The calculated 25-year height is 6.8 feet. There is no record of bore formation in this area of Oahu, so the tsunami can be expected to take a form of a rapidly rising and falling tide, with a wave period of approximately 10 to 15 minutes.

4.2 Winds

The International Station Meteorological Climate Summary (1996) jointly produced by Fleet Numerical Meteorology and Oceanography Detachment, National Climatic Data Center, and USAFETAC OL-A provides monthly peak gusts based on daily measurements at Kaneohe Bay Marine Corps Air Station (MCAS). The peak gusts are instantaneous winds and specific time duration for the gust is not defined. Table A-38 presents the monthly peak gusts measured at the site during a period between 1948 and 1995. When 90% or more of the daily observations of peak gust data are available for a month, the extreme is selected and presented. Table A-39 summarizes the monthly wind conditions, including average winds, peak gusts, and estimated 1-minute and 10-minute wind speeds. The average wind speeds are measurement-based speeds from Tables 2 and 13, but the 1-minute and 10-minute wind speeds are calculated by assuming that the peak gusts on Table A-38 are 3-second wind speeds. The calculations of 1-minute and 10-minute wind speeds were calculated based on methodology described in *Shore Protection Manual* (1984).

The thirty-six annual peak gusts listed in Table A-38 were used to determine the statistical peak gusts for given return periods, using Gumbel's asymptotic distribution. The predicted peak gusts were further converted to the 1-minute and 10-minute wind speeds. The predicted gusts for the 2-year, 5-year, 10-year and 25-year events are 23.7, 29.9, 34.2 and 39.5 m/s, respectively. Corresponding 1-minute wind speeds are 19.5, 24.6, 28.2 and 32.5 m/s, and 10-minute speeds are 15.7, 19.8, 22.6 and 26.1 m/s. The results are summarized in Table A-40.

During Hurricane Iwa in November 1982, the peak gust recorded at MCBH was 80 knots (41.2 m/s), which was greater than the 25-year peak gust. During Hurricane Iniki in September 1992 the peak gust was 55 knots (28.3 m/s), which was approximately the 5-year peak gust.

4.3 Waves

The project site is exposed to North Pacific Swell and tradewind generated waves. Extreme wave conditions for these two wave types are discussed below.

4.3.1 Extreme North Pacific Swell

The annual percent frequency distribution for wave data at the Mokapu Point buoy is given in Appendix A - Table A-14. Although the less than one year of data recording duration was not sufficient to predict long-term wave heights, we used the data to attempt to estimate the swell heights for given return periods. Waves with a period greater than 12 seconds were used for swell analysis.

To evaluate the probability of occurrence of severe swell conditions, a cumulative provability function is developed for the wave height based on information in Table 14. The probability of exceedance versus the wave height was modeled to fit the Weibull Distribution given by:

$$P(H) = exp[-\{(H-b)/a\}^c]$$

where, $P(H)$ is the probability that H is exceeded, and a, b and c are constants. For simplicity we assumed $c = 1$. We were interested in large waves for this analysis and we limited to the largest 30% of waves for the analysis. Then the probability $Q(H,Y)$ that the wave height H would not be exceeded over a specified number of years Y is defined as:

$$Q(H,Y) = [1-P(H)]^{Y/m}$$

where m = average time between uncorrelated wave height observations.

During a period of time Y, there will occur Y/m waves, which are statistically independent, and each one of waves has a chance $[1-P(H)]$ of not exceeding H. The risk of exceedance R is then expressed by:

$$R = 1 - Q.$$

Combining these equations the wave height H is express in terms of the period of time Y and the risk R as:

$$H = [\ln\{1-(1-R)^{m/Y}\}-a_1]/b_1$$

Where a_1=b/a and b_1=-1/a.

We assumed that an average time between uncorrelated waves was 24 hours in calculations of wave heights for given periods. The results are summarized in Table A-41 for a risk of exceedance of 30%. The predicted swell heights for the 2-year, 5-year, 10-year and 25-year return periods are 3.7, 3.9, 4.0 and 4.2 m, respectively. The periods for these waves can be expected to range from 12 to 24 seconds.

Corresponding swell heights versus return periods at the 30 m water depth were similarly determined using the data in Table A-26. Table A-42 summarizes the results. In 30 meters of water, swell heights of 3.7, 3.9, 4.1 and 4.3m correspond to 2, 5, 10 and 25-year return periods, respectively. The wave heights in 30 m of water are nearly similar heights at the buoy site.

4.3.2 Wind Waves

Extreme wind waves were also estimated using the same analysis used for swell. The waves with a period less than 14 seconds were defined as wind waves. The predicted wind wave heights for the 2-year, 5-year, 10-year and 25-year return periods are 4.5, 4.8, 5.0 and 5.3 m, respectively. Corresponding wave heights at a water depth of 30 meters are 4.1, 4.3, 4.5 and 4.8

m, resulting in slightly smaller wave heights than the waves at the buoy. These results are given in Table A-43 for the wind waves at the buoy and in Table A-44 for the wind waves at a 30-meter water depth.

4.3.3 Hurricane Waves

In any given year, one or more hurricanes can be expected to occur in the central North Pacific Ocean. Although hurricanes occur infrequently in the immediate vicinity of Hawaii, they do occasionally pass near the islands. Notable recent examples are Hurricane Iwa, which passed within 30 miles of Kauai in 1982, and Hurricane Iniki, which passed directly over Kauai in 1992. Because hurricanes directly impact the Hawaiian Islands at such infrequent intervals, there is no realistic method to calculate a return period.

Wave hindcasts of Hurricanes Iwa and Iniki for the project area on the windward coast of Oahu indicated that the waves generated in those hurricanes approached from the southeast through the west clockwise, preventing those waves from directly approaching the project site. The project site would be relatively sheltered from severe storm waves during Hurricanes Iwa and Iniki.

Storms with hurricane intensity rarely pass directly north of the Hawaiian Islands. The most recent historical hurricane passing north of the islands was Hurricane Hiki in 1950.

4.3.4 Design Wave Parameters

The University of Hawaii, Hawaii National Marine Renewable Energy Center recently conducted a study of the wave environment for various locations around the Hawaiian Islands. In that study, they used the peaks-over-threshold (POT) method to estimate the extreme wave periods and wave heights at the sites of interest. These data are of particular importance for designing wave energy devices exposed to rough seas. The outcomes of the analysis are the 100 years significant wave heights and periods (Table 2). It should be noted that the statistics for each variable have been treated independently therefore, the extreme values of Hs and Tp are very likely not related to the same event.

Table 2 – Extreme Significant Wave Height and Period for WETS Sites

Site	Latitude (N)	Longitude (W)	Water Depth (m)	Hs, 100yrs (m)	Tp, 100yrs (s)
Kaneohe	21.465	157.752	27	5.30	15.43
Kaneohe II	21.472	157.747	58	5.53	15.79

5.0 WAVE ENERGY RESOURCE

The average monthly wave power flux (Table 3) for the two Kaneohe sites was estimated using Equation 1. The median, 5th and 95th percentile of the wave power flux were also estimated and are shown in Figure 17 and Figure 19 below. The sites are characterized by significant seasonal variation, with the largest fluctuation occurring between winter and summer months.

The average daily and monthly wave energy power flux for each site is shown in Figure 16 through Figure 19.

$$\boldsymbol{P} = \boldsymbol{\rho g} \int_{\omega=0}^{\omega=\infty} \boldsymbol{Cg}(\boldsymbol{\omega}, \boldsymbol{h}) \left(\int_{\theta=0}^{\theta=2\pi} \boldsymbol{S}(\boldsymbol{\omega}, \boldsymbol{\theta}, \boldsymbol{h}) \boldsymbol{d\theta} \right) \boldsymbol{d\omega} \qquad \textbf{(Eq 1)}$$

where,

- $S(\omega,\theta,h)$ = local wave spectrum
- θ = wave direction
- ω = wave frequency
- h = local water depth
- C_g = local group speed
- g = gravitational acceleration, 9.81 m/s^2
- ρ = density of sea water, 1025 kg/m^3

Table 3 – Monthly Average Wave Power Flux

	Power Flux (kW/m)											
Site	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Kaneohe	17.2	15.0	14.9	13.2	6.9	6.2	6.6	6.8	7.6	12.1	18.3	19.0
Kaneohe II	17.4	14.9	14.8	12.9	6.8	6.1	6.4	6.6	7.5	12.0	18.3	19.4

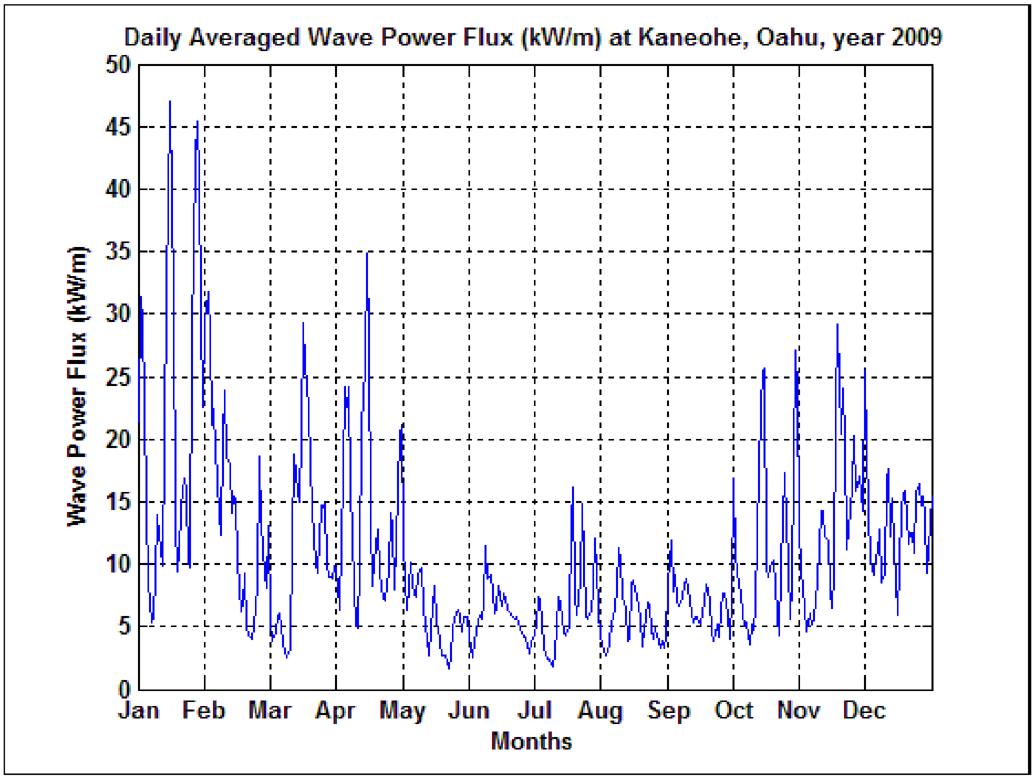


Figure 16 – Daily Average Wave Power Flux for Kaneohe Site.

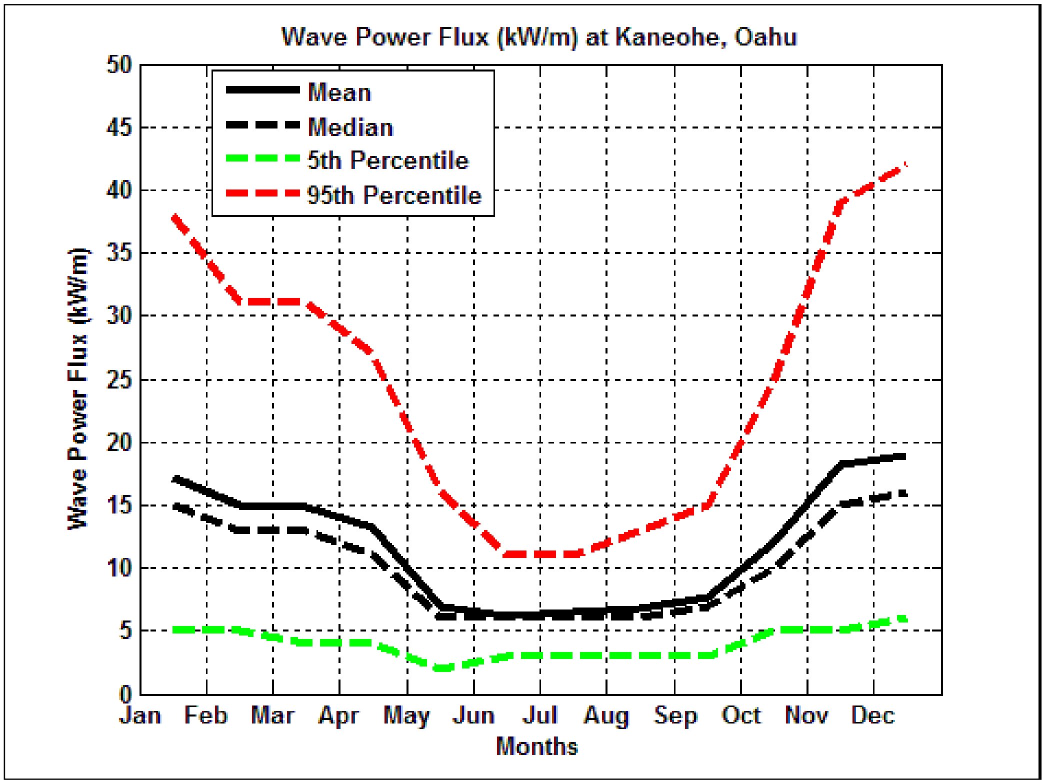


Figure 17 – Monthly Average Wave Power Flux for Kaneohe Site.

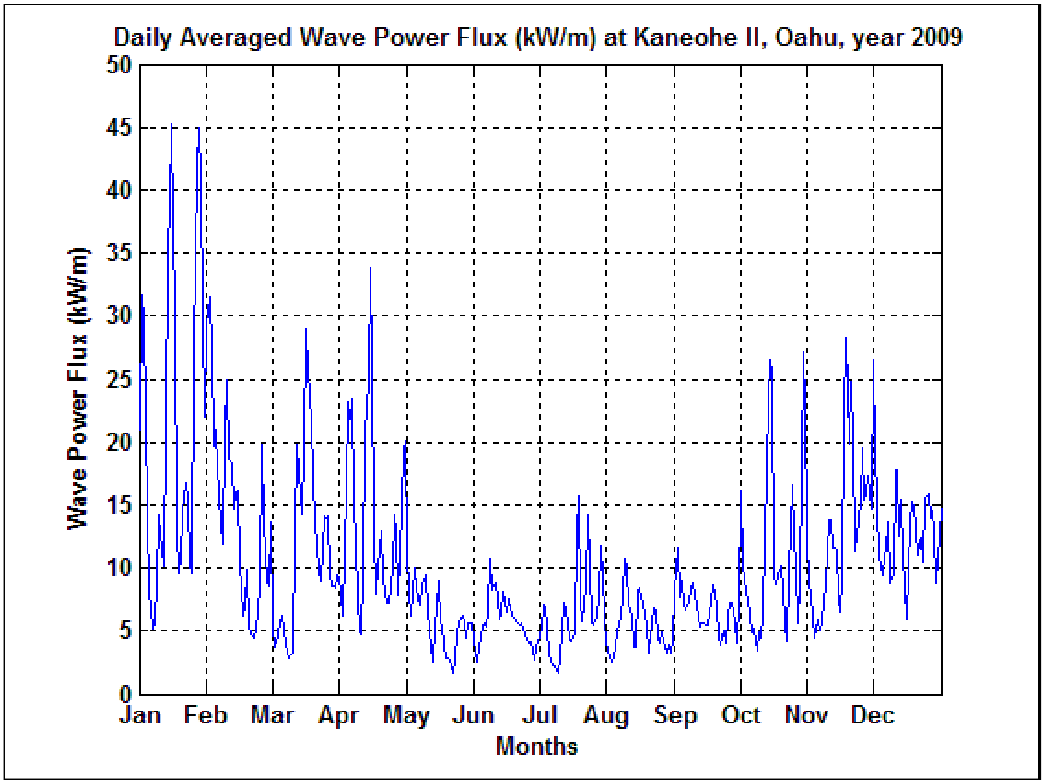


Figure 18 – Daily Average Wave Power Flux for Kaneohe II Site.

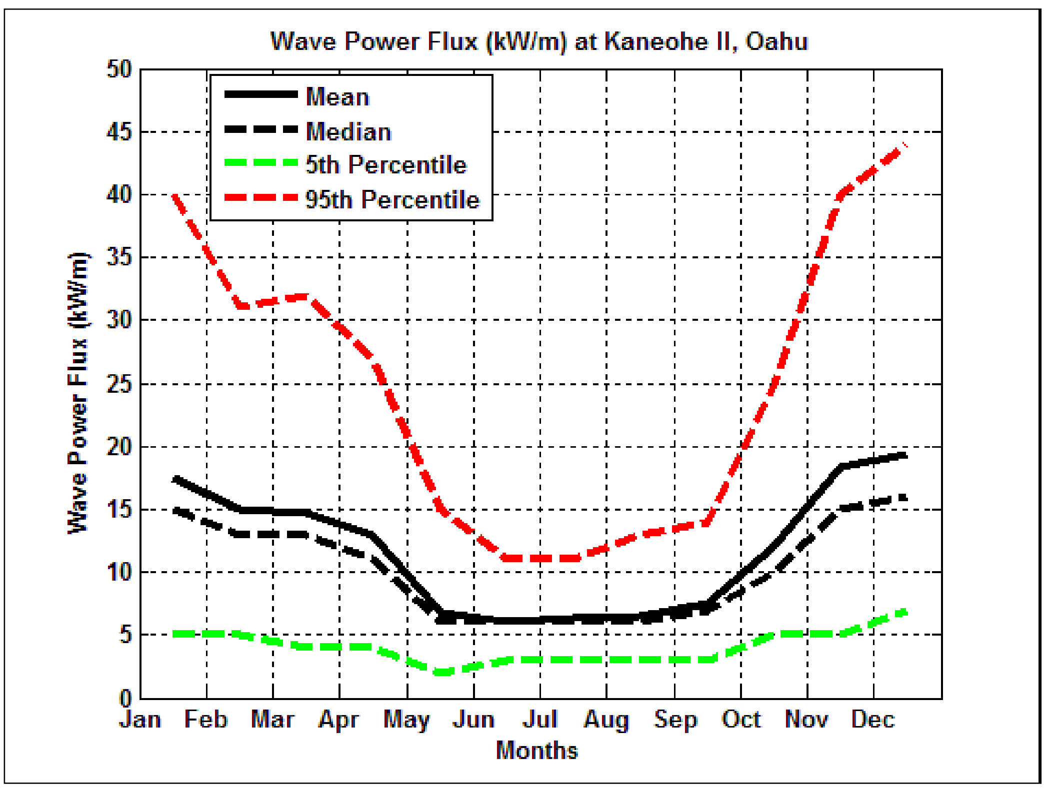


Figure 19 – Monthly Average Wave Power Flux for Kaneohe II Site.

6.0 MARINE BIOLOGICAL RESOURCES

The physical characteristics and associated marine biological resources of the nearshore ocean bottom off North Beach can be described by several bands, or zones, which approximately parallel the shoreline and are defined by water depth. The marine biological resources in the nearshore ocean zones are described herein. The general area of these zones relative to the depth contours are depicted in Figure 20.

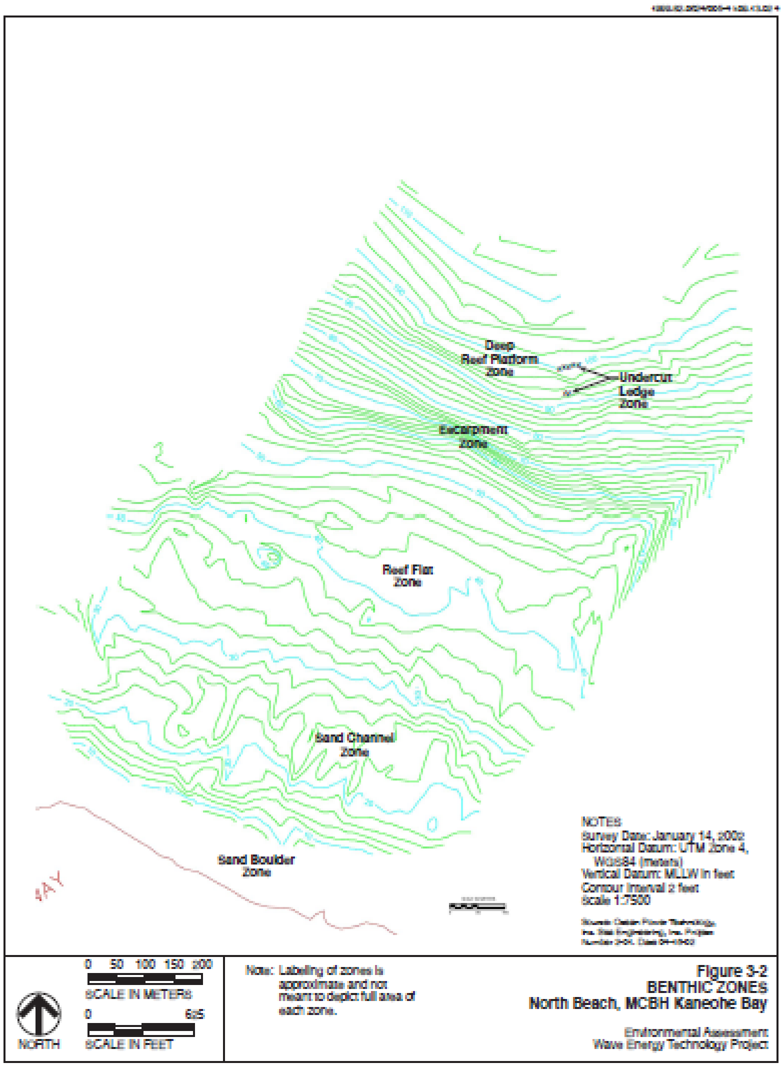


Figure 20 – Biological Resource Zones

6.1 Sand-Boulder Zone

The ocean bottom just seaward of the beach, from a depth of zero to approximately 12 to 15 feet (3.7 to 4.6 m) consists of a bed of coarse-grain carbonate sand that is kept in a state of continous resuspension by wave energy. Interspersed on the sand bed are boulders that are continually swept by resuspended sand. Some of the boulder riprap used to construct the revetment securing the end of the runway has separated from the structure and is submerged in the nearshore area.

The sandy area immediately off the base runway may shift seasonally with the limestone outcrops alternately being buried and exposed. This zone ranges from a width of 400 feet (122 m) at the east end of the beach to 700 feet (213 m) near Pyramid Rock. As a result of continuous resuspension of sand with passing waves, the substrate from the shoreline through the sand-boulder zone contains little marine vegetation or coral.

No fish or other marine vertebrates were observed residing in the sand-boulder zone during the underwater site assessment. Green sea turtles (*Chelonia mydas*) are known to inhabit the waters around the project area and feed on *limu* (seaweed) growing near the shore. False green sea turtle nests (unfinished nest cavities) have been discovered in this zone. A dead hawksbill turtle (*Eretmochelys imbricata*) was reported on shore near the proposed project area. Hawaiian monk seals (*Monachus schauinslandi*) are occasionally sighted in the water and on shore near the project area. Humpback whales (*Megaptera novaeangliae*) have been observed throughout the project area from November through April. Tail slapping, breaching, and pods are routinely observed off MCBH Kaneohe Bay shores. As many as 15 individuals have been observed at one time. On occasion, humpback whales have been observed in less than 15 feet (4.6 m) of water along the MCBH Kaneohe Bay coastline.

6.2 Sand Channel Zone

Farther offshore from the sand-boulder zone, the ocean bottom consists of consolidated limestone bisected by small channels, which vary in width and eventually end in ridge formations. These spur and groove formations are generally oriented perpendicular to the bottom contours and the shoreline. Generally, 3 to 4 feet (0.9 to 1.2 m) of relief is present between the bottom of the channels and the adjacent ridges. While the channel bottoms typically consist of flat and scoured limestone with a thin veneer of sand, some live coral is present on the ridges. The sand channel zone transitions from the sand-boulder zone at approximately 12 to 18 feet (3.6 to 5.5 m) and extends to a depth of 30 to 35 feet (9 to 11 m).

The constant state of resuspension in the sand channel zone restricts settlement of bottom dwelling organisms on both the sand and limestone surfaces. Macrobiota observed in this zone were scattered heads of the branching coral *Pocillopora meandrina*, which grow along the vertical sides of the reef channels.

6.3 Reef Flat Zone

Offshore from the sand channel zone, the emergent reef platform becomes more solid as sand cover decreases. The spur and groove formations end around the 30- to 35-feet (9- to 11-m) water depth, and the bottom from that point to approximately the 50-feet (15-m) depth is a wide plateau of relatively solid, flat limestone. Some scattered areas of vertical relief exist, generally due to potholing, coral growth, or the presence of small limestone ridges and ledges. The bottom slope in this zone is approximately 1 to 70 (rise to run).

The surface of the limestone reef flat consists of a short algal turf that binds a thin layer of carbonate sediment. Macrobiota in this zone include sporadic heads of the coral *P. meandrina* and flat encrustations of the corals *Porites lobata*, *Montipora capitata*, *Montipora patula*, and *Montipora flabellate*. The dominant algae on the platform are clumps of the genera *Porolithon*. Coral growth is greater along the edge of the ledges than the flat areas, and fish are more likely to frequent the areas of coral growth. Colonies of the coral *Pocillopora eydouxi* up to 2 feet (0.6

m) in height occur infrequently in this zone; schools of alo‘ilo‘i or damselfish (*Dascyllus albisella)* reside within the coral. Damselfish are endemic to the Hawaiian Islands.

6.4 Escarpment Zone

The escarpment zone can be defined from of the 50-feet (15-m) contour to approximately the 90- to 95-feet (27- to 29-m) depth contour. At a depth of 50 to 65 feet (15 to 20 m), the angle of the bottom increases 25 to 30 degrees. While there are bottom slopes (rise to run) as steep as 1 to 7, no prominent vertical ledges or wave-cut notches are present in the project area. The bottom is In many areas around O‘ahu, wave-cut notches at the 60-feet (18-m) depth, created during a lower stand of sea level, serve as preferred habitat for fish and turtles. These areas are considered HAPC. However, as described above, the project site seafloor at this depth (escarpment zone) does not have the characteristics of a wave-cut notch. Hence, the escarpment zone is not considered an HAPC.

The primary macrobiota on the escarpment is the flat encrusting coral *M. capitata*. In some localized areas, this species covers up to 50 percent of the substrate. The following fish were observed in the escarpment zone during the underwater site assessments:

- ta‘ape or blue-lined snapper (*Lutjanus kasmira*),
- ala‘ihi or crown squirrelfish (*Sargocentron diadema),*
- yellowstripe squirrelfish (*Sargocentron ensiferum*),
- ‘u‘u or bigscale soldierfish (*Myripristis berndti*),
- kumu or whitesaddle goatfish (*Parapeneus porphyreus*),
- lauwiliwili or milletseed butterflyfish (*Chaetodon miliaris*),
- kikakapu or multiband or pebbled butterflyfish (*Chaetodon multicinctus*),
- lau‘i pala or yellow tang (*Zebrasoma flavescens*),
- papio or ‘omilu or bluefin trevally (*Caranx melampygus*),
- damselfish.

Of these species, the milletseed butterflyfish, multiband butterflyfish, and damselfish are known to be endemic to the Hawaiian Islands.

6.5 Deep Reef Platform Zone

From the bottom of the escarpment zone, the bottom slopes gradually to a depth of approximately 100 feet (30.5 m) where it becomes almost featureless. There is a thin veneer of sand 1 to 2 in (25.4 to 50.8 mm) thick bound to the pitted, flat limestone surface by a thin veneer of algal turf in some areas. The bottom topography remains relatively constant and barren through the depth range of the zone.

The predominant macrobiota are scattered heads of the coral *P. meandrina* and flat encrustations of the coral *M. capitata*. Macrobiotic composition varies from relatively high coral cover above the 95-feet (29-m) depth contour to relatively little cover below this boundary. Other species known to transit the area at this depth include humpback whales, green sea turtles, and Hawaiian monk seals. Fish and turtle species tend to aggregate in areas of higher relief than that found in the proposed project area.

6.6 Undercut Ledges

At several locations at the eastern end of the deep reef platform, a system of small undercut ledges runs parallel to the depth contours. A ledge with an approximate length of 25 feet (7.6 m) exists at the 93-feet (28.3-m) depth and a 150-feet (45.7-m) long ledge system exists around the 100-feet (30.5-m) depth contour.

Increased populations of fish and coral occur around the ledges. Species of reef fish observed during the underwater site assessments included blue-lined snapper, squirrelfish, goatfish, milletseed butterflyfish, multiband butterflyfish, and yellow tang. The predominant coral was the encrusting form of *M. capitata*, which covered large areas of the upper lips of the undercut ledges.

Undercut ledges can be designated as HAPC; however, based on the relatively small size of these ledges, they would not fall under this classification. While several species of sea urchins are present along these undercut ledges, other invertebrates have not been identified in the area.

6.7 Threatened or Endangered Species

Species listed under the ESA as threatened or endangered, and listed as threatened or endangered by the State, include the threatened green sea turtle, endangered hawksbill turtle, endangered humpback whale, and endangered Hawaiian monk seal.

The green sea turtle occurs commonly throughout the Hawaiian Islands. While no turtles were observed during the underwater site assessments, existence of the green sea turtle and hawksbill turtle in the waters and nearshore areas around the project area has been previously documented. Preferred forage species of algae were not found in the proposed project area, and the physical structures of the reef surface in the project area are not considered preferred resting habitat for turtles.

Endangered humpback whales transit the project area seasonally. Humpback whale activity in the project area is described in Section 6.1. Endangered Hawaiian monk seals have infrequently been observed near the project area. An average of three sightings a year occurs on the shoreline and in nearshore waters. No monk seals were observed during the underwater site assessments for this proposed project.

6.8 Commercial, Subsistence, and Recreational Species

Fish such as ono or wahoo (*Acanthocybium solandri*), aku or skipjack tuna (*Katsuwonus pelamis*), and moano ukali-ulua or goatfish (*Parupeneus cyclostomus*) typically occur along the 100-feet (30.5-m) depth contour in the project area. For this reason, commercial, limited subsistence, and recreational fishing is conducted near the project area at this depth. The bottom conditions at the proposed project site do not offer unique habitat for species occurring in the area, and the site is not considered highly productive for spear fishing or uniquely attractive for SCUBA diving.

6.9 Marine Mammals

The MMPA protects any ocean dwelling mammal that primarily inhabits the marine environment. Within the proposed project area, Kaneohe Bay, mammals possibly present in the area and protected under the MMPA include the endangered Hawaiian monk seal, the endangered humpback whale, and various species of dolphin.

7.0 CULTURAL AND HISTORICAL RESOURCES

The Mokapu Peninsula, inhabited since the 13th century, was originally valued by the Hawaiian royalty who owned it as one of the most productive agricultural areas in all of the islands. The fishponds, including Nu’upia Ponds, were reserved for royalty’s exclusive use. The entire Kailua-Kane’ohe area was at some time in the past a retreat or resort area for royalty and the court favorites.

Kane’ohe and its surrounds were used as a burial ground for centuries. The largest pre-contact Native Hawaiian burial removal occurred at Mokapu and Heleloa in Kane`ohe and He`eia. Following the intentional removal of ancestral remains by the Bishop Museum and the University of Hawai`i Department of Anthropology, and following the inadvertent discovery of additional ancestors over the years, the skeletal remains and burial objects of approximately 1,600 ancestral Native Hawaiians were disturbed and removed from Mokapu and Heleloa and are currently stored at the Bishop Museum. At various Mokapu Peninsula sites, sixty-two individual resources have been identified, twenty-seven Hawaiian pre-contact and early contact sites, and thirty-five historic period resources (Shilz and Allen, 1996). The latter category is further divided into pre-WWII, WWII, and post-WWII groupings. Of the total sixty-two resources, one (Mokapu Burial Area – the dunes complex along North Beach) is listed in the National Register of Historic Places, while forty-nine others are considered eligible for listing (Schilz and Allen, 1996), including Nu‘upia Pond. Figure 21 shows the Archaeological Sensitivity Zones within the Marine Corp Base.

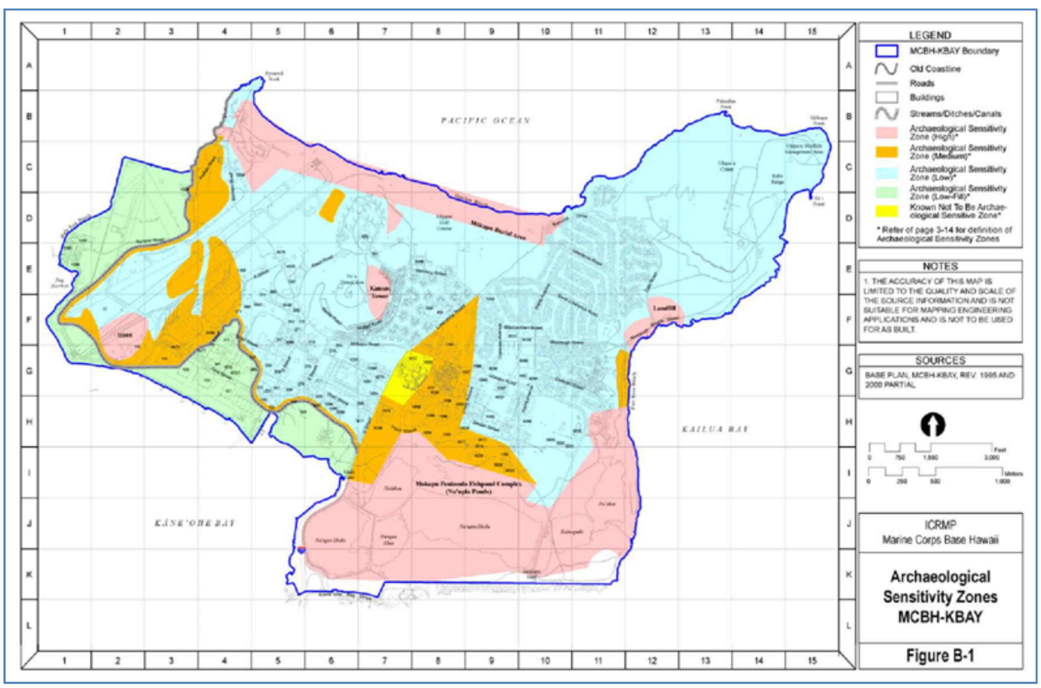


Figure 21 - Archaeological Sensitivity Zones, MCBH-K

8.0 SITE INFRASTRUCTURE

8.1 Power Transmission System

The power transmission system consists of: (1) Subsea Power and Fiber-Optic Cable, (2) Subsea Cable Stabilization/Immobilization Components, (3) On-shore Cable Vault, (4) On-shore Power and Fiber-Optic Cable, (5) Switch Gear, (6) Power Conditioning and Monitoring Equipment, and (7) Grid Connection Transformer. Figure 22 is a one-line power system diagram depicting the major components of the power transmission system.

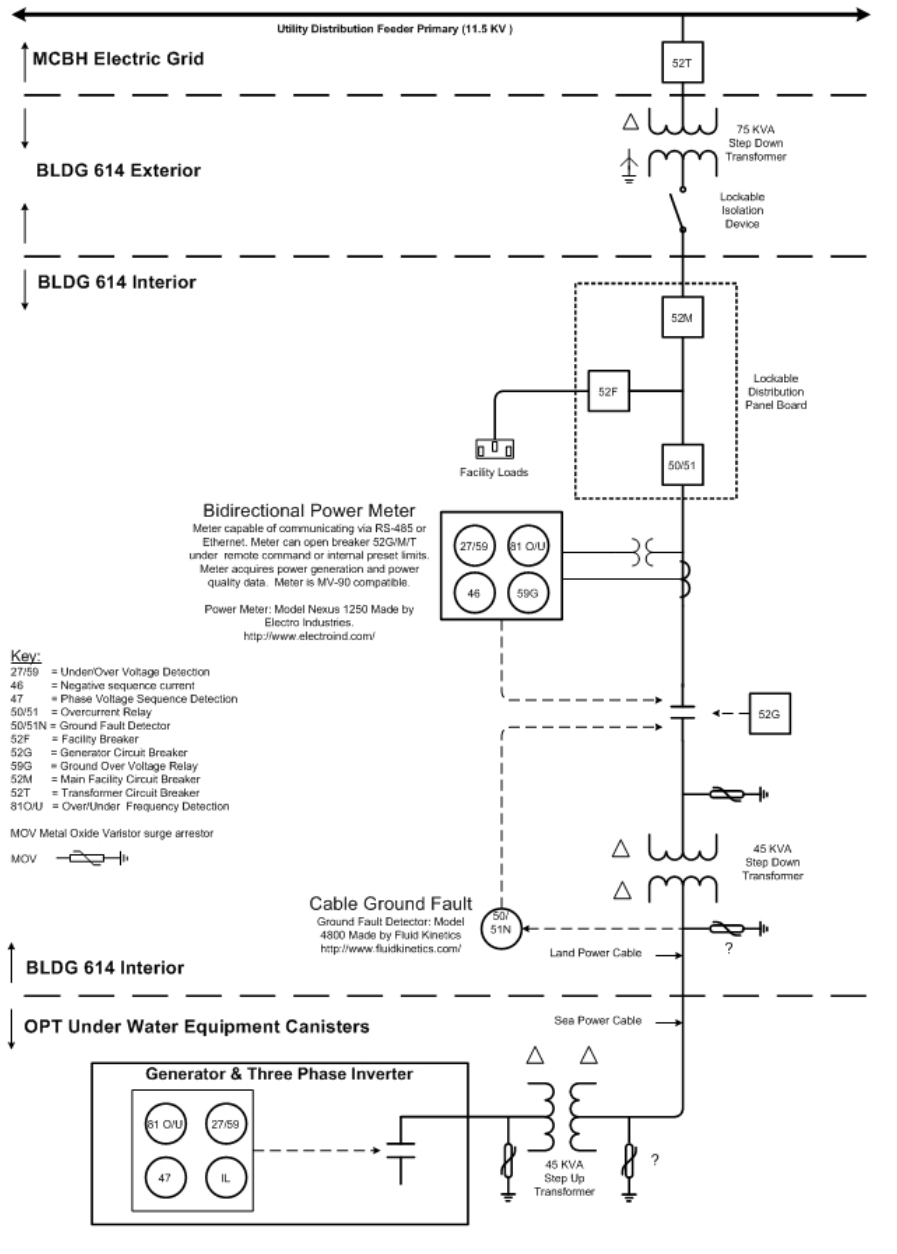


Figure 22 – Power Transmission System One-Line Diagram

8.1.1 Subsea Power and Fiber-Optic Cable,

The submarine cable was fabricated by Olex Cables, Tottenham, Victoria, Australia. This cable is a three (3) conductor double armored submarine cable incorporating Optical Fibres. Properties of the subsea cable are presented in Table 4. Figure 23 shows the cross section view of the subsea cable. The route for the subsea cable is depicted in the chart shown in Figure 24. The procurement specification for the subsea cable is presented in Appendix B.

Table 4 – Subsea Power Cable Properties

Physical Properties:			
	Net mass of cable:		7800 kg/km
	Cable dimensions:		
		Overall cable diameter	59.8 mm nom ± 1.6 mm
		Diameter over armour:	45.1 mm
		Diameter under armour:	38.8 mm
		Diameter over laying-up:	30.6 mm
		Conductor Diameter:	4.7 mm
	Recommended minimum internal bending radius:		
		Pulling In:	1500 mm
		Set in Position:	900 mm
	Recommended maximum safe pulling/working tension:		
		Conductors:	1.9 kN
		Armour:	30.0 kN
Electrical Properties:			
	Maximum conductor dc resistance:		1.16 ohm/km
	Minimum insulation resistance:		12500 megohm/km
	Capacitance of main conductor:		0.23 µF/km
Despatch Parameters:			
	Length:		1250 m
	Internal drum size		2700 mm x 1500 mm B x 1400 mm
	Overall drum size		2850 mm x 1620 mm (Steel drum)
	Gross mass per drum:		11500 kg

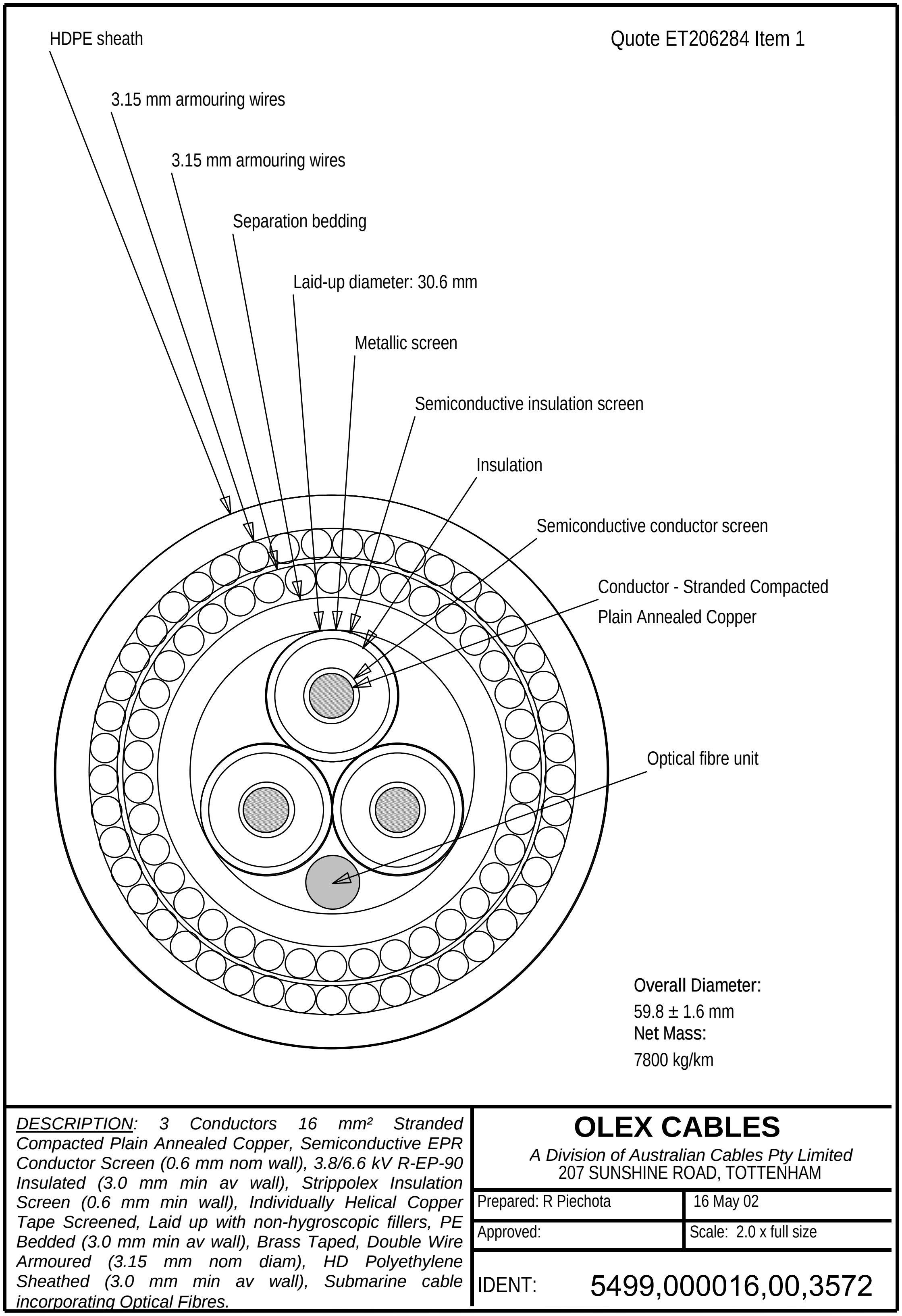


Figure 23 – Cross Section of Subsea Power Transmission Cable

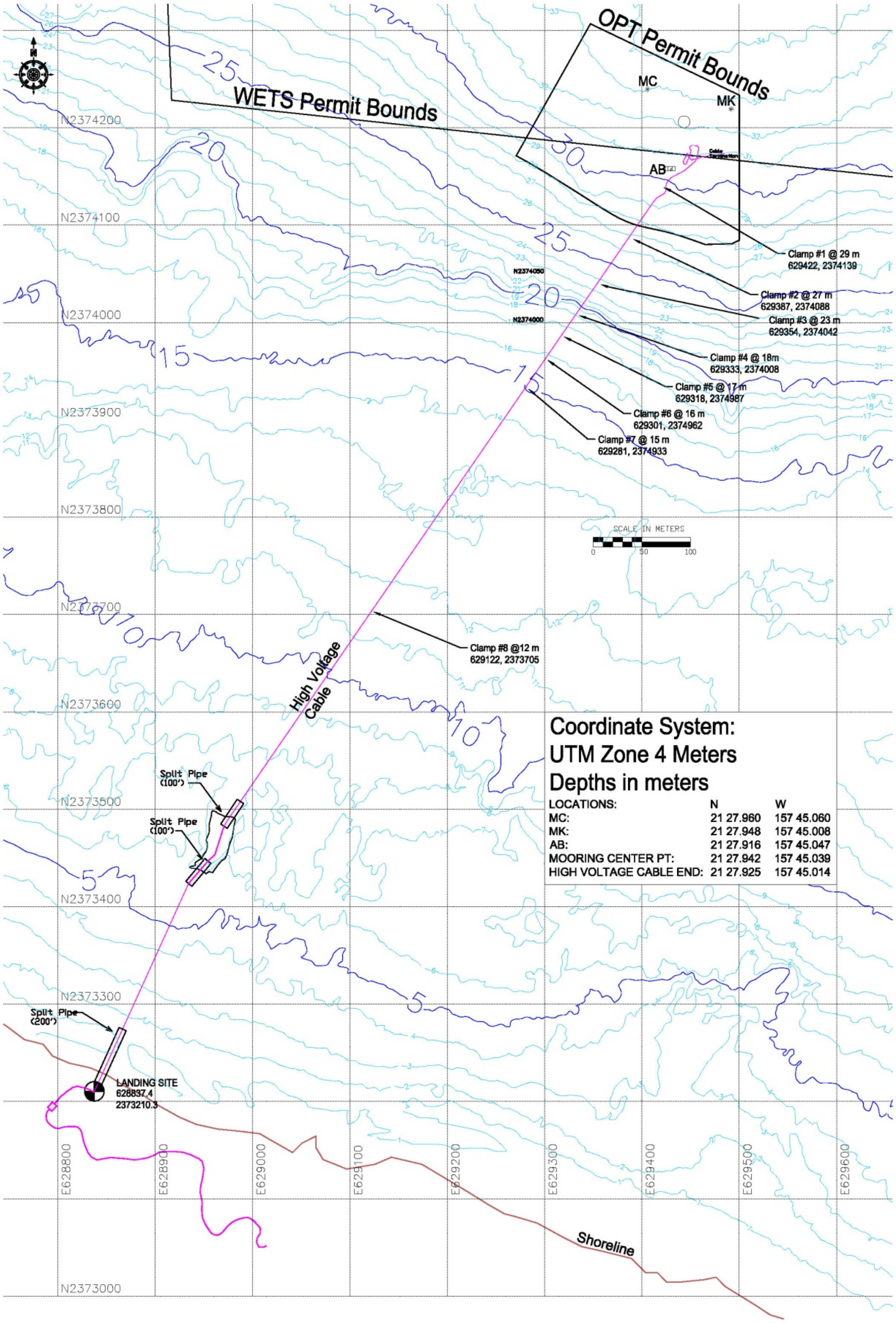


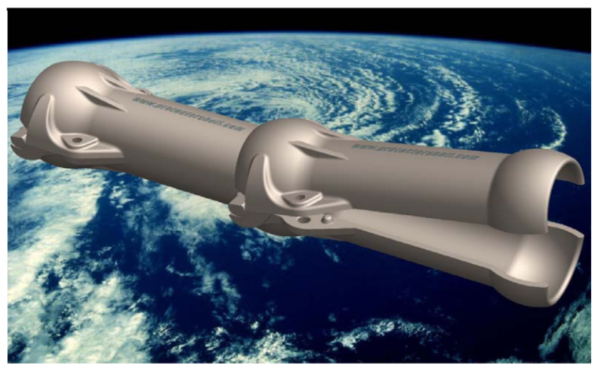
Figure 24 – Subsea Cable Route

8.1.2 Subsea Cable Stabilization/Immobilization Components

The subsea cable is anchored along its length to a depth of approximately 100 feet (30 m) by either protective split pipe (Figure 25) or rock bolts (Figure 27), with the type of anchoring and spacing dependent upon the environmental conditions (e.g., the substrate). Figure 24 shows the cable route, which was selected to avoid areas of vertical relief to the maximum extent practicable and follow branches of sand deposits that extend seaward from the beach through the sand channel zone.

8.1.2.1 Split Pipe

Split Pipe is cast using Sphiroidal Graphidic Iron. Figure 26 shows the dimensions for a 3-inch ID pipe. Each identical half section has a pin and camlock configuration such that when assembled, the socket end of one section of split pipe locks the ball end of the previous section closed. The two half sections are secured using two (2) one-half inch diameter nuts and bolts. Two hundred feet of split pipe was applied to the cable from the back of the beach area to a water depth of approximately 2.5 meters. Two additional 100-foot long sections of pipe were installed to the cable at a depth of 6 meters and 7 meters respectively as shown in Figure 24.



SPECIFICATIONS

Segment Length - Overall	506mm
Effective Installed Length/segment pair	440mm
Minimum Internal Diameter	130mm - for cables up to 115mm Dia
Maximum External Diameter	290mm
Material	Spheroidal Graphitic Iron to AS1431
Wall thickness (9mm)	(ISO 1083) 400MPa / 12% elongation
Impact Resistance	12m Drop test or 26kg
Tensile Strength	>100kN
Minimum Bend Diameter	4.0m
Weight per Segment	21kg
Weight per installed metre (air)	48kg
Weight per installed metre (water)	42kg

Figure 25– Split Pipe Cable Protection

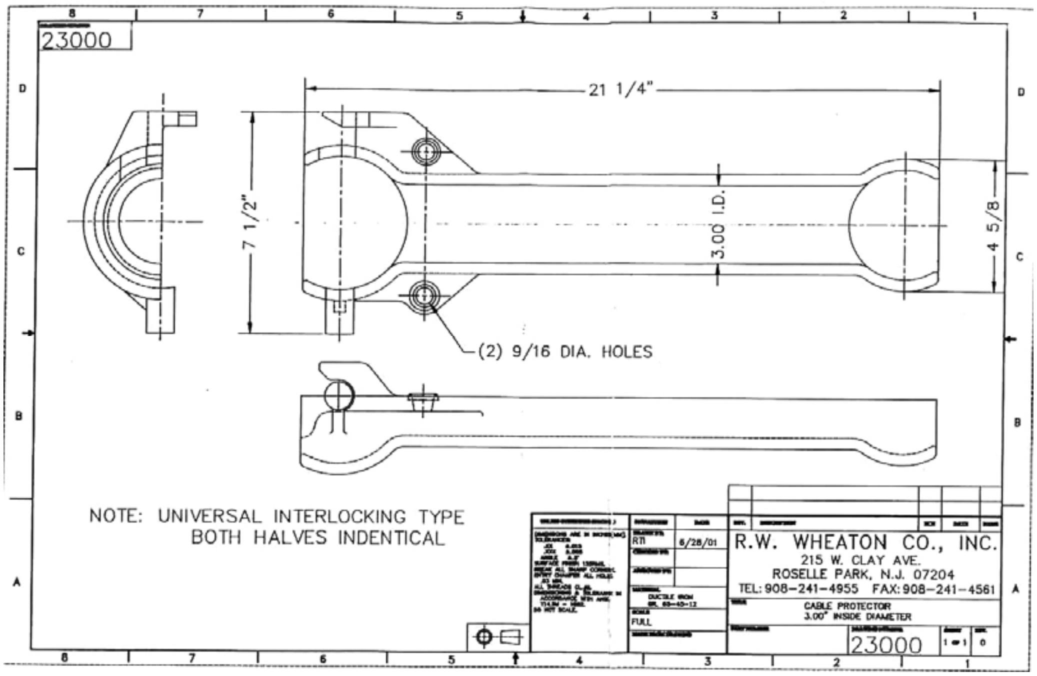


Figure 26 – Split Pipe Dimensions

8.1.2.2 Rockbolt & Clamps

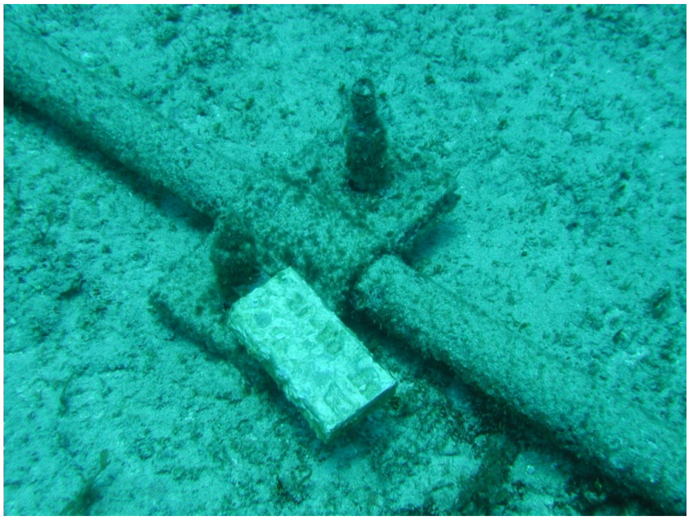
Two different sizes of rock bolts (Table 5) were used during the installation of the cable and mooring anchors. The Grade 75 All-Thread rock bolts were manufactured by Williams Form Engineering Corporation. The ¾-inch bolts were used in conjunction with cable clamps (Figure 27) to secure the cable to the seafloor. The location of the cable clamos is shown in Figure 24. The 1-inch rock bolts were used to secure the mooring anchors to the limestine bottom.

Table 5 – Bolt Specifications

Bolt Size (Nominal)	Bolt Diameter (Actual)	Hole Diameter	Hole Depth	Average Time to Drill
0.75"	0.875"	1.375"	18"	30 min
1.0"	1.125"	1.5"	24"	45 min

A hydraulic sinker drill with air flush was used to drill holes in the limestone bottom. Once a hole was drilled, any remaining debris in the hole was removed by water jetting. The two component structural epoxy, called CIA-Fluid, was then injected with a pneumatic dispenser gun. This is a moisture insensitive epoxy designed for ultra high strength. Once the hole was filled, the bolts were slowly screwed into the epoxy, allowing maximum surface coverage between the epoxy and the bolt. The recommended minimum cure time for the epoxy is 36 hours.

Results of the rock bolt shear and tensil tests are presented in Table 6 and Table 7.



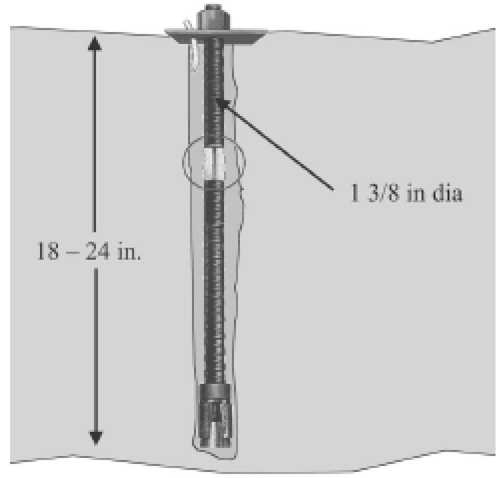


Figure 27 – Cable anchored with grouted rock bolts

Table 6 - Rock Bolt Shear Test

Bolt Number	Force (lbs)	Pressure (Psi)	Notes
#1	28,500	2,280	Bolt began to yield
#2	28,750	2,300	Bolt began to yield
#3	28,250	2,260	Bolt began to yield, initially bent at 15,625 lbs

Table 7 – Rock Bolt Tension Test

Bolt Number	Force (lbs)	Pressure (Psi)	Notes
#4	72,756	8,600	Eye bolt broke
#5	67,680	8,000	Held with no change
#6	64,296	7,600	Held with no change, frame yielded

8.1.3 Transformer Pod

The transformer pod (T-Pod) consists of a 15:1 electrical step up transformer and control system housed inside a steel cylindrical housing (Figure 28). The step up transformer converts the 208VAC power from the WEC to 4160 VAC power for more efficient transmission to shore. Mounted to the housing end cap are ports (Figure 29) for electrical and fiber optic cable connections (Figure 30) to the shore cable and to the Low Voltage Cable running to the buoy. An additional port allows a hard wire connection to an Acoustic Doppler Current Profiler (ADCP) unit. The ADCP is used to collect wave data. The T-Pod also contains electrical switches, communications, and control equipment for operating the unit. At one end of the T-Pod, a structural frame supports the electrical cable attachments and their mechanical strain relief elements.

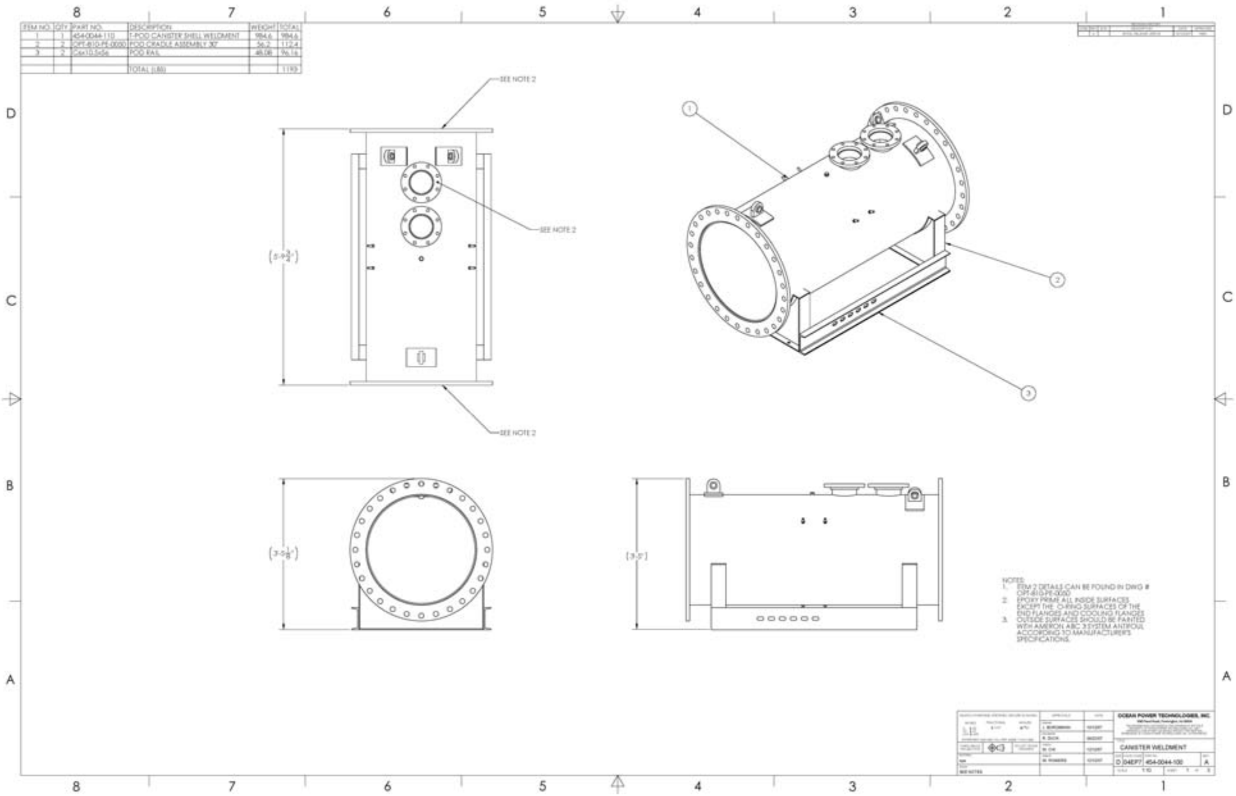


Figure 28 – Transformer Pod (T-Pod) Housing

Figure 29 – T-Pod End Cap with Connectors

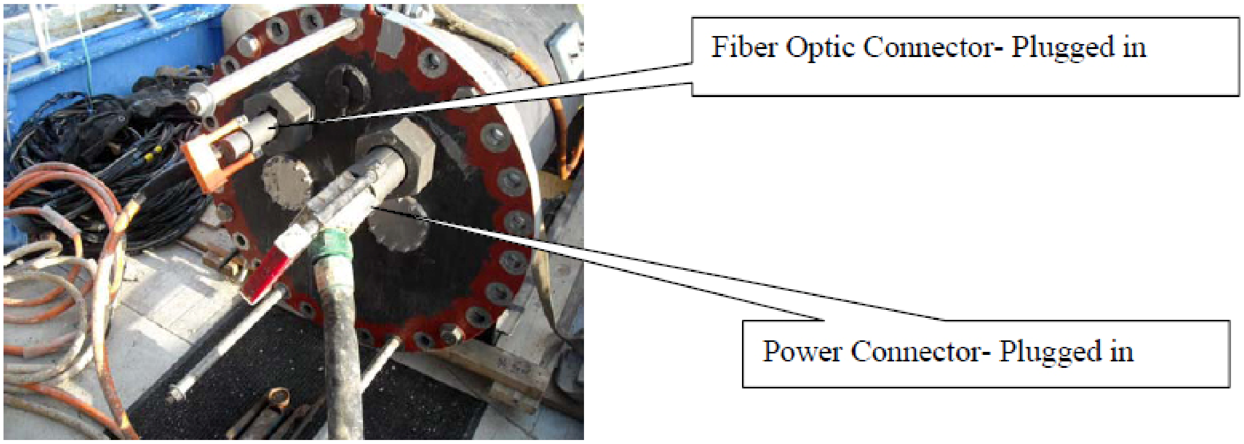


Figure 30 – T-Pod with Power and Fiber Optic Cables Connected

8.1.4 On-shore Cable Vault

The cable Vault is an above ground concrete utility vault located at the shore end of the subsea cable. It is located approximately 40 meters shoreward of the high tide line. The vault provides the transition point between the subsea cable and the terrestrial cable. It also serves as a weatherproof environment for the conductor and fiber optic splices.

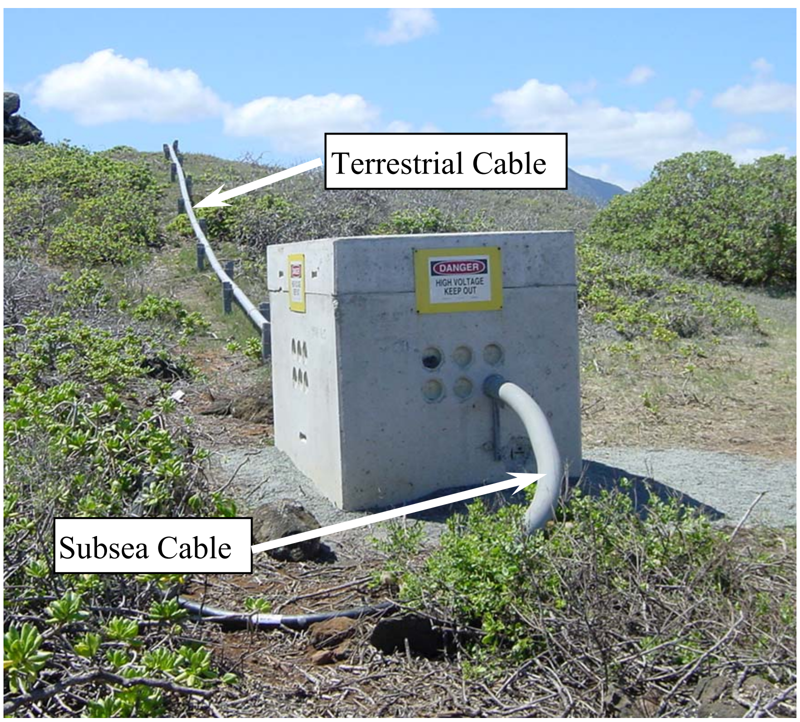


Figure 31 – Cable Vault

8.1.5 On-shore Power and Fiber-Optic Cable

The terrestrial portion of the power and fiber optic cable had to traverse an ancient Hawaiian Burial Ground (Figure 32). Because of the culturial sensitivity of this area, the cable had to be installed in an above ground conduit supported by short PVC pilings (Figure 33).

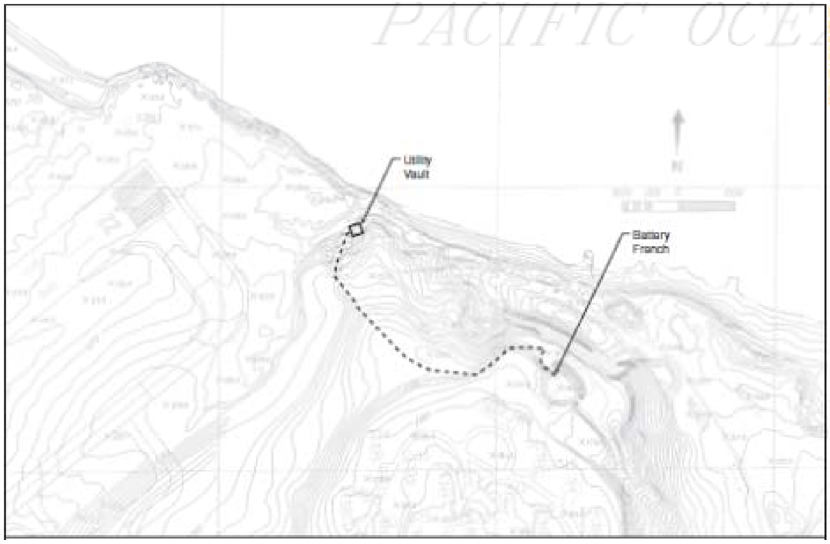


Figure 32 – Shore Cable Conduit Route

Figure 33 – Terreestrial Cable Pedistal & Conduit

8.1.6 Power Conditioning and Monitoring Equipment

The on-shore power conditioning and monitoring equipment (Figure 34) is located in Room 106 in Building 614 (see Section 8.3 Shore Facility). The power conditioning equipment consists of: (1) a 45 KVA step down transformer, which drops the 4160 volt transmission voltage to 220 volt power bus voltage, (2) an over/under voltage detector, (3) an over/under frequency detector, (4) a bidirectional power quality meter, and (5) a ground fault detector.

The 45 KVA transformer (Figure 35) was specifically designed to handle the power from OPT's H3 Buoy and cannot be adapted to input voltages other than 4160 volts or to handle more power than 45 KVA.

Figure 34 – Power Conditioning & Monitoring Equipment

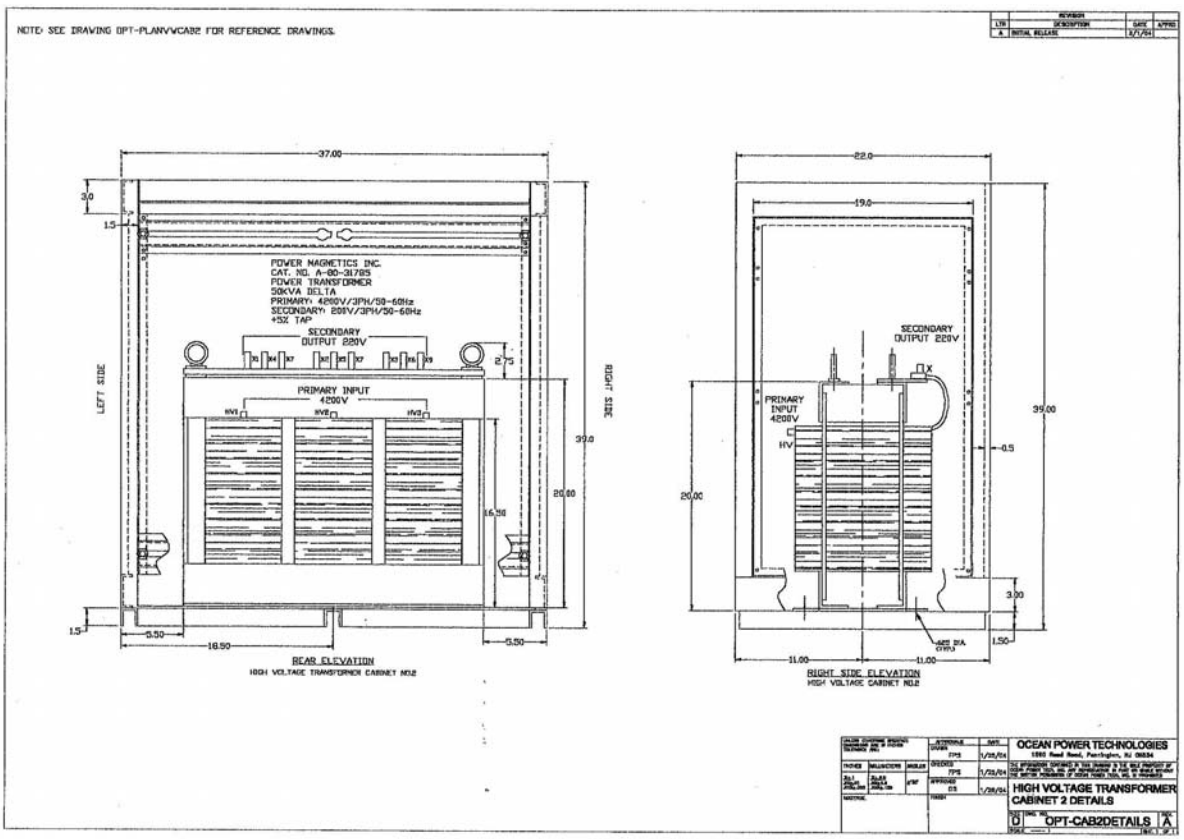


Figure 35 – 45 KVA Step Down Transformer

8.1.7 Grid Connection Transformer

A 150 KVA transformer, located near the south entrance of building 614, provides power from the MCBH power grid and, in the event that wave energy device delivers more power than is being consumed within the facility, this transformer will step up the 220 volt power from the building bus to the 11.5 KV utility grid voltage.

8.2 Mooring System

8.2.1 Mooring configuration

Figure 36 shows the configuration of the three moorings at the 30-meter site.

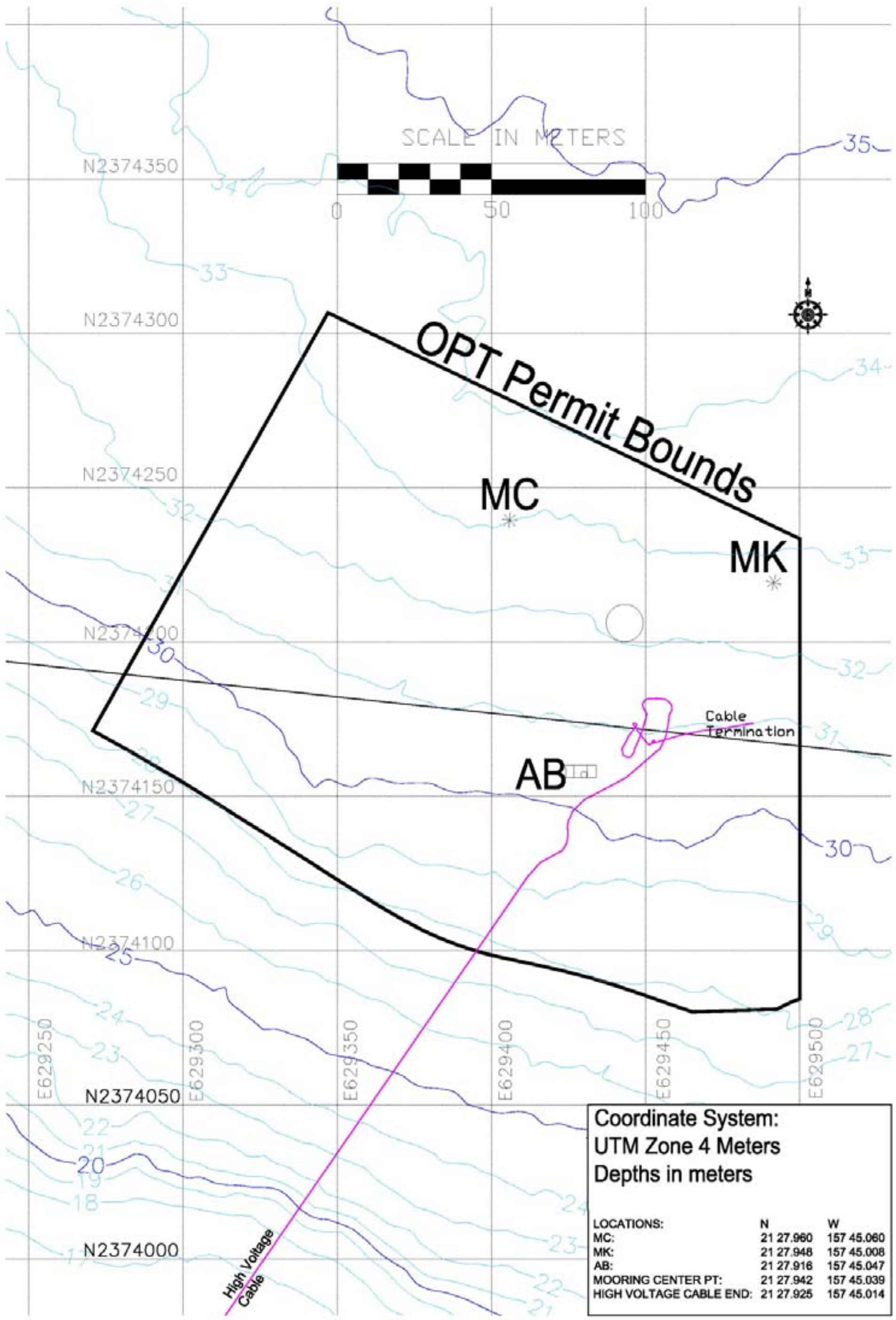
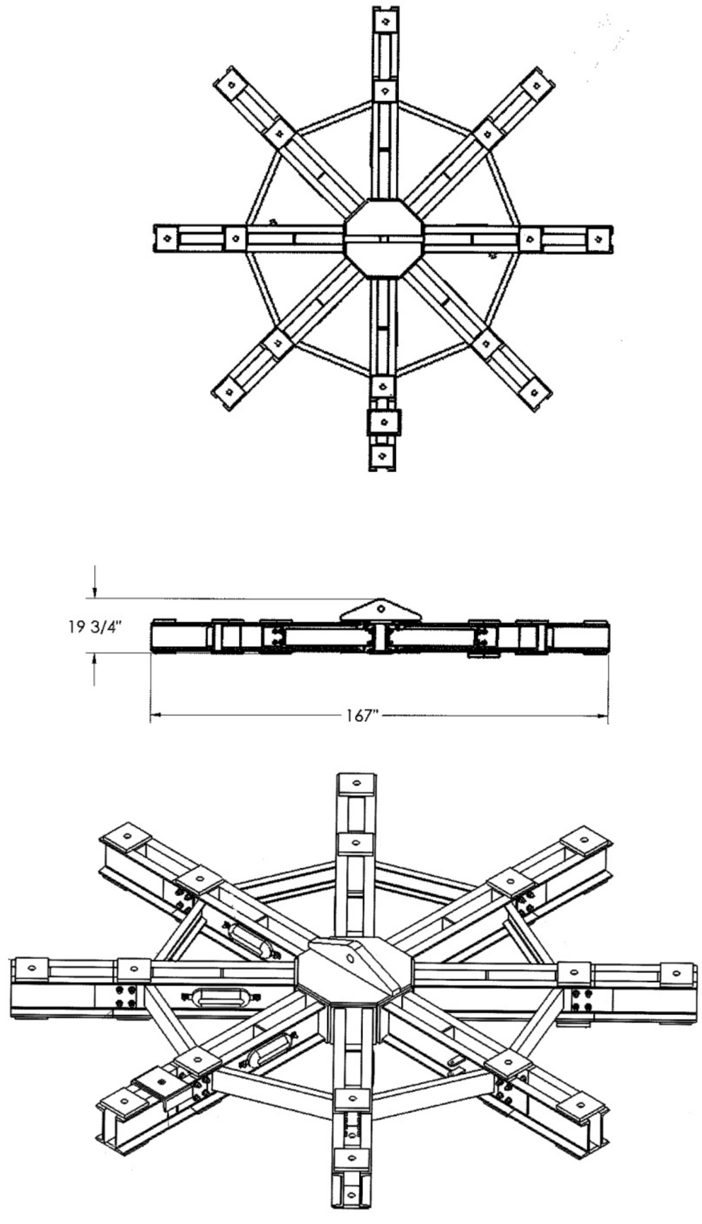


Figure 36 – Mooring Anchor Configuration

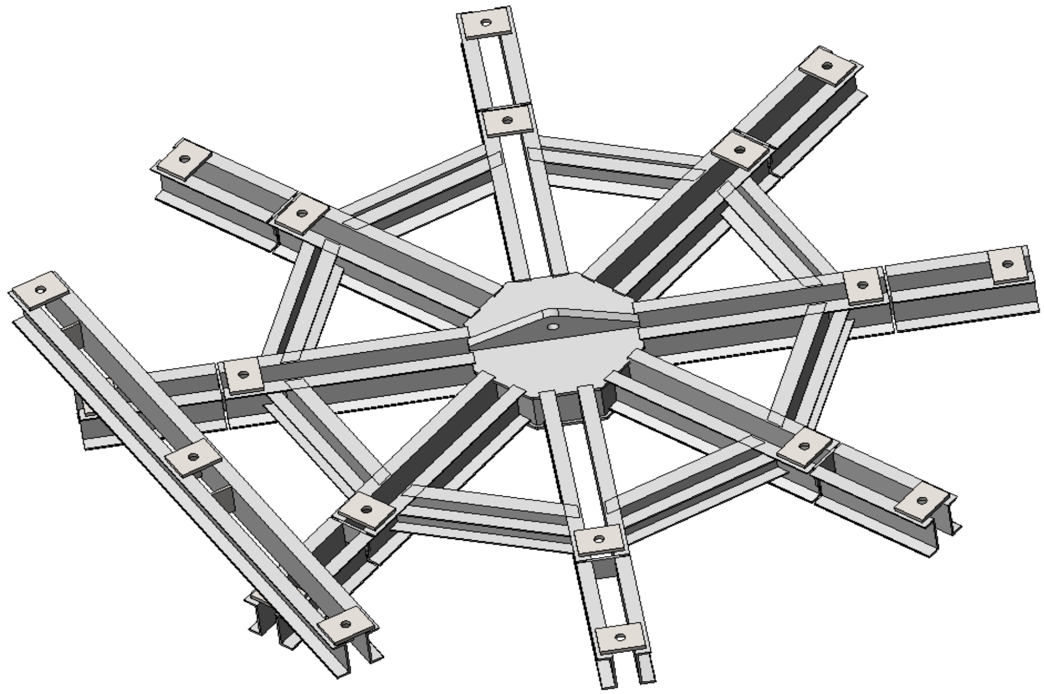
8.2.2 Anchor MC

Anchors MC is a spoke and wheel configured anchor plates fabricated from welded steel channel sections. The anchor plate is secured to the seafloor by eight 1-inch diameter threaded rebar anchors, which are grouted into predrilled holes using epoxy grout.



8.2.3 Anchor MK

Anchors MK is a spoke and wheel configured anchor plates fabricated from welded steel channel sections. The anchor plate is secured to the seafloor by eight 1-inch diameter threaded rebar anchors, which are grouted into predrilled holes using epoxy grout.



8.2.4 Anchor AB

Anchor AB (Figure 37 and Figure 38) is a one hundred thousand pound gravity anchor that was originally used for the original H1 OPT Buoy deployed at this site. Is consists of a welded steel frame with two large steel bins mounted on either side of the frame that were filled with used anchor chain to bring the total submerged weigh up to 100,000 pounds after the frame was deployed.

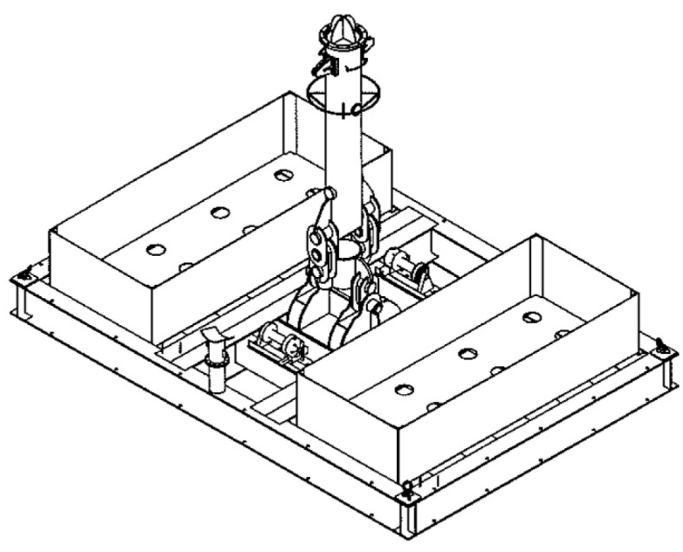


Figure 37 – Anchor AB Isometric View

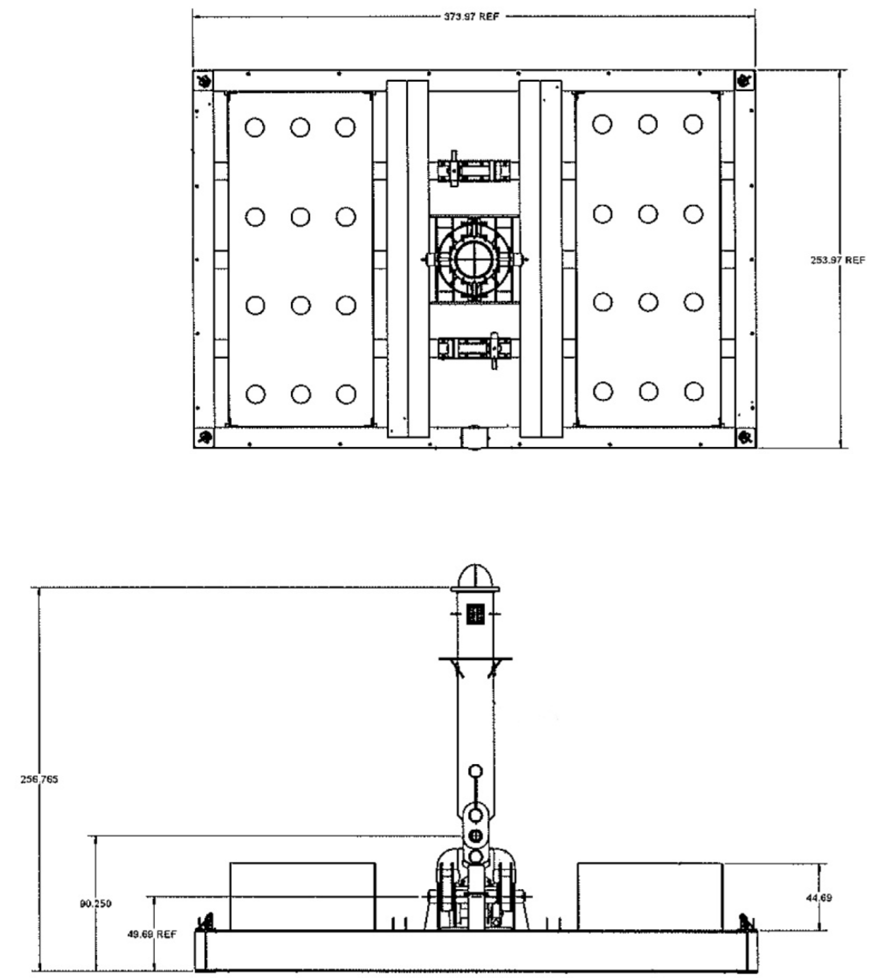


Figure 38 – Anchor AB Plan and Elevation View

8.2.5 Subsurface Buoy

The 30-meter site mooring consisted of three auxiliary submerged buoys (ASB) (Figure 39) that each connect to an anchor that is rock-bolted to the seabed. Each anchor connects to the ASB's through a tether that is tensioned by the buoyancy in the ASB. The ASB's are then each connected to the wave energy device through a catenary mooring line. The ASB's allow these catenaries to be elevated enough that seabed interference does not occur. The 30,000-pound buoyancy of each ASB provides the necessary stiffness for the mooring to limit the watch circle of the wave energy device to an acceptable diameter. Two-inch diameter ball valves on each emd allow for flooding and deballasting the buoys during deployment and recovery. The basic properties of the buoys are presented in Table 8.

Figure 39 – Subsurface Buoy

Table 8 – Subsurface Buoy Properties

Parameter	**Value**
Construction	Cylindrical body with hemispherical end caps
Diameter	7.5 feet
Length	14.7 feet
Depth Rating	100 FSW (33psid)
Buoyancy	30,000 lbs

8.3 Shore Facility

The terrestrial facility utilized for monitoring and control of the wave energy devices is building 614 referred to the French Battery. Building 614 is a bunker located adjacent to the golf course, an on-base residential area, and the shoreline. The present layout of the bunker as it is used for the 30-meter site support is shown in Figure 40.

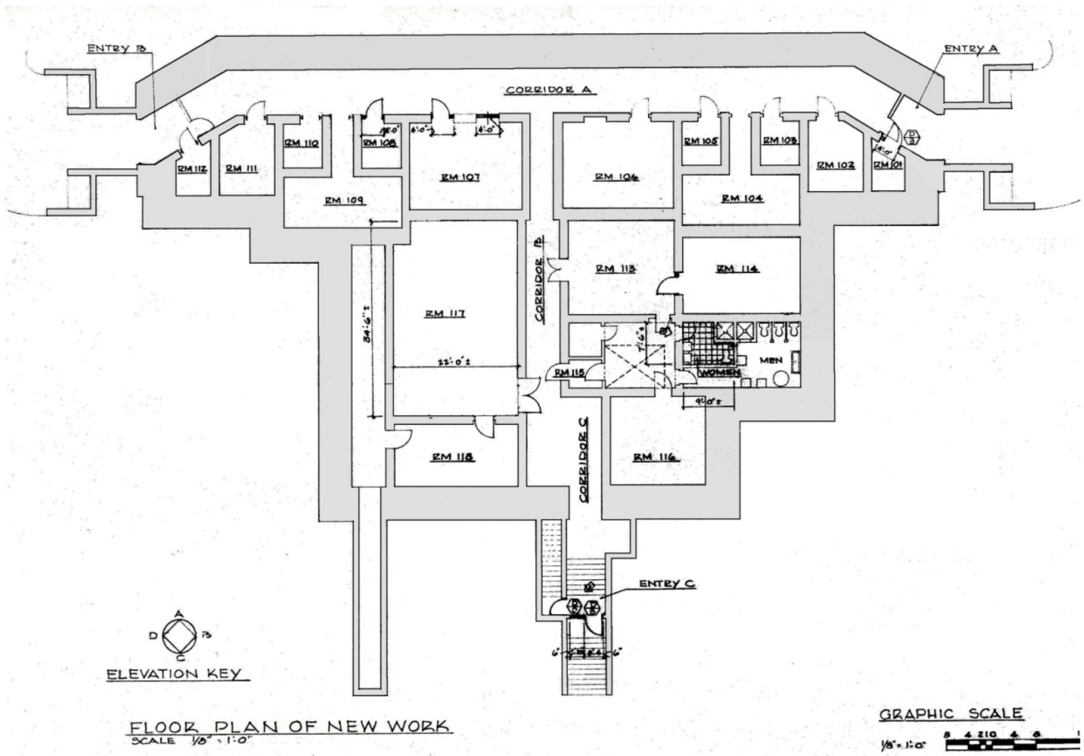


Figure 40 - Building 614 Floor Plan

The power conditioning and monitoring equipment for the 30-meter site is currently located in Room 106.

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Appendix A

Wind and Wave Data for Kaneohe Bay (1945 – 1995)

TABLE A - 1. ANNUAL PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT. DIR.	SPEED (KNOTS) 1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.3	.9	1.0	.6	.1	*	0	0	0	0	0	2.8	7.8
NNE	.5	1.8	3.3	1.7	.2	*	*	0	0	0	0	7.5	8.5
NE	.7	3.0	7.2	5.5	.5	.1	*	0	0	0	0	17.5	9.5
ENE	1.0	4.7	11.8	11.4	1.4	.1	*	0	0	0	0	30.5	10.1
E	.7	2.9	6.9	6.9	.9	.1	*	0	0	0	0	17.9	10.1
ESE	.3	.8	1.8	1.7	.2	*	*	0	0	0	0	5.1	9.8
SE	.2	.4	.3	.1	*	*	0	0	0	0	0	1.1	7.2
SSE	.4	.4	.3	.1	*	*	*	0	0	0	0	1.2	6.3
S	.9	.7	.4	.2	.1	*	*	*	0	0	0	2.2	5.5
SSW	.9	.7	.4	.2	.1	*	*	*	0	0	0	2.4	6.2
SW	.7	.5	.3	.2	*	*	*	*	*	0	0	1.9	6.2
WSW	.6	.4	.2	.1	*	*	*	*	0	0	0	1.3	5.4
W	.4	.4	.2	.1	*	*	*	0	0	0	0	1.1	4.6
WNW	.2	.3	.2	.1	*	*	*	0	0	0	0	.8	5.9
NW	.2	.3	.2	.1	*	*	0	0	0	0	0	.9	7.8
NNW	.2	.5	.4	.3	.1	*	*	0	0	0	0	1.6	8.5
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	4.6	0
TOTAL	8.4	18.8	34.6	29.3	3.8	.4	*	*	*	0	0	100	8.8

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 128321

TABLE A - 2. JANUARY PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT.	SPEED (KNOTS)												
DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.8	1.5	1.6	1.2	.3	*	0	0	0	0	0	4.9	8.1
NNE	.7	1.7	2.4	1.9	.4	.1	*	0	0	0	0	7.3	8.9
NE	.7	1.7	2.9	2.9	.5	.1	0	0	0	0	0	9.4	9.5
ENE	.7	2.5	5.3	4.5	.6	.1	0	0	0	0	0	13.8	9.6
E	.7	2.3	4.8	3.9	.7	*	0	0	0	0	0	11.9	9.6
ESE	.5	1.3	1.7	1.3	.2	*	0	0	0	0	0	5.3	8.8
SE	.5	.9	.7	.3	.1	0	0	0	0	0	0	2.5	7.2
SSE	.9	.9	.7	.3	*	*	0	0	0	0	0	3.1	6.4
S	2.0	1.9	1.4	.9	.3	.1	*	*	0	0	0	6.3	6.8
SSW	2.2	2.3	1.3	.9	.4	.2	.1	*	0	0	0	7.7	7.5
SW	1.6	1.3	.9	.9	.3	.1	.1	*	*	0	0	5.4	8.0
WSW	1.1	1.0	.7	.5	.1	.1	*	*	0	0	0	3.6	7.3
W	.8	1.0	.6	.3	.1	*	0	0	0	0	0	2.6	6.0
WNW	.4	.8	.3	.2	*	*	*	0	0	0	0	1.9	6.8
NW	.4	.7	.5	.4	.1	*	0	0	0	0	0	2.3	8.4
NNW	.4	.8	.9	1.0	.2	*	0	0	0	0	0	3.5	9.2
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	8.6	0
TOTAL	14.7	22.7	27.1	21.4	4.2	1.0	.2	.1	*	0	0	100	7.7

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10746

TABLE A - 3. FEBRUARY PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT.	SPEED (KNOTS)												
DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.5	1.2	1.4	1.3	.2	*	0	0	0	0	0	4.4	8.5
NNE	.6	1.7	2.6	2.2	.4	.1	0	0	0	0	0	7.7	9.1
NE	.6	2.0	3.7	3.9	1.0	.1	0	0	0	0	0	12.0	10.2
ENE	.8	2.8	5.8	6.4	1.4	.2	0	0	0	0	0	17.6	10.4
E	.8	2.4	4.8	4.8	.8	*	*	0	0	0	0	13.0	9.8
ESE	.5	1.2	2.2	1.8	.2	*	0	0	0	0	0	6.2	9.2
SE	.4	.7	.6	.1	*	*	0	0	0	0	0	2.0	6.8
SSE	.7	1.0	.5	.2	.1	*	0	0	0	0	0	2.5	6.5
S	1.9	1.4	1.0	.5	.1	.1	*	0	0	0	0	4.7	5.7
SSW	1.7	1.6	1.1	.9	.3	.1	*	0	0	0	0	5.6	7.1
SW	1.6	1.2	.8	.8	.1	.1	*	0	0	0	0	4.7	7.0
WSW	1.2	.9	.6	.5	.1	*	0	0	0	0	0	3.3	6.2
W	.8	.9	.5	.2	0	*	*	0	0	0	0	2.3	5.0
WNW	.5	.8	.4	.3	*	*	0	0	0	0	0	2.2	6.5
NW	.4	.5	.5	.4	.1	0	0	0	0	0	0	1.7	8.4
NNW	.6	.7	.8	.8	.1	.1	0	0	0	0	0	3.2	8.9
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	7.1	0
TOTAL	13.6	21.0	27.4	25.2	4.9	.8	.1	0	0	0	0	100	8.1

* = PERCENT < .05
\# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 9543

TABLE A - 4. MARCH PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT.	SPEED (KNOTS)												
DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.4	1.0	1.3	1.2	.2	*	0	0	0	0	0	3.9	8.6
NNE	.4	1.6	3.4	2.1	.4	.1	*	0	0	0	0	8.1	9.4
NE	.6	2.1	5.8	5.9	.6	*	0	0	0	0	0	15.5	10.1
ENE	1.0	3.2	8.2	11.3	2.1	.1	0	0	0	0	0	26.0	10.9
E	.8	2.2	5.4	8.7	2.2	.2	*	0	0	0	0	18.9	11.5
ESE	.3	.7	1.8	1.8	.3	*	0	0	0	0	0	5.2	10.0
SE	.3	.4	.3	.1	0	0	0	0	0	0	0	1.1	7.1
SSE	.4	.4	.3	.1	0	0	0	0	0	0	0	1.2	6.0
S	1.0	.8	.4	.3	.1	*	*	0	0	0	0	2.5	5.6
SSW	1.1	.9	.4	.2	*	*	0	0	0	0	0	2.8	5.8
SW	.7	.8	.4	.3	.1	*	*	0	0	0	0	2.3	6.6
WSW	.6	.4	.2	.1	.1	*	0	0	0	0	0	1.5	5.7
W	.5	.6	.3	.1	*	0	0	0	0	0	0	1.4	4.9
WNW	.3	.4	.3	*	0	0	0	0	0	0	0	1.1	6.0
NW	.2	.5	.4	.2	*	*	0	0	0	0	0	1.4	8.3
NNW	.2	.7	.7	.5	.1	*	*	0	0	0	0	2.4	9.2
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	5.0	0
TOTAL	8.8	16.7	29.6	33.1	6.2	.6	*	0	0	0	0	100	9.3

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10625

TABLE A - 5. APRIL PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT.	SPEED (KNOTS)												
DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.2	.8	1.1	.7	.2	*	0	0	0	0	0	2.8	8.4
NNE	.3	1.7	4.0	2.9	.4	*	0	0	0	0	0	9.2	9.6
NE	.5	3.0	7.8	7.0	.9	.1	0	0	0	0	0	19.7	10.1
ENE	.8	4.3	10.8	13.6	2.4	.1	0	0	0	0	0	31.9	10.8
E	.6	2.4	6.2	7.6	1.2	.1	0	0	0	0	0	17.6	10.7
ESE	.2	.7	1.5	2.2	.2	*	0	0	0	0	0	5.1	10.7
SE	.2	.3	.2	.2	0	0	0	0	0	0	0	.9	7.1
SSE	.3	.3	.2	.1	*	0	0	0	0	0	0	1.0	6.2
S	.5	.4	.3	.2	*	0	0	0	0	0	0	1.4	5.7
SSW	.6	.5	.2	.1	*	0	*	0	0	0	0	1.5	5.7
SW	.6	.3	.1	.1	0	0	0	0	0	0	0	1.1	4.3
WSW	.5	.3	.1	*	0	0	0	0	0	0	0	.9	4.1
W	.3	.3	.1	*	0	0	0	0	0	0	0	.7	4.0
WNW	.3	.3	.1	*	0	0	0	0	0	0	0	.8	4.9
NW	.2	.3	.2	.1	*	*	0	0	0	0	0	.8	7.1
NNW	.2	.5	.5	.2	.1	*	0	0	0	0	0	1.6	8.9
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	3.4	0
TOTAL	6.2	16.3	33.3	34.7	5.6	.5	*	0	0	0	0	100	9.6

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10533

TABLE A - 6. MAY PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT. DIR.	SPEED (KNOTS) 1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.2	.9	1.2	.7	.1	*	0	0	0	0	0	2.9	7.9
NNE	.3	1.7	3.1	1.7	.2	*	0	0	0	0	0	7.0	8.7
NE	.7	3.2	8.1	6.2	.6	*	0	0	0	0	0	19.5	9.5
ENE	1.0	5.4	14.5	14.9	1.6	.1	0	0	0	0	0	37.6	10.2
E	.7	2.8	7.9	7.3	.6	*	0	0	0	0	0	18.7	9.9
ESE	.2	.7	1.6	1.3	.2	0	0	0	0	0	0	4.2	9.6
SE	.1	.1	.2	*	0	0	0	0	0	0	0	.5	7.3
SSE	.2	.1	.1	0	0	0	0	0	0	0	0	.4	4.8
S	.5	.3	.2	.1	0	0	0	0	0	0	0	1.0	3.9
SSW	.5	.4	.1	*	*	0	0	0	0	0	0	1.1	4.8
SW	.4	.3	.2	.1	0	0	0	0	0	0	0	.9	5.4
WSW	.3	.2	.1	*	0	0	0	0	0	0	0	.6	4.4
W	.3	.3	.1	*	0	0	0	0	0	0	0	.7	4.2
WNW	.1	.3	*	*	0	0	0	0	0	0	0	.4	4.8
NW	.1	.2	.1	*	0	0	0	0	0	0	0	.5	6.4
NNW	.1	.4	.4	.2	*	0	0	0	0	0	0	1.2	8.1
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	3.3	0
ALL	5.8	17.3	37.7	32.4	3.3	.2	0	0	0	0	0	100	9.2

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10908

TABLE A - 7. JUNE PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT.							SPEED (KNOTS)						
DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.2	.6	.8	.3	0	0	0	0	0	0	0	1.8	7.2
NNE	.4	1.8	3.3	1.5	*	0	0	0	0	0	0	6.9	8.1
NE	.6	3.4	9.5	7.0	.3	*	0	0	0	0	0	21.2	9.4
ENE	1.1	5.7	16.3	14.3	1.0	*	0	0	0	0	0	38.2	9.8
E	.6	3.0	9.1	9.2	.9	*	0	0	0	0	0	22.5	10.2
ESE	.1	.5	1.8	2.0	.3	0	0	0	0	0	0	4.8	10.6
SE	*	.1	.1	.1	0	0	0	0	0	0	0	.3	9.0
SSE	.1	.1	.1	*	0	0	0	0	0	0	0	.3	6.4
S	.3	.2	.1	*	0	0	0	0	0	0	0	.6	3.9
SSW	.2	.1	*	*	0	0	0	0	0	0	0	.3	5.5
SW	.2	.1	*	0	0	0	0	0	0	0	0	.3	3.6
WSW	.1	.1	*	0	0	0	0	0	0	0	0	.3	4.0
W	.1	.1	*	*	0	0	0	0	0	0	0	.2	3.6
WNW	.1	.1	*	0	0	0	0	0	0	0	0	.2	4.5
NW	*	.1	*	*	0	0	0	0	0	0	0	.2	6.3
NNW	*	.2	.2	*	0	0	0	0	0	0	0	.5	7.3
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	2.0	0
TOTAL	4.0	16.1	40.9	34.3	2.6	.1	0	0	0	0	0	100	9.4

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10659

TABLE A - 8. JULY PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT. DIR.	SPEED (KNOTS) 1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.1	.5	.6	.2	0	0	0	0	0	0	0	1.3	6.6
NNE	.3	1.8	4.2	1.7	.1	0	0	0	0	0	0	8.0	8.3
NE	.5	3.6	11.1	7.4	.4	*	0	0	0	0	0	23.4	9.5
ENE	.9	6.2	17.5	15.9	1.3	.1	0	0	0	0	0	41.5	10.0
E	.4	3.3	8.6	7.8	.6	.1	*	0	0	0	0	20.4	10.0
ESE	.1	.5	1.2	1.3	.1	0	0	0	0	0	0	3.3	10.1
SE	.1	.1	*	*	0	0	0	0	0	0	0	.2	7.3
SSE	*	*	0	*	0	0	0	0	0	0	0	.1	5.8
S	.1	.1	*	0	0	0	0	0	0	0	0	.2	2.8
SSW	.1	.1	*	0	0	0	0	0	0	0	0	.2	3.6
SW	.1	*	*	0	0	0	0	0	0	0	0	.2	3.8
WSW	.1	.1	*	0	0	0	0	0	0	0	0	.2	4.7
W	.1	*	*	0	0	0	0	0	0	0	0	.1	2.7
WNW	*	*	*	0	0	0	0	0	0	0	0	.1	4.2
NW	*	*	*	0	0	0	0	0	0	0	0	.1	6.3
NNW	*	.1	.1	*	0	0	0	0	0	0	0	.3	7.5
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	.9	0
TOTAL	3.0	16.4	43.0	34.1	2.5	.1	*	0	0	0	0	100	9.6

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 11057

TABLE A - 9. AUGUST PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT. DIR.	SPEED (KNOTS) 1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.1	.3	.5	.1	*	0	0	0	0	0	0	.9	6.8
NNE	.3	1.5	3.5	1.1	.1	*	0	0	0	0	0	6.3	8.1
NE	.8	4.0	10.9	7.1	.2	0	0	0	0	0	0	23.3	9.2
ENE	1.1	6.4	17.2	15.5	1.0	*	*	0	0	0	0	41.0	9.8
E	.7	3.4	8.4	7.7	.8	*	0	0	0	0	0	20.6	9.9
ESE	.2	.7	1.7	1.7	.3	*	0	0	0	0	0	4.7	10.2
SE	.1	.1	.1	.1	*	0	0	0	0	0	0	.3	9.3
SSE	*	*	*	0	*	0	0	0	0	0	0	.1	7.3
S	.1	.1	.1	*	0	*	0	0	0	0	0	.3	5.2
SSW	.1	.1	*	*	0	0	0	0	0	0	0	.2	4.6
SW	.2	.1	*	0	0	0	0	0	0	0	0	.3	3.4
WSW	.1	.1	0	0	0	0	0	0	0	0	0	.2	3.5
W	.1	.1	*	0	0	0	0	0	0	0	0	.2	3.3
WNW	.1	.1	*	0	0	0	0	0	0	0	0	.1	4.9
NW	*	.1	.1	*	0	0	0	0	0	0	0	.2	6.9
NNW	*	.1	.1	*	0	0	0	0	0	0	0	.3	7.8
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	1.4	0
TOTAL	4.0	16.9	42.1	33.1	2.4	.1	*	0	0	0	0	100	9.4

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 11101

TABLE A - 10. SEPTEMBER PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT.	SPEED (KNOTS)												
DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.3	.7	.6	*	0	0	0	0	0	0	0	1.5	5.6
NNE	.5	2.0	3.2	.7	*	0	0	0	0	0	0	6.4	7.2
NE	.9	3.8	9.2	5.0	.2	0	0	0	0	0	0	19.5	8.7
ENE	1.5	6.6	15.1	11.4	.7	*	0	0	0	0	0	35.3	9.3
E	1.0	3.8	8.7	7.0	.6	0	0	0	0	0	0	20.7	9.4
ESE	.3	1.0	2.1	2.0	.2	*	0	0	0	0	0	5.7	9.7
SE	.2	.2	.2	*	0	*	0	0	0	0	0	.7	6.7
SSE	.2	.2	.1	*	0	0	0	0	0	0	0	.5	5.4
S	.6	.4	.2	*	*	*	0	0	0	0	0	1.1	3.7
SSW	.6	.3	.1	*	0	0	0	0	0	0	0	1.1	4.3
SW	.5	.4	.1	0	*	0	0	0	0	0	0	1.0	4.3
WSW	.4	.2	.1	*	0	0	0	0	0	0	0	.7	3.9
W	.3	.3	.1	*	0	0	0	0	0	0	0	.7	3.7
WNW	.2	.2	*	0	0	0	0	0	0	0	0	.4	4.6
NW	.1	.2	.1	*	*	0	0	0	0	0	0	.4	6.3
NNW	.2	.4	.2	.1	0	0	0	0	0	0	0	.8	6.2
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	4.1	0
TOTAL	7.7	20.4	39.6	26.3	1.7	*	0	0	0	0	0	100	8.3

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10543

TABLE A - 11. OCTOBER PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT. DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
	SPEED (KNOTS)												
N	.4	1.2	.9	.2	*	0	0	0	0	0	0	2.6	6.2
NNE	.6	2.6	3.6	1.4	.1	0	0	0	0	0	0	8.2	7.6
NE	.8	3.7	7.2	4.2	.3	*	0	0	0	0	0	16.8	8.7
ENE	1.4	5.6	12.4	8.6	1.0	.2	0	0	0	0	0	29.3	9.4
E	1.0	3.4	7.8	6.5	.8	.1	0	0	0	0	0	19.0	9.7
ESE	.3	.9	2.1	1.9	.3	*	0	0	0	0	0	5.7	9.6
SE	.3	.4	.3	.1	*	0	0	0	0	0	0	1.1	6.9
SSE	.4	.4	.3	*	0	0	0	0	0	0	0	1.1	5.7
S	.9	.7	.4	.2	0	0	0	0	0	0	0	2.1	4.5
SSW	1.0	.7	.2	.1	0	0	0	0	0	0	0	2.1	4.2
SW	.9	.5	.1	*	0	0	0	0	0	0	0	1.6	4.0
WSW	.7	.5	*	*	0	0	0	0	0	0	0	1.3	3.7
W	.5	.3	.1	*	0	0	0	0	0	0	0	1.0	3.6
WNW	.4	.3	.1	*	0	0	0	0	0	0	0	.8	4.2
NW	.2	.4	.1	*	0	0	0	0	0	0	0	.8	5.6
NNW	.2	.5	.4	.1	0	0	0	0	0	0	0	1.3	6.7
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	5.6	0
TOTAL	10.1	22.2	35.7	23.6	2.5	.3	0	0	0	0	0	100	8.0

* = PERCENT < .05
# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10893

TABLE A - 12. NOVEMBER PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT.	SPEED (KNOTS)											
DIR.	1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.4	1.0	1.0	.7	.1	*	0	0	0	0	0	3.1	7.4
NNE	.4	1.8	2.9	1.7	.2	*	0	0	0	0	0	7.0	8.5
NE	.8	2.6	5.6	4.9	.7	*	0	0	0	0	0	15.2	9.6
ENE	1.0	4.7	10.2	10.7	1.8	.1	0	0	0	0	0	28.5	10.2
E	1.0	3.0	6.9	6.5	.9	*	0	0	0	0	0	17.6	9.8
ESE	.4	1.1	2.5	2.0	.3	.1	0	0	0	0	0	6.6	9.6
SE	.2	.5	.5	.1	*	0	0	0	0	0	0	1.5	7.6
SSE	.5	.5	.4	.2	*	0	*	0	0	0	0	1.6	6.7
S	1.1	.8	.5	.3	*	*	*	*	0	0	0	2.6	5.5
SSW	1.0	.6	.3	.1	.1	0	0	0	0	0	0	2.2	5.6
SW	1.0	.6	.3	*	0	0	0	0	0	0	0	1.9	4.3
WSW	.9	.6	.1	*	0	0	0	0	0	0	0	1.6	3.6
W	.6	.4	.2	*	*	0	0	0	0	0	0	1.2	4.0
WNW	.2	.3	.2	.1	*	*	0	0	0	0	0	.9	6.3
NW	.2	.4	.2	.1	.1	*	0	0	0	0	0	1.0	7.7
NNW	.3	.6	.4	.3	*	*	0	0	0	0	0	1.7	7.9
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	6.1	0
TOTAL	10.2	19.5	31.9	27.7	4.2	.3	*	*	0	0	0	100	8.5

* = PERCENT < .05
\# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 10695

TABLE A - 13. DECEMBER PERCENT FREQUENCY DISTRIBUTION FOR WINDS AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

PERCENT FREQUENCY (%)
(1945 – 1995)

16 PT. DIR.	SPEED (KNOTS) 1 - 3	4 – 6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	>=56	TOTAL	MEAN
N	.5	1.1	1.3	1.1	.3	.1	0	0	0	0	0	3.8	8.8
NNE	.8	2.0	3.0	1.6	.3	*	0	0	0	0	0	7.6	8.3
NE	.9	2.6	4.3	4.6	.7	.1	*	0	0	0	0	13.8	9.8
ENE	1.1	3.4	7.4	9.1	2.2	.4	*	0	0	0	0	23.6	10.8
E	.8	2.6	4.3	5.0	1.2	.2	0	0	0	0	0	13.6	10.3
ESE	.5	1.0	1.5	1.0	.4	.1	*	0	0	0	0	4.8	9.7
SE	.4	.7	.5	.2	*	*	0	0	0	0	0	1.8	6.8
SSE	.6	.7	.4	.2	*	*	0	0	0	0	0	2.1	6.7
S	1.9	1.1	.8	.3	.1	.1	0	0	0	0	0	4.0	5.3
SSW	1.6	1.3	.6	.3	.1	*	*	0	0	0	0	4.2	5.9
SW	1.2	.9	.6	.3	.1	*	*	0	0	0	0	3.1	6.4
WSW	1.0	.7	.2	.2	*	*	0	*	0	0	0	2.2	5.2
W	.9	.7	.3	.1	.1	0	0	0	0	0	0	1.8	4.2
WNW	.4	.4	.4	.1	*	*	0	0	0	0	0	1.3	6.5
NW	.3	.4	.2	.3	.1	*	0	0	0	0	0	1.4	8.7
NNW	.4	.7	.7	.6	.1	*	*	0	0	0	0	2.7	9.0
VAR	0	0	0	0	0	0	0	0	0	0	0	0	0
CLM	0	0	0	0	0	0	0	0	0	0	0	8.3	0
TOTAL	13.1	20.2	26.4	24.9	5.8	1.2	.1	*	0	0	0	100	8.3

* = PERCENT < .05
\# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED
THE TOTAL NUMBER OF DATA = 11018

TABLE A - 14. ANNUAL PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(8/9/00 - 6/13/01)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	20.0-22.0	22.0-24.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.36	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41
0.9- 1.2	0.00	0.25	2.44	1.97	0.58	0.26	0.11	0.03	0.00	0.00	0.00	5.64
1.2- 1.5	0.00	2.54	4.86	5.14	2.61	1.19	0.38	0.11	0.06	0.02	0.01	16.92
1.5- 1.8	0.00	2.81	5.75	8.61	2.48	1.19	0.54	0.10	0.13	0.02	0.00	21.63
1.8- 2.1	0.00	1.51	6.34	8.54	2.17	0.70	0.61	0.25	0.14	0.01	0.00	20.28
2.1- 2.4	0.00	0.20	5.22	6.67	1.22	0.38	0.78	0.20	0.14	0.00	0.00	14.82
2.4- 2.7	0.00	0.07	2.97	4.59	1.34	0.25	0.49	0.24	0.06	0.00	0.00	10.01
2.7- 3.0	0.00	0.00	0.92	2.87	1.22	0.20	0.13	0.11	0.00	0.00	0.00	5.45
3.0- 3.3	0.00	0.00	0.20	1.29	1.19	0.09	0.01	0.01	0.00	0.00	0.00	2.80
3.3- 3.6	0.00	0.00	0.05	0.59	0.63	0.02	0.00	0.00	0.00	0.00	0.00	1.29
3.6- 3.9	0.00	0.00	0.02	0.24	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.47
3.9- 4.2	0.00	0.00	0.00	0.09	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.16
4.2- 4.5	0.00	0.00	0.00	0.08	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.11
TOTAL	0.00	7.38	29.15	40.75	13.73	4.29	3.06	1.06	0.52	0.06	0.01	100.00

THE TOTAL NUMBER OF DATA = 14156
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.66 - 4.49
THE RANGE OF WAVE PERIODS (SEC.) : 4.0 - 22.2

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 15. JANUARY PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(JANUARY 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	20.0-22.0	22.0-24.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.34	3.50	1.82	1.21	0.94	0.27	0.00	0.00	0.00	8.08
1.2- 1.5	0.00	0.20	0.40	4.85	4.37	2.89	0.74	0.27	0.13	0.07	0.07	14.00
1.5- 1.8	0.00	1.08	1.68	7.60	2.42	2.02	0.67	0.34	0.34	0.20	0.00	16.35
1.8- 2.1	0.00	1.88	3.90	8.34	3.10	1.41	1.55	0.81	1.01	0.13	0.00	22.14
2.1- 2.4	0.00	0.20	4.91	3.77	2.02	1.75	4.58	0.47	1.28	0.00	0.00	18.98
2.4- 2.7	0.00	0.00	2.09	3.16	0.34	0.54	2.83	1.68	0.54	0.00	0.00	11.17
2.7- 3.0	0.00	0.00	1.48	3.97	0.07	0.20	0.54	1.08	0.00	0.00	0.00	7.34
3.0- 3.3	0.00	0.00	0.40	1.14	0.00	0.13	0.00	0.07	0.00	0.00	0.00	1.75
3.3- 3.6	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
TOTAL	0.00	3.36	15.21	36.54	14.13	10.16	11.84	4.98	3.30	0.40	0.07	100.00

THE TOTAL NUMBER OF DATA = 1486
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.90 - 3.35
THE RANGE OF WAVE PERIODS (SEC.) : 5.0 - 22.2

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 16. FEBRUARY PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(FEBRUARY 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.07
0.9- 1.2	0.00	0.07	0.82	3.50	0.15	0.45	0.07	0.00	0.00	5.07
1.2- 1.5	0.00	0.00	2.98	5.44	0.45	0.60	0.75	0.00	0.07	10.28
1.5- 1.8	0.00	0.67	4.02	7.15	1.12	1.04	2.76	0.45	0.22	17.44
1.8- 2.1	0.00	1.19	7.75	4.40	1.64	0.30	1.42	0.97	0.15	17.81
2.1- 2.4	0.00	0.15	2.31	4.77	4.55	0.00	0.00	0.00	0.00	11.77
2.4- 2.7	0.00	0.00	1.04	5.14	5.44	0.30	0.00	0.00	0.00	11.92
2.7- 3.0	0.00	0.00	0.22	2.46	5.07	0.37	0.00	0.00	0.00	8.12
3.0- 3.3	0.00	0.00	0.37	2.16	4.55	0.75	0.00	0.00	0.00	7.82
3.3- 3.6	0.00	0.00	0.22	2.24	2.16	0.22	0.00	0.00	0.00	4.84
3.6- 3.9	0.00	0.00	0.22	1.56	0.67	0.00	0.00	0.00	0.00	2.46
3.9- 4.2	0.00	0.00	0.00	0.82	0.75	0.00	0.00	0.00	0.00	1.56
4.2- 4.5	0.00	0.00	0.00	0.60	0.22	0.00	0.00	0.00	0.00	0.82
TOTAL	0.00	2.09	19.97	40.31	26.75	4.02	4.99	1.42	0.45	100.00

THE TOTAL NUMBER OF DATA = 1342
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.88 - 4.31
THE RANGE OF WAVE PERIODS (SEC.) : 4.8 - 18.2

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 17. MARCH PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(MARCH 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.07
1.2- 1.5	0.00	0.00	0.34	4.91	0.60	1.14	0.00	0.00	6.99
1.5- 1.8	0.00	1.81	3.09	10.15	6.79	3.83	1.08	0.07	26.81
1.8- 2.1	0.00	1.88	6.18	11.29	8.60	2.35	0.40	0.00	30.71
2.1- 2.4	0.00	0.13	8.06	9.21	2.02	0.34	0.13	0.00	19.89
2.4- 2.7	0.00	0.07	1.68	3.29	2.76	1.01	0.47	0.00	9.27
2.7- 3.0	0.00	0.00	0.20	2.55	1.61	1.14	0.54	0.00	6.05
3.0- 3.3	0.00	0.00	0.00	0.07	0.00	0.07	0.07	0.00	0.20
TOTAL	0.00	3.90	19.56	41.53	22.38	9.88	2.69	0.07	100.00

THE TOTAL NUMBER OF DATA = 1488
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.18 - 3.05
THE RANGE OF WAVE PERIODS (SEC.) : 5.0 - 16.7

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 18. APRIL PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(APRIL 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2- 1.5	0.00	0.00	0.07	1.25	0.21	0.00	1.53
1.5- 1.8	0.00	0.28	1.60	10.01	0.90	0.07	12.86
1.8- 2.1	0.00	2.50	4.03	10.15	0.97	0.07	17.72
2.1- 2.4	0.00	0.28	7.51	5.91	0.69	0.07	14.45
2.4- 2.7	0.00	0.07	4.93	6.39	2.43	0.00	13.83
2.7- 3.0	0.00	0.00	2.02	9.24	4.10	0.00	15.36
3.0- 3.3	0.00	0.00	0.56	7.30	7.02	0.00	14.87
3.3- 3.6	0.00	0.00	0.28	2.71	4.17	0.00	7.16
3.6- 3.9	0.00	0.00	0.00	0.83	1.39	0.00	2.22
TOTAL	0.00	3.13	20.99	53.79	21.89	0.21	100.00

THE TOTAL NUMBER OF DATA = 1439
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.34 - 3.87
THE RANGE OF WAVE PERIODS (SEC.) : 5.3 - 12.5

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 19. MAY PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(MAY 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	3.39	0.14	0.00	0.00	0.00	3.53
0.9- 1.2	0.00	1.49	10.45	6.72	0.14	0.00	0.00	18.79
1.2- 1.5	0.00	6.24	13.43	8.48	1.02	0.00	0.00	29.17
1.5- 1.8	0.00	8.62	14.11	6.58	0.95	1.56	0.20	32.02
1.8- 2.1	0.00	0.68	2.92	3.87	0.54	0.47	0.00	8.48
2.1- 2.4	0.00	0.00	0.00	3.80	0.41	0.00	0.00	4.21
2.4- 2.7	0.00	0.00	0.41	2.24	0.20	0.00	0.00	2.85
2.7- 3.0	0.00	0.00	0.20	0.61	0.07	0.00	0.00	0.88
3.0- 3.3	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.07
TOTAL	0.00	17.03	44.91	32.50	3.32	2.04	0.20	100.00

THE TOTAL NUMBER OF DATA = 1474
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.66 - 3.01
THE RANGE OF WAVE PERIODS (SEC.) : 4.0 - 15.4

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 20. JUNE PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(JUNE 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.17	0.00	0.17
1.2- 1.5	0.00	11.31	15.81	0.17	27.29
1.5- 1.8	0.00	10.98	24.13	8.65	43.76
1.8- 2.1	0.00	0.67	15.31	9.65	25.62
2.1- 2.4	0.00	0.00	1.16	2.00	3.16
TOTAL	0.00	22.96	56.57	20.47	100.00

THE TOTAL NUMBER OF DATA = 601
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.18 - 2.29
THE RANGE OF WAVE PERIODS (SEC.) : 4.8 - 9.1

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 21. AUGUST PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(AUGUST 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.38	1.41	0.09	0.00	0.00	0.09	1.97
1.2- 1.5	0.00	8.73	8.17	1.97	0.00	0.00	0.75	19.62
1.5- 1.8	0.00	5.45	9.39	7.98	0.00	0.00	0.00	22.82
1.8- 2.1	0.00	2.63	12.30	12.96	0.38	0.00	0.00	28.26
2.1- 2.4	0.00	0.19	6.48	8.08	0.38	0.00	0.00	15.12
2.4- 2.7	0.00	0.00	0.85	3.38	1.22	0.00	0.00	5.45
2.7- 3.0	0.00	0.00	0.28	2.82	0.85	0.00	0.00	3.94
3.0- 3.3	0.00	0.00	0.09	0.75	0.28	0.00	0.00	1.13
3.3- 3.6	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.94
3.6- 3.9	0.00	0.00	0.00	0.09	0.09	0.00	0.00	0.19
3.9- 4.2	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.19
4.2- 4.5	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.38
TOTAL	0.00	17.37	38.97	39.62	3.19	0.00	0.85	100.00

THE TOTAL NUMBER OF DATA = 1065
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.11 - 4.49
THE RANGE OF WAVE PERIODS (SEC.) : 4.2 - 15.4

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 22. SEPTEMBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(SEPTEMBER 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.35	4.46	0.56	1.95	0.70	0.00	0.00	8.01
1.2- 1.5	0.00	5.15	13.79	7.73	7.45	1.60	0.21	0.07	36.00
1.5- 1.8	0.00	3.48	11.00	11.63	2.44	0.14	0.07	0.00	28.76
1.8- 2.1	0.00	1.74	12.60	5.57	0.00	0.00	0.00	0.00	19.92
2.1- 2.4	0.00	0.21	4.60	1.53	0.00	0.00	0.00	0.00	6.34
2.4- 2.7	0.00	0.00	0.91	0.07	0.00	0.00	0.00	0.00	0.97
TOTAL	0.00	10.93	47.35	27.09	11.84	2.44	0.28	0.07	100.00

THE TOTAL NUMBER OF DATA = 1436
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.91 - 2.60
THE RANGE OF WAVE PERIODS (SEC.) : 4.5 - 16.7

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 23. OCTOBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(OCTOBER 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	1.71	1.71	0.00	0.00	0.00	3.42
1.2- 1.5	0.00	0.00	1.49	4.91	3.64	1.12	0.07	11.23
1.5- 1.8	0.00	2.08	2.30	9.14	2.83	0.07	0.00	16.43
1.8- 2.1	0.00	2.16	7.88	12.34	1.04	0.00	0.00	23.42
2.1- 2.4	0.00	0.15	11.60	14.94	0.59	0.30	0.00	27.58
2.4- 2.7	0.00	0.07	4.16	10.41	0.22	0.00	0.00	14.87
2.7- 3.0	0.00	0.00	1.12	1.86	0.00	0.07	0.00	3.05
TOTAL	0.00	4.46	30.26	55.32	8.33	1.56	0.07	100.00

THE TOTAL NUMBER OF DATA = 1345
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.01 - 2.92
THE RANGE OF WAVE PERIODS (SEC.) : 5.3 - 14.3

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 24. NOVEMBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(NOVEMBER 2000)

HEIGHT (MTRS)	2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	TOTAL
	WAVE PERIOD (SEC.)								
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2- 1.5	0.00	0.00	0.10	1.60	0.00	0.00	0.00	0.00	1.70
1.5- 1.8	0.00	1.10	1.10	6.89	0.10	0.00	0.00	0.00	9.18
1.8- 2.1	0.00	0.70	2.50	11.48	0.30	0.60	0.30	0.00	15.87
2.1- 2.4	0.00	0.80	9.58	17.56	1.50	0.60	0.70	0.90	31.64
2.4- 2.7	0.00	0.30	13.77	14.07	0.50	0.50	1.60	0.20	30.94
2.7- 3.0	0.00	0.00	3.29	5.49	0.20	0.30	0.10	0.00	9.38
3.0- 3.3	0.00	0.00	0.40	0.90	0.00	0.00	0.00	0.00	1.30
TOTAL	0.00	2.89	30.74	57.98	2.59	2.00	2.69	1.10	100.00

THE TOTAL NUMBER OF DATA = 1002
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.33 - 3.16
THE RANGE OF WAVE PERIODS (SEC.) : 5.3 - 16.7

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 25. DECEMBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE MOKAPU POINT BUOY

SITE : MOKAPU POINT BUOY
WATER DEPTH: 100 METERS MLLW

PERCENT FREQUENCY (%)
(DECEMBER 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	20.0-22.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.07	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.34
0.9- 1.2	0.00	0.20	4.94	3.25	1.56	0.20	0.00	0.00	0.00	0.00	10.15
1.2- 1.5	0.00	2.03	2.50	10.28	7.78	4.19	1.42	0.74	0.34	0.14	29.43
1.5- 1.8	0.00	0.14	0.88	8.25	6.63	2.77	0.61	0.14	0.68	0.00	20.09
1.8- 2.1	0.00	0.20	0.54	6.63	4.60	1.69	2.37	0.74	0.20	0.00	16.98
2.1- 2.4	0.00	0.14	0.88	3.32	0.61	0.81	2.30	0.88	0.07	0.00	9.00
2.4- 2.7	0.00	0.27	3.92	2.84	0.74	0.20	0.34	0.47	0.00	0.00	8.80
2.7- 3.0	0.00	0.00	1.29	1.62	0.54	0.00	0.14	0.00	0.00	0.00	3.59
3.0- 3.3	0.00	0.00	0.34	0.88	0.27	0.00	0.00	0.00	0.00	0.00	1.49
3.3- 3.6	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.14
TOTAL	0.00	2.98	15.36	37.48	22.73	9.88	7.17	2.98	1.29	0.14	100.00

THE TOTAL NUMBER OF DATA = 1478
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.85 - 3.33
THE RANGE OF WAVE PERIODS (SEC.) : 4.5 - 20.0

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 26. ANNUAL PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(8/9/00 - 6/13/01)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	20.0-22.0	22.0-24.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.49	0.23	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.78
0.9- 1.2	0.00	0.25	2.88	3.06	1.29	0.42	0.11	0.03	0.00	0.00	0.00	8.05
1.2- 1.5	0.00	2.67	5.10	6.24	2.78	1.36	0.41	0.08	0.02	0.00	0.00	18.66
1.5- 1.8	0.00	2.82	6.24	10.33	2.88	1.19	0.54	0.11	0.09	0.04	0.01	24.24
1.8- 2.1	0.00	1.40	6.20	8.36	1.66	0.54	0.66	0.22	0.14	0.01	0.00	19.19
2.1- 2.4	0.00	0.18	5.06	5.71	1.38	0.27	0.69	0.20	0.11	0.01	0.00	13.61
2.4- 2.7	0.00	0.06	2.44	3.86	1.25	0.28	0.52	0.23	0.12	0.00	0.00	8.77
2.7- 3.0	0.00	0.00	0.53	1.75	1.43	0.17	0.11	0.15	0.04	0.00	0.00	4.17
3.0- 3.3	0.00	0.00	0.14	0.73	0.72	0.04	0.01	0.06	0.00	0.00	0.00	1.70
3.3- 3.6	0.00	0.00	0.05	0.29	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.55
3.6- 3.9	0.00	0.00	0.00	0.11	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.20
3.9- 4.2	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
TOTAL	0.00	7.38	29.15	40.75	13.73	4.29	3.06	1.06	0.52	0.06	0.01	100.00

THE TOTAL NUMBER OF DATA = 14156
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.62 - 4.16
THE RANGE OF WAVE PERIODS (SEC.) : 4.0 - 22.2

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 27. JANUARY PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(JANUARY 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	20.0-22.0	22.0-24.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.13	0.34	0.07	0.07	0.00	0.00	0.00	0.00	0.61
0.9- 1.2	0.00	0.00	0.34	4.44	2.62	1.55	0.87	0.27	0.00	0.00	0.00	10.09
1.2- 1.5	0.00	0.20	0.61	4.85	4.24	3.36	0.74	0.20	0.07	0.00	0.00	14.27
1.5- 1.8	0.00	1.14	2.22	10.57	2.89	1.75	0.81	0.34	0.13	0.27	0.07	20.19
1.8- 2.1	0.00	1.82	4.17	6.59	3.30	1.62	2.15	0.47	0.81	0.07	0.00	21.00
2.1- 2.4	0.00	0.20	4.58	3.50	0.67	1.08	3.70	0.74	0.81	0.07	0.00	15.34
2.4- 2.7	0.00	0.00	2.09	4.24	0.00	0.47	3.03	1.21	1.14	0.00	0.00	12.18
2.7- 3.0	0.00	0.00	0.87	1.82	0.07	0.27	0.40	1.21	0.34	0.00	0.00	4.98
3.0- 3.3	0.00	0.00	0.34	0.40	0.00	0.00	0.07	0.54	0.00	0.00	0.00	1.35
TOTAL	0.00	3.36	15.21	36.54	14.13	10.16	11.84	4.98	3.30	0.40	0.07	100.00

THE TOTAL NUMBER OF DATA = 1486
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.84 - 3.20
THE RANGE OF WAVE PERIODS (SEC.) : 5.0 - 22.2

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 28. FEBRUARY PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(FEBRUARY 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.30
0.9- 1.2	0.00	0.07	0.97	5.07	0.22	0.67	0.07	0.00	0.00	7.08
1.2- 1.5	0.00	0.00	3.06	6.78	0.52	0.60	1.04	0.00	0.07	12.07
1.5- 1.8	0.00	0.82	4.99	6.11	1.71	1.04	2.53	0.37	0.22	17.81
1.8- 2.1	0.00	1.12	7.00	5.44	3.80	0.07	1.34	0.97	0.00	19.75
2.1- 2.4	0.00	0.07	2.38	4.55	5.66	0.00	0.00	0.07	0.15	12.89
2.4- 2.7	0.00	0.00	0.67	4.10	5.29	0.45	0.00	0.00	0.00	10.51
2.7- 3.0	0.00	0.00	0.15	2.01	5.14	0.75	0.00	0.00	0.00	8.05
3.0- 3.3	0.00	0.00	0.30	2.61	2.76	0.45	0.00	0.00	0.00	6.11
3.3- 3.6	0.00	0.00	0.45	1.79	0.67	0.00	0.00	0.00	0.00	2.91
3.6- 3.9	0.00	0.00	0.00	0.97	0.97	0.00	0.00	0.00	0.00	1.94
3.9- 4.2	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.60
TOTAL	0.00	2.09	19.97	40.31	26.75	4.02	4.99	1.42	0.45	100.00

THE TOTAL NUMBER OF DATA = 1342
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.82 - 4.00
THE RANGE OF WAVE PERIODS (SEC.) : 4.8 - 18.2

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 29. MARCH PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(MARCH 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.07	1.14	0.00	0.00	0.00	0.00	1.21
1.2- 1.5	0.00	0.00	0.60	6.52	2.35	1.81	0.07	0.00	11.36
1.5- 1.8	0.00	2.08	3.16	11.96	10.62	4.77	1.08	0.00	33.67
1.8- 2.1	0.00	1.61	7.86	13.10	4.37	0.94	0.40	0.07	28.36
2.1- 2.4	0.00	0.13	6.79	5.04	2.49	0.40	0.07	0.00	14.92
2.4- 2.7	0.00	0.07	1.08	3.36	2.35	1.28	0.60	0.00	8.74
2.7- 3.0	0.00	0.00	0.00	0.40	0.20	0.67	0.40	0.00	1.68
3.0- 3.3	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.07
TOTAL	0.00	3.90	19.56	41.53	22.38	9.88	2.69	0.07	100.00

THE TOTAL NUMBER OF DATA = 1488
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.11 - 3.00
THE RANGE OF WAVE PERIODS (SEC.) : 5.0 - 16.7

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 30. APRIL PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(APRIL 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2- 1.5	0.00	0.00	0.07	2.57	0.35	0.00	2.99
1.5- 1.8	0.00	0.35	2.15	14.80	1.39	0.14	18.83
1.8- 2.1	0.00	2.50	4.93	6.18	0.69	0.00	14.32
2.1- 2.4	0.00	0.21	8.55	7.23	1.95	0.07	18.00
2.4- 2.7	0.00	0.07	3.41	8.96	3.20	0.00	15.64
2.7- 3.0	0.00	0.00	1.39	9.80	8.41	0.00	19.60
3.0- 3.3	0.00	0.00	0.42	3.27	4.52	0.00	8.20
3.3- 3.6	0.00	0.00	0.07	0.97	1.39	0.00	2.43
TOTAL	0.00	3.13	20.99	53.79	21.89	0.21	100.00

THE TOTAL NUMBER OF DATA = 1439
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.24 - 3.59
THE RANGE OF WAVE PERIODS (SEC.) : 5.3 - 12.5

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 31. MAY PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(MAY 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	4.07	1.15	0.00	0.00	0.00	5.22
0.9- 1.2	0.00	1.49	11.60	9.09	0.54	0.00	0.00	22.73
1.2- 1.5	0.00	6.78	13.64	7.87	1.09	0.07	0.00	29.44
1.5- 1.8	0.00	8.14	13.30	5.83	0.54	1.83	0.20	29.85
1.8- 2.1	0.00	0.61	1.70	4.41	0.75	0.14	0.00	7.60
2.1- 2.4	0.00	0.00	0.07	2.78	0.27	0.00	0.00	3.12
2.4- 2.7	0.00	0.00	0.41	1.29	0.14	0.00	0.00	1.83
2.7- 3.0	0.00	0.00	0.14	0.07	0.00	0.00	0.00	0.20
TOTAL	0.00	17.03	44.91	32.50	3.32	2.04	0.20	100.00

THE TOTAL NUMBER OF DATA = 1474
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.62 - 2.79
THE RANGE OF WAVE PERIODS (SEC.) : 4.0 - 15.4

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 32. JUNE PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(JUNE 2001)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.17	0.33	0.00	0.50
1.2- 1.5	0.00	11.65	19.63	1.50	32.78
1.5- 1.8	0.00	10.48	27.12	13.48	51.08
1.8- 2.1	0.00	0.67	8.99	5.32	14.98
2.1- 2.4	0.00	0.00	0.50	0.17	0.67
TOTAL	0.00	22.96	56.57	20.47	100.00

THE TOTAL NUMBER OF DATA = 601
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.15 - 2.16
THE RANGE OF WAVE PERIODS (SEC.) : 4.8 - 9.1

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 33. AUGUST PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(AUGUST 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.38	2.25	0.38	0.00	0.00	0.09	3.10
1.2- 1.5	0.00	8.92	8.92	2.91	0.00	0.00	0.75	21.50
1.5- 1.8	0.00	5.45	10.52	12.58	0.19	0.00	0.00	28.73
1.8- 2.1	0.00	2.44	10.80	12.39	0.28	0.00	0.00	25.92
2.1- 2.4	0.00	0.19	5.45	4.51	1.41	0.00	0.00	11.55
2.4- 2.7	0.00	0.00	0.75	3.94	0.85	0.00	0.00	5.54
2.7- 3.0	0.00	0.00	0.19	0.94	0.38	0.00	0.00	1.50
3.0- 3.3	0.00	0.00	0.09	1.13	0.00	0.00	0.00	1.22
3.3- 3.6	0.00	0.00	0.00	0.28	0.09	0.00	0.00	0.38
3.6- 3.9	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.28
3.9- 4.2	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.28
TOTAL	0.00	17.37	38.97	39.62	3.19	0.00	0.85	100.00

THE TOTAL NUMBER OF DATA = 1065
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.06 - 4.16
THE RANGE OF WAVE PERIODS (SEC.) : 4.2 - 15.4

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 34. SEPTEMBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(SEPTEMBER 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.35	0.00	0.00	0.07	0.00	0.00	0.42
0.9- 1.2	0.00	0.35	5.64	2.58	5.50	1.11	0.00	0.00	15.18
1.2- 1.5	0.00	5.57	14.07	10.52	5.50	1.11	0.21	0.07	37.05
1.5- 1.8	0.00	3.27	11.42	9.40	0.84	0.14	0.07	0.00	25.14
1.8- 2.1	0.00	1.60	11.98	4.32	0.00	0.00	0.00	0.00	17.90
2.1- 2.4	0.00	0.14	3.48	0.28	0.00	0.00	0.00	0.00	3.90
2.4- 2.7	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.42
TOTAL	0.00	10.93	47.35	27.09	11.84	2.44	0.28	0.07	100.00

THE TOTAL NUMBER OF DATA = 1436
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.88 - 2.55
THE RANGE OF WAVE PERIODS (SEC.) : 4.5 - 16.7

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 35. OCTOBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(OCTOBER 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	2.60	2.53	0.82	0.22	0.00	6.17
1.2- 1.5	0.00	0.00	0.82	6.84	4.39	0.89	0.07	13.01
1.5- 1.8	0.00	2.53	3.20	11.52	1.93	0.07	0.00	19.26
1.8- 2.1	0.00	1.71	9.67	16.51	0.82	0.07	0.00	28.77
2.1- 2.4	0.00	0.22	10.48	13.01	0.37	0.22	0.00	24.31
2.4- 2.7	0.00	0.00	3.05	4.68	0.00	0.07	0.00	7.81
2.7- 3.0	0.00	0.00	0.45	0.22	0.00	0.00	0.00	0.67
TOTAL	0.00	4.46	30.26	55.32	8.33	1.56	0.07	100.00

THE TOTAL NUMBER OF DATA = 1345
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.95 - 2.83
THE RANGE OF WAVE PERIODS (SEC.) : 5.3 - 14.3

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 36. NOVEMBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(NOVEMBER 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9- 1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2- 1.5	0.00	0.00	0.20	2.79	0.00	0.00	0.00	0.00	2.99
1.5- 1.8	0.00	1.10	1.60	10.28	0.40	0.00	0.00	0.00	13.37
1.8- 2.1	0.00	0.70	2.69	14.47	1.00	0.80	0.30	0.00	19.96
2.1- 2.4	0.00	0.80	11.98	19.36	1.00	0.50	0.70	0.50	34.83
2.4- 2.7	0.00	0.30	12.57	9.38	0.20	0.70	1.60	0.60	25.35
2.7- 3.0	0.00	0.00	1.70	1.70	0.00	0.00	0.10	0.00	3.49
TOTAL	0.00	2.89	30.74	57.98	2.59	2.00	2.69	1.10	100.00

THE TOTAL NUMBER OF DATA = 1002
THE RANGE OF WAVE HEIGHTS (MTRS) : 1.23 - 2.98
THE RANGE OF WAVE PERIODS (SEC.) : 5.3 - 16.7

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 37. DECEMBER PERCENT FREQUENCY DISTRIBUTION FOR WAVES AT THE WATER DEPTH OF 30 METERS

SITE : KANEOHE BAY MCAS
WATER DEPTH: 30 METERS MLLW

PERCENT FREQUENCY (%)
(DECEMBER 2000)

HEIGHT (MTRS)	WAVE PERIOD (SEC.) 2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0-10.0	10.0-12.0	12.0-14.0	14.0-16.0	16.0-18.0	18.0-20.0	20.0-22.0	TOTAL
0.0- 0.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3- 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.6- 0.9	0.00	0.00	0.27	0.61	0.14	0.00	0.00	0.00	0.00	0.00	1.01
0.9- 1.2	0.00	0.20	5.14	4.94	2.91	0.61	0.07	0.00	0.00	0.00	13.87
1.2- 1.5	0.00	2.03	2.23	10.76	8.73	5.35	1.35	0.47	0.07	0.00	30.99
1.5- 1.8	0.00	0.14	0.81	9.34	7.51	1.69	0.68	0.34	0.54	0.14	21.18
1.8- 2.1	0.00	0.27	0.74	4.74	1.69	1.76	2.37	0.68	0.54	0.00	12.79
2.1- 2.4	0.00	0.07	1.35	3.65	0.68	0.47	2.30	0.74	0.14	0.00	9.40
2.4- 2.7	0.00	0.27	3.65	2.17	0.81	0.00	0.27	0.54	0.00	0.00	7.71
2.7- 3.0	0.00	0.00	0.88	1.08	0.27	0.00	0.14	0.20	0.00	0.00	2.57
3.0- 3.3	0.00	0.00	0.27	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.47
TOTAL	0.00	2.98	15.36	37.48	22.73	9.88	7.17	2.98	1.29	0.14	100.00

THE TOTAL NUMBER OF DATA = 1478
THE RANGE OF WAVE HEIGHTS (MTRS) : 0.79 - 3.18
THE RANGE OF WAVE PERIODS (SEC.) : 4.5 - 20.0

THE WAVE HEIGHT IS THE SPECTRALLY BASED SIGNIFICANT WAVE HEIGHT.
THE WAVE PERIOD IS THE PERIOD ASSOCIATED WITH THE SPECTRAL PEAK.

TABLE A - 38. MONTHLY PEAK GUST (KNOTS) AT KANEOHE BAY MCAS

STATION : KANEOHE BAY MCAS ,HI,US
LOCATION: LAT 21 27N, LONG 157 47W, ELEV 6(m)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1948	53*	35E	42E	36*	36*	31E	37*	32E	33E	-	40E	42E	53*
1949	53SW	36*	36E	33*	-	-	-	-	-	-	-	-	-
1950	-	-	-	-	-	-	-	-	-	-	-	-	-
1951	-	-	-	-	-	-	-	-	-	-	-	-	-
1952	-	-	-	-	-	-	24E	23ENE	29ENE	25NNE	35NE	34VAR	-
1953	32SW	36E	33ENE	34NW	-	-	30SE	30ENE	32*	36ENE	37ENE	37E	37*
1954	61SSW	52N	51NNE	52SSW	38*	-	-	32*	35*	37*	47*	51*	61*
1955	57*	42SSE	39*	40*	32*	32*	35*	34*	-	-	-	-	-
1956	-	-	-	-	-	-	-	-	-	-	-	-	-
1957	-	-	-	-	-	-	-	-	-	28*	43SSW	41ESE	-
1958	33NNW	36SSW	30*	33*	29ENE	31ENE	38E	46*	29*	-	-	-	46*
1959	-	-	-	-	33ENE	30*	31E	43SE	29E	26E	39NE	40ENE	43*
1960	45ENE	39N	33*	29E	31ENE	29E	28NE	28E	34E	28ENE	30*	29NNE	45*
1961	36*	36E	37E	36ESE	30E	36ESE	40E	37E	30E	36*	39ENE	30E	40*
1962	43SSW	32NNW	34*	28E	29ENE	27ENE	28ENE	26ENE	27ENE	34E	31ENE	32WSW	43*
1963	73SW	65SW	41NW	34NE	30NNE	31ENE	28ENE	24ENE	32E	26NE	26ENE	34WNW	73SW
1964	30NE	33NE	30*	32*	29ENE	32NE	28NE	28ENE	28ENE	32NNE	35NE	56S	56*
1965	32*	-	-	-	-	-	-	-	-	-	-	-	-
1966	-	-	-	-	-	-	-	-	-	-	-	-	-
1967	-	-	-	-	-	-	-	-	-	-	-	-	-
1968	-	-	-	-	-	-	-	28*	23E	20*	37NNE	36NW	-
1969	40S	35NE	28NE	33NE	31NE	25NE	30NE	27NE	25*	25ENE	32NE	41NNW	41*
1970	83SSW	35NNW	31NE	28NE	29NE	28NE	30NE	25NE	26NE	30NE	29SW	35NE	83SSW
1971	55S	36NE	35S	30NE	25*	24NE	28NE	26NE	26ENE	27NE	32*	35ENE	55*
1972	28ESE	45*	37S	29ENE	26NNE	28NE	29E	27NE	33ENE	25E	31E	32SSW	45*
1973	29ENE	27NNE	32E	33E	28ESE	31E	31E	29E	27ENE	27E	29ENE	32W	33E
1974	44WSW	26ENE	44WSW	32E	27E	25E	27E	28E	28SE	27ENE	29NNW	31E	44WSW
1975	33ENE	28NE	30NNW	32ENE	29ESE	29E	25ENE	26ENE	28E	27ESE	30S	-	33*
1976	24*	47*	32*	31*	26*	29*	24*	-	-	23*	31*	25*	47*
1977	31*	25*	33*	27ENE	29*	27*	29*	26*	27ENE	34NE	32E	33WSW	34*
1978	33*	25N	27W	29E	28ESE	31E	27E	25ESE	27E	25NNE	29N	34E	34*
1979	40SW	41SSW	33WNW	29E	27E	28E	27ENE	24E	26E	29E	30N	37W	41SSW
1980	68SW	38N	38E	30E	26E	28E	28E	25E	27E	34E	28E	35NW	68SW
1981	34WSW	52SW	30E	28*	30*	29ENE	28E	26E	27ENE	37E	35E	37W	52*
1982	48WSW	54WSW	30ENE	24E	27*	24E	27E	35E	32E	30E	80SSW	29NE	80*
1983	32WSW	30WSW	31WSW	32E	28ENE	30NE	33*	28E	26E	24E	26E	34WSW	34*
1984	25?	26?	37?	33?	28?	28NNE	26?	25?	25?	23?	30?	35?	37?
1985	55?	43?	32?	24?	27?	23?	27?	25?	-	-	33*	34N	55*
1986	-	41?	27?	32?	24?	25?	26?	24?	21?	-	33ESE	49?	49*
1987	34?	33?	33?	33?	27?	27?	26?	24?	24?	22?	27?	32?	34?
1988	31?	26?	27?	26?	24?	30?	28?	28?	25?	22?	36NNW	41?	41?
1989	30?	38?	54?	31?	25?	24?	31?	35?	27?	24?	-	28ESE	54*
1990	27?	37?	29?	23*	28?	25?	24?	24?	24*	29*	-	-	37*
1991	-	-	-	-	22*	23?	21*	32?	30?	22NNW	26?	29?	-
1992	37?	33?	26?	20?	30NE	28?	23?	34?	55?	22?	33?	32?	55?
1993	48?	33ESE	36?	24?	25?	25?	33?	23?	27?	28ENE	29?	31?	48?
1994	28?	24?	35?	25?	24?	23?	24?	27?	23?	24?	29?	32?	35?
1995	42?	33?	39?	29?	24?	22?	24?	23?	20?	24?	29?	34ESE	42?
MEAN	42.0	36.4	34.7	30.3	27.7	27.5	28.3	27.8	28.2	27.3	33.6	35.2	48.8
STDV	14.6	9.0	6.7	5.5	2.3	3.2	3.6	4.5	5.8	4.3	9.5	5.7	16.2
#OBS	30	33	30	29	28	32	32	34	32	30	32	35	13

@ = Maximum 1 - Minute Speed (For Foriegn Stations)
* = INCOMPLETE
\- = MISSING DATA
? = UNKNOWN WIND DIRECTION
\# = EXCESSIVE MISSING DATA - VALUE NOT COMPUTED

TABLE A - 39. MONTHLY WIND CONDITIONS AT KANEOHE BAY MCAS

(Data Period: 1945 - 1995)

Month	Most Freq. Direction (Dir./ %)	Average Wind Speed (m/s)	Maximum Peak Gust (m/s, (knts))	Estimated Max. Speed (m/s)	
				1-Minute Speed	10-Minute Speed
January	ENE (14)	7.7	42.7 (83)	35.2	28.2
February	ENE (17)	8.1	33.5 (65)	27.6	22.2
March	ENE (26)	9.3	27.8 (54)	22.9	18.4
April	ENE (32)	9.6	26.8 (52)	22.1	17.7
May	ENE (38)	9.2	19.6 (38)	16.2	13.0
June	ENE (38)	9.4	18.5 (36)	15.2	12.2
July	ENE (42)	9.6	20.6 (40)	17.0	13.6
August	ENE (41)	9.4	23.7 (46)	19.5	15.7
September	ENE (35)	8.3	28.3 (55)	23.3	18.7
October	ENE (29)	8.0	19.0 (37)	15.7	12.6
November	ENE (29)	8.5	41.2 (80)	33.9	27.2
December	ENE (24)	8.3	28.8 (56)	23.7	19.0
Overall	ENE (31)	8.8	42.7 (83)	35.2	28.2

TABLE A - 40. RETURN PERIODS VERSUS. WIND SPEEDS AT THE WAVE BUOY

Return Period (years)	Peak Gust (m/s (knts))	1-Minute Wind Speed (m/s)	10-minute Wind Speed (m/s)
2	23.7 (46.0)	19.5	15.7
5	29.9 (58.1)	24.6	19.8
10	34.2 (66.4)	28.2	22.6
25	39.5 (76.8)	32.5	26.1

TABLE A - 41. RETURN PERIODS VERSUS SWELL HEIGHTS AT THE WAVE BUOY

Return Period (years)	Wave Height (meters)
2	3.7
5	3.9
10	4.0
25	4.2

TABLE A - 42. RETURN PERIODS VERSUS SWELL HEIGHTS AT THE WATER DEPTH OF 30 METERS

Return Period (years)	Wave Height (meters)
2	3.7
5	3.9
10	4.1
25	4.3

TABLE A - 43. RETURN PERIODS VERSUS WIND WAVE HEIGHTS AT THE WAVE BUOY

Return Period (years)	Wave Height (meters)
2	4.5
5	4.8
10	5.0
25	5.3

TABLE A - 44. RETURN PERIODS VERSUS WIND WAVE HEIGHTS AT THE WATER DEPTH OF 30 METERS

Return Period (years)	Wave Height (meters)
2	4.1
5	4.3
10	4.5
25	4.8

TABLE A - 45. SUMMARY OF HINDCAST HURRICANE WAVE CONDITIONS

	Model Hurricane
Wave Period:	
Significant Wave Period (sec.)	11.5
Average Wave Period (sec.)	8.0
Deepwater Wave Height:	
Significant Wave (m)	8.4
Maximum Wave (m)	14.9
Wave Height at 30-Meter Water Depth:	
Significant Wave (m)	7.7
Significant Wave Crest Elevation (m)	4.5
Maximum Wave (m)	13.6
Maximum Wave Crest Elevation (m)	9.8

Appendix B

TECHNICAL SPECIFICATIONS
FOR THE
PROCUREMENT OF A SUBMARINE CABLE TO BE
INSTALLED AT THE MARINE CORP BASE, KANEOHE, HAWAII

Prepared for:

Ocean Power Technologies, Inc.

1590 Reed Road, Pennington

New Jersey, 08534

Prepared by:

Makai Ocean Engineering, Inc.

Kailua, Hawaii

February 2002

TECHNICAL SPECIFICATIONS FOR THE SUBMARINE CABLE TO BE INSTALLED AT THE MARINE CORP BASE, KANEOHE, HAWAII

1.0 GENERAL

1.1 These specifications detail the technical requirements for a submarine power cable to be installed at the Marine Corp Base Hawaii, at Kaneohe, Hawaii

1.2 The cable required is a 3.8/6.6kV, three-conductor power cable (90^{o} C rating) with 100% insulation level, suitable for three-phase ac transmission. The cable furnished under this specification shall be suitable for continuous submersion in ocean waters and direct burial.

1.3 The cable shall have a double-layer contrahelical wound steel armor, resulting in torque balanced construction. The cable shall have pulling eyes at the end terminations suitable for pulling the cable during the shore landing operations. Maximum pulling tension of at least 1,500 kg (with a safety factor of 2) is required on the cable and on the end terminations. No portion of the cable shall have breaking strength less than 90% of the mean breaking strength of the overall cable, even when passing or having passed through a tensioner and/or over an over boarding sheave or chute.

1.4 A single-length of 1,300 meters of unspliced cable is required. The cable shall be marked at 10 m intervals with a durable, high visual band (e.g. paint, tape), with accuracy of plus or minus 0.5%. These marks shall last during the installation process and shall not interfere with the cable-tensioning machine as the cable is deployed.

1.5 The cable shall be transported to Oahu, Hawaii on a single turning reel suitable to be directly installed on a deployment vessel.

1.6 The cable will be laid on the seabed in a maximum water depth of 100 feet (30 m). The cable is to be deployed from a barge equipped with a single linear tensioning machine. During the deployment, the cable will be passed from the turning reel through the linear tensioner machine on the lay vessel.

1.7 Any exceptions to this specification must be submitted in writing for client approval. Detailed explanations for the modifications suggested shall be included.

2.0 APPLICABLE INDUSTRY STANDARDS

The following industry standards (latest editions) apply except this specification's requirements shall govern when conflict occurs.

AEIC CS6-87 (R 1990):

Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 through 69 kV.

ICEA S-68-516/NEMA WC-8 (R 1988):

Ethylene-Propylene Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

ASTM B 8-86:

Specifications for Concentric-Lay Stranded Cooper Conductors, Hard, Medium-Hard or Sofeet.

ASTM B 3-74 (R 1980,1985):

Specification for Sofeet or Annealed Copper Wire.

3.0 CONDUCTOR

3.1 The cable shall have three conductors for three phase ac operation.

3.2 The conductors shall be Class B, bare copper with concentric lay round stranding, in accordance with the current ASTM B8-86 "Specifications for Concentric-Lay Stranded Cooper Conductors, Hard, Medium-Hard or Sofeet". The conductor temper shall be sofeet or annealed and shall meet the elongation, finish and coating continuity requirements of ASTM Standard B-3-74 (R 1980,1985) "Specification for Sofeet or Annealed Copper Wire". The conductor size shall be such that meet the power requirements of 250 kW for the voltage established.

3.3 The design and construction of the cable shall be such that the cable will operate satisfactorily at continuous conductor temperatures of 90^{o}C, at emergency operation temperatures of 130^{o}C and at short circuit operation temperatures of 250^{o}C, in accordance with the requirements of ICEA S68-516.

3.4 Conductors shall meet the electrical resistance per unit length requirements of ICEA S68-516.

4.0 STRESS CONTROL LAYER (CONDUCTOR SCREEN)

4.1 Conductor shall be covered with a separate stress controlling material compatible with the conductor and the insulation used and shall have allowable operating temperatures equal to or higher than those of the insulation material used.

4.2 The stress control layer shall be a round, extruded thermosetting covering material and may be a semi-conducting or a non-conducting material in accordance with the requirements of ICEA S68-516.

4.3 The outer surface of the conductor shall be cylindrical and shall be firmly bonded to the overlaying insulation. The extruded shield shall be easily removable from the conductor.

4.4 Extrusions for the stress control layer shall be free of any voids larger than 5 mils at the insulation interfaces. The contact surface between the stress control layer and the insulation shall be cylindrical and free from protrusions and irregularities which, at the stress control layer, extend by more than 5 mils into the insulation and 10 mils into the stress layer. Protrusions at the surface between insulation and stress layer shall be limited to 10 mils into the insulation and 10 mils into the stress control layer.

4.5 The electrical characteristics of the stress control layer shall meet the requirements of ICEA

S-68-516.

5.0 INSULATION

5.1 The insulation used shall be a high quality thermosetting dielectric based on an ethylene-propylene rubber elastomer conforming to the requirements of Part 3 of ICEA S-68-516, unless otherwise noted in the following paragraphs. The color of the insulating compound shall be in contrast to the color of the stress control layer so that any remaining particles can be readily seen if they remain on the surface of the insulation. The insulation of the complete cable shall be free of any voids larger than 5 mils and any contaminant larger than 10 mils in its largest dimension. The method of examination and frequency shall be in accordance with sections D and G of AEIC CS6-87. In-plant repairs of the insulation are prohibited unless specifically agreed upon by the purchaser.

5.2 The insulation shall be compatible with the conductor stress layer and insulation shield materials. The insulation compound shall not contain any polyethylene to limit the degree of susceptibility to treeing experienced by highly crystalline materials.

5.3 The insulation shall be concentrically extruded directly over the conductor stress control layer surface and shall be cylindrical and smooth. Prior to extrusion, the insulation compound shall be screened through a 100 mesh or finer size mesh.

5.4 The level of insulation shall be 100%. The minimum average insulation thickness for the cable shall not be less than the value specified in the table below. The average thickness of insulation shall be determined as specified in AEIC CS6-87. The minimum thickness at any cross-section of the insulation shall be not less than 90% of the specified minimum average.

Rated Voltage Voltage to Ground (kV)	Rated Voltage Phase to Phase (kV)	Minimum Average Insulation Thickness (Mils)	5 minute ac Test Voltage (kV)	15 minute dc Test Voltage (kV)
3.8	6.6	120	23	45

5.5 The insulated conductor in the completed cable shall be tested in accordance with part 6 of ICEA S-68-516 at the voltages provided by the table presented in 5.4. In addition, the insulation material shall meet the electrical and physical characteristics for Type II insulation presented in part 3, ICEA S-68-516. Tests to measure the physical and electrical characteristics of the insulation material shall be completed in accordance with Part 6, ICEA S-68-516 and AEIC CS6-87.

6.0 INSULATION SCREEN

6.1 The insulation screen shall consist of a layer of semiconducting material extruded directly over the insulation.

6.2 The outer surface of the insulation screen shall be printed indicating the need to remove the semi-conducting screen before splicing or terminating.

6.3 The insulation shield shall meet the requirements established in Table 4a of ICEA S-68-516 and in AEIC CS6-87.

7.0 METALLIC SHIELD

7.1 The metallic shield shall be made of two nonmagnetic metal components. The first component, consisting of a tape or tapes, wires, straps, or sheets of copper, shall be applied over the semiconducting material extruded directly over the insulation and shall be electrically continuous throughout each cable length. If metal tape(s) is used, it shall be made of copper with a minimum thickness of 2.5 mils. Wires, straps or sheets shall be of copper and have a total area at any cross section of at least 5000 circular mils per inch of insulated conductor diameter.

7.2 Metal components shall be applied in such a manner that electrical continuity or contiguity will not be distorted or disrupted during normal installation bending (bending not exceeding the minimum radius of curvature stated in Appendix H, NEMA W-C8-88.

8.0 OPTICAL FIBERS

8.1 A non-metallic tube containing 4 single mode optical fibers, 10 microns, shall be included.

9.0 JACKETS AND ARMORS

9.1 A continuously extruded jacket of moisture and abrasion resistant material (e.g. Medium to High Density Polyethylene) shall be applied under the armor layer. The jacket once extruded, shall be cylindrical and smooth and be free of blisters, holes, cracks and other imperfections. The minimum average thickness of the outer serving shall be 3.0 mm. The minimum thickness at any point shall not be less than 80% of the stated minimum average thickness.

9.2 A brass tape (10 mil thick minimum) shall be applied under the armor layer to protect the cable against marine worms that inhabit warm waters climate areas.

9.3 The cable shall have a double-layer contrahelical wound steel armor, resulting in torque balanced construction. Steel wires must be 3.15 mm minimum diameter and shall be placed over the bedding with 95% minimum coverage. The zinc coated wires shall meet the tensile strength, elongation and torsion tests of ICEA S-68-516.

9.4 An outer jacket shall be used above the armor layer. A continuously extruded jacket of moisture and abrasion resistant material (e.g. High Density Polyethylene) shall be applied over the metallic shield. The jacket once extruded, shall be cylindrical and smooth and be free of blisters, holes, cracks and other imperfections. The minimum average thickness of the outer serving shall be 3.0 mm. The minimum thickness at any point shall not be less than 80% of the stated minimum average value.

10.0 SEALING AND END TERMINATIONS

10.1 Each cable end shall be effectively sealed to prevent the entrance of moisture into the cable construction afeeter performing the specific tests.

10.2 The cable shall have pulling eyes at the end terminations suitable for pulling the cable during the shore landing operations. The pulling eyes shall be attached to the steel armor wires so that the cable can be pulled through the eyes with the maximum cable tension without failure of the connections. The size of the eye shall be such that a one-inch diameter pin can be passed through the eye.

11.0 CABLE IDENTIFICATION

11.1 The outer surface of each cable shall be durably marked throughout its length with the manufacturer's identification, type of insulation (i.e., EP, not manufacturer's trade name), size of conductor, whether aluminum or copper, rated voltage, year of manufacture, and insulation thickness. A manufacturer's trade name may be added to the above required information. Durable marking on a jacket may be accomplished by indenting (but not to a depth greater than 15 percent of its thickness) or by approved surface printing.

11.2 Polymeric insulation shielding and semiconducting jackets shall be conspicuously identified as semiconducting. Identification shall be repeated along the cable at regular intervals with unmarked surfaces not exceeding six inches. Marking on the semiconducting shielding shall be by surface printing only.

12.0 QUALITY ASSURANCE

12.1 The seller shall submit all the laboratory results from the quality assurance tests conducted on the cable in the factory during manufacture and afeeter cable has been completed to assure the quality of the finished product. As a minimum, the following tests must be a part of the quality assurance program, in accordance with AEIC CS6-87:

- Structural Stability Test, to demonstrate that the power cable will operate and remain stable while being thermally cycled.
- High Voltage Time Test (HVTT), to show that the power cable meets the HVTT breakdown requirements as manufactured.
- Impulse Test, to show that the power cable, as manufactured, meets the impulse strength requirements.
- Cyclic Aging Test, to demonstrate that the power cable will operate and remain stable while being thermally cycled to its emergency conductor temperature (130^{o}C).
- Resistance Stability of Semiconducting Layer, to demonstrate that the volume resistivity of the semiconducting insulation shield material will exhibit stability when exposed to emergency overload temperatures.

In addition to the electrical tests, the quality assurance program shall include thermomechanical qualifications tests to demonstrate that the power cable construction, complete with jacket, will withstand repeated cycling to the maximum emergency operating conductor temperature.

12.2 The cable shall be new, and constructed of all new materials. The seller shall provide test reports certifying the quality of the materials to be incorporated into the cable.

12.3 The cable shall not be shipped (except when agreed to by the purchaser) unless all required tests have been completed and results of tests show compliance with all the requirements of these specifications.

13.0 SHIPMENT AND REELS

13.1 The cable shall be placed on a single reel and be protected from damage during shipment. Each end of the cable shall be firmly and properly secured to the reel. Care shall be taken to prevent looseness of reeled cable. The drum shall be such that it can be transferred to the installation winch without further spooling or handling. At least one meter at each end of the cable shall be easily accessible by the installer.

13.2 There shall be no water in the completed cable when the reel is shipped. If the conductor shows evidence of slight corrosion and no pitting, then the manufacturer shall verify that the cable was dried prior to shipping. Each end of each length of cable shall be durably sealed before shipment to prevent entrance of moisture.

13.3 The reel shall be lagged or covered with suitable material to provide physical protection for the cables during transit and during ordinary storage and handling operations.

13.4 The inner or drum end of the cable shall be allowed to project through the flange of the reel. This end shall be protected to avoid damage to the cable or seal.

13.5 Each reel shall be marked with a durable label securely attached to a flange of the reel and plainly stating the destination, the purchaser's order number, shipping length of cable on reel, number, type and size of conductors, cable configuration, thickness and type of insulation, voltage rating, gross, tare and net weight. The shipping reel shall be free of any information not pertaining to the order.

14.0 SUBMITTALS

14.1 The seller shall supply a detailed drawing of a cross section of the cable showing dimensions of cable components and overall cable diameter.

14.2 The seller shall supply with the bid the physical and mechanical properties of the cable as follow:

- Weight of the cable
- Bending stiffness of the cable (EI)
- Maximum tension that can be applied to the cable
- Minimum bending radius at zero and maximum tension
- Torque developed vs. pulling tension
- Rotation of cable vs. pulling tension
- Maximum squeeze (under zero tension and maximum tension respectively) that can be applied to proposed cable without causing cable damage

14.3 Drawings of proposed pulling eyes connections for the cable end terminations shall be provided within two weeks afeeter receiving the purchase order.

14.4 The seller shall provide information with his quote as to minimum sheave diameter recommended and sheave shape on which cable can meet requirements. The seller to provide data with the quote on any special sheave requirements for seller's cable, concerning required cable support on sheave.

14.5 The seller shall provide information with quote on:

- Overall drum size
- Internal drum size
- Minimum barrel diameter
- Shipping gross mass (drum and cable)

14.6 Details of packing for shipment and drawings of proposed shipping reel shall be provided within two weeks afeeter receiving the purchase order.

14.7 Delivery time for the cable afeeter order is placed shall be submitted with quote.

15.0 GUARANTEE

15.1 The manufacturer shall guarantee that the cable furnished under these specifications is of first class material and workmanship throughout, that it has been tested in accordance with these specifications, and that the results of the tests comply with the requirements of these specifications.

16.0 DELIVERY REQUIREMENTS

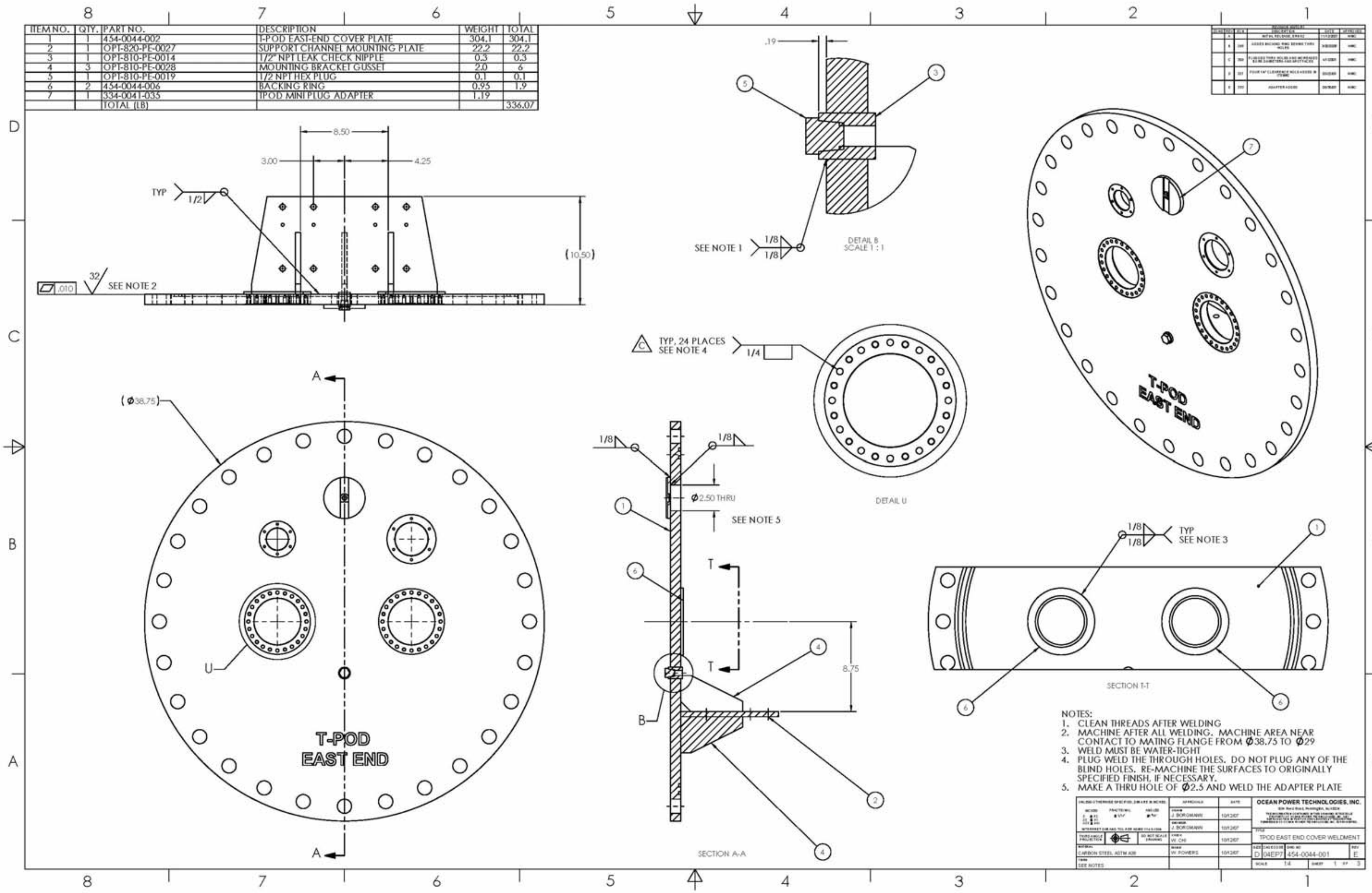
16.1 The cable manufacturer shall deliver the cable at Oahu, Hawaii.

16.2 Any additional costs, including but not limited to export duties, taxes, or fees relating to the cable, are the sole responsibility of the seller and will be considered included in the quoted price.

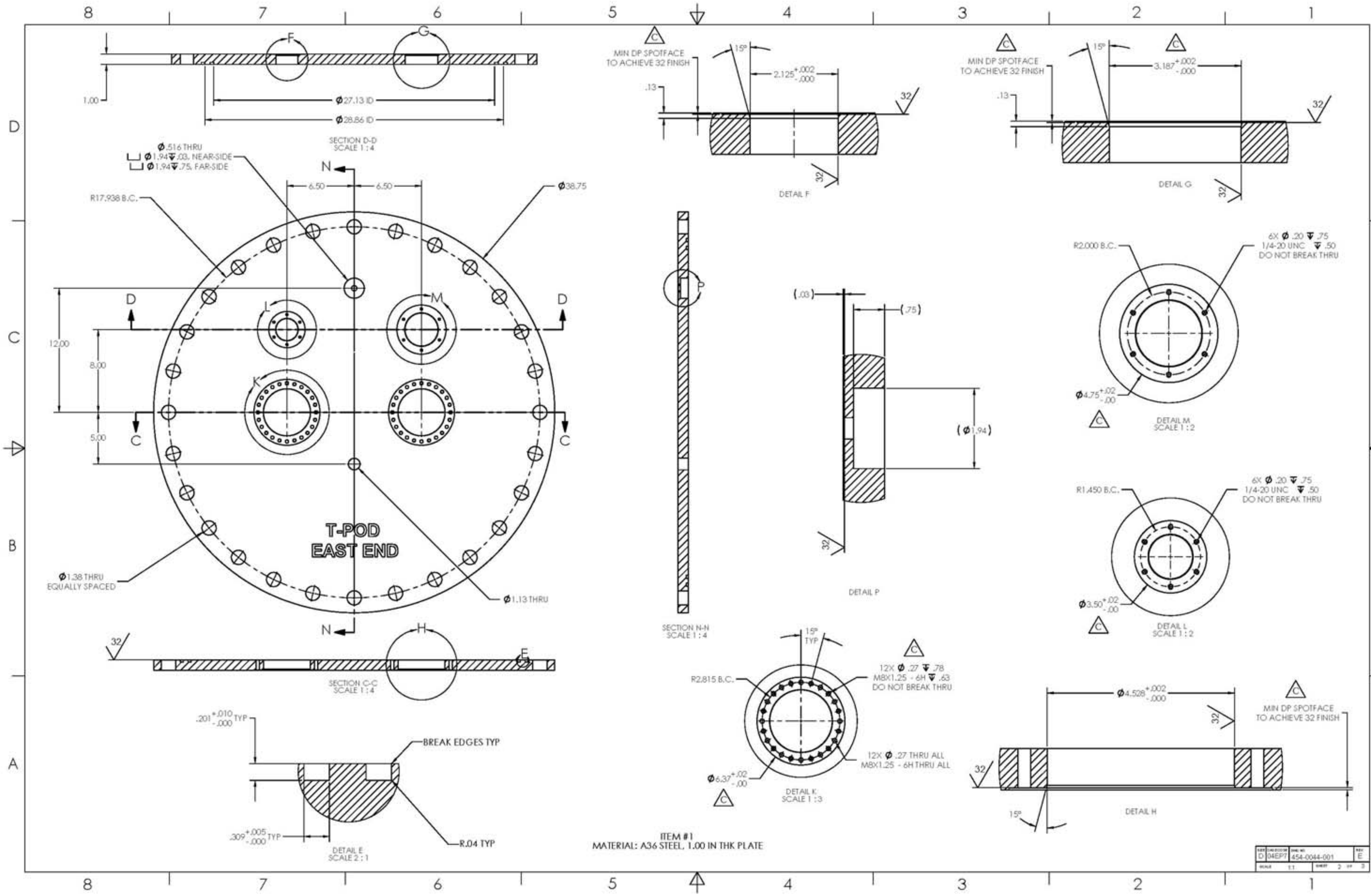
16.3 The buyer will have no further use for shipping reel afeeter cable is installed. Seller may offer credit to be deducted from his lump sum bid for the return of the reel to a designated point, in good condition with reasonable wear and tear.

Appendix C

T-Pod End Cap and Penetrator Design Drawings



ITEM NO.	QTY.	PART NO.	DESCRIPTION	WEIGHT	TOTAL
1	1	454-0044-002	T-POD EAST-END COVER PLATE	304.1	304.1
2	1	OPT-820-PE-0027	SUPPORT CHANNEL MOUNTING PLATE	22.2	22.2
3	1	OPT-810-PE-0014	1/2" NPT LEAK CHECK NIPPLE	0.3	0.3
4	3	OPT-810-PE-0028	MOUNTING BRACKET GUSSET	2.0	6
5	1	OPT-810-PE-0019	1/2 NPT HEX PLUG	0.1	0.1
6	2	454-0044-006	BACKING RING	0.95	1.9
7	1	334-0041-035	TPOD MINI PLUG ADAPTER	1.19	
		TOTAL (LB)			336.07


SECTION D-D
SCALE 1 : 4
DETAIL F
DETAIL G
MIN DP SPOTFACE TO ACHIEVE 32 FINISH
R17.938 B.C.
Ø38.75
T-POD
EAST END
Ø1.38 THRU
EQUALLY SPACED
Ø1.13 THRU
SECTION N-N
SCALE 1 : 4
DETAIL P
DETAIL M
SCALE 1 : 2
DETAIL L
SCALE 1 : 2
6X Ø .20 ▼ .75
1/4-20 UNC ▼ .50
DO NOT BREAK THRU
SECTION C-C
SCALE 1 : 4
DETAIL K
SCALE 1 : 3
12X Ø .27 THRU ALL
M8X1.25 - 6H THRU ALL
DETAIL H
BREAK EDGES TYP
R.04 TYP
DETAIL E
SCALE 2 : 1
ITEM #1
MATERIAL: A36 STEEL, 1.00 IN THK PLATE
454-0044-001

Appendix B – Umbilical Cable Information

Umbilical Cable Specification

Revised May 16, 2013

1. Major Components

NWEI Device – Wave energy converter which produces DC power and data signals

Dry Box – located on the NWEI Device. Connection point between the NWEI Device and the Umbilical Cable

Umbilical Cable – new cable which will interconnect NWEI Device to the T-Pod via the T-Plate

Device Bend Restrictor – located on NWEI Device and is the point at which the Umbilical Cable leaves the NWEI Device

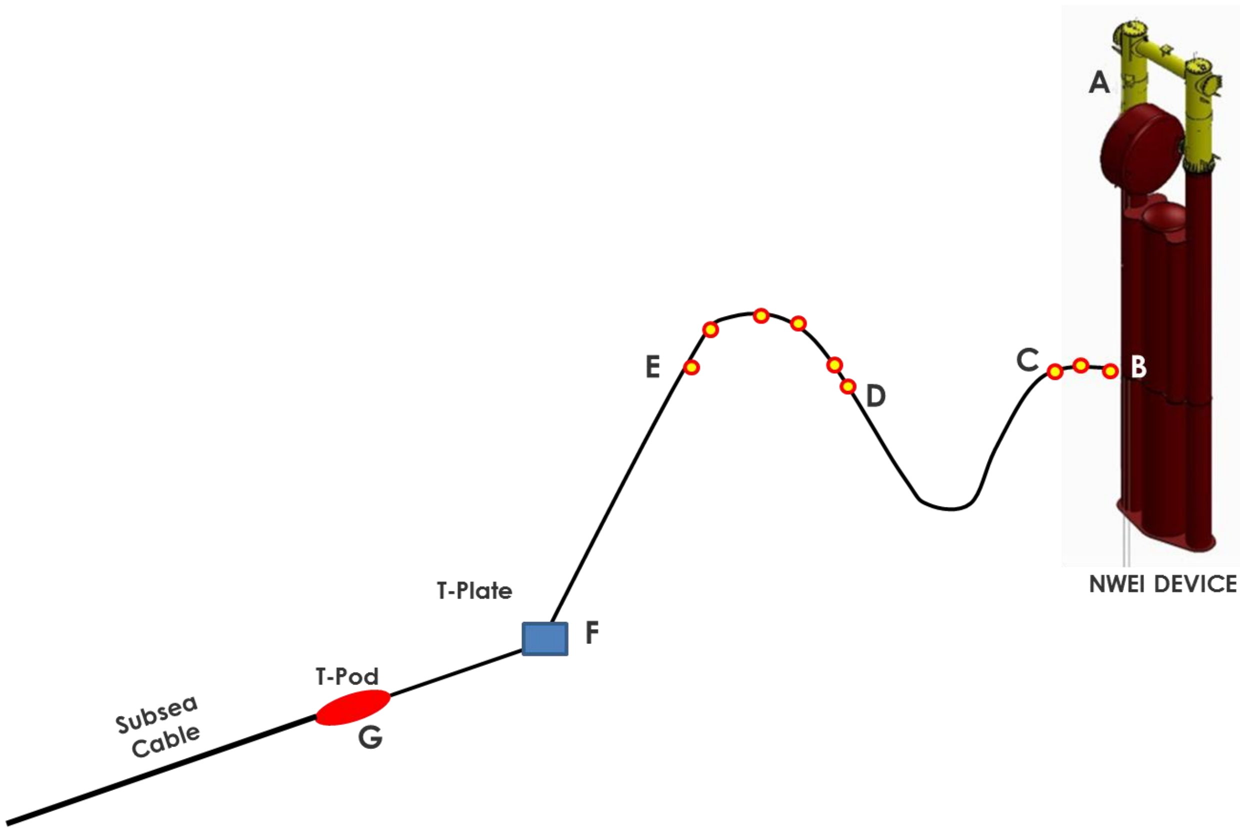
T-Plate – Located on seabed and is the point at which the Umbilical Cable is attached to the seabed. Includes a strength terminator which is to be designed.

T-Pod – waterproof housing as described in Section xx of the Site Report

Subsea Cable – existing subsea cable as described in Section yy of the Site Report

AWAC – Acoustic Wave and Current Profiler which is mounted on top of T-Pod. Connector cable has separate penetrator into T-Pod

2. General Arrangement (not to scale)



			Distance from Drybox	
Point/Segment	**Description**	**Segment Length, meters**	**Start Point**	**End Point**
A	DryBox	1.0	0.0	1.0
A-B	Cable attached to NWEI Device	12.0	1.0	13.0
B	Device Strength Termination Point	0.0	13.0	13.0
B-C	Cable with Added Flotation	3.5	13.0	16.5
C-D	Cable without Flotation	16.0	16.5	32.5
D-E	Cable with Added Flotation	12.0	32.5	44.5
E-F	Cable without Flotation	20.0	44.5	64.5
F	T-Plate	0.0	64.5	64.5
F-G	Cable lying on Seabed between T-Plate and T-Pod	30.5	64.5	95.0
G	T-Pod inlcuding extra cable for contingencies	15.0	95.0	110.0
	Total Cable Length, meters	110.0		

3. Umbilical Cable

3.1. Power

Function	Provides DC power connection from NWEI Device to T-Pod
Conductor Size	3 x 6 AWG (Connect to subsea conductors 16mm^2 each)
Max voltage	420 V above seawater ground
Nominal current	20 A
Max current	50 A
Device Connection	Bare wires; connect to terminal blocks or equivalent
T-Pod Connection	Bare wires; connect to terminal blocks or equivalent

3.2. AWAC

Function	Provide power and data interconnection from NWEI Device to AWAC via the T-Pod
Data Conductor Size	4 x 30 AWG (0.05 mm^2 each); 3 primary/1 spare. Two twisted pairs with overall shield preferred but not required. Larger wire sizes OK.
Power Conductor Size	2 x 22 AWG (0.33 mm^2 each)
Device Connection	Bare wires; either connect to terminal blocks or NREL/NWEI to provide/install connectors.
T-Pod Connection	Bare wires; either connect to terminal blocks or NREL/NWEI to provide/install connectors.

3.3. Device Data

Function	Provide data interconnection from NWEI Device to the T-Pod
Type	Single mode optical fibers
Number of Fibers	6 each (4 primary and 2 spares)
Size	10 microns each
Device Connection	ST connectors to couplers inside dry box
T-Pod Connection	ST connectors to couplers inside T-Pod

3.4. Penetrator for entry into T-Pod

All umbilical cable conductors will enter the T-Pod through a single penetrator that will be supplied and installed by the umbilical supplier.

A protective housing will be supplied with the umbilical to protect umbilical cable conductors on the T-Pod side of the terminator during deployment of the WET-NZ. Prior to deployment, the umbilical will be terminated at the WET-NZ end, but T-Pod end will not be terminated until after deployment.

Brock – we are still working on drawing/dimensions of bolt circle & flange on T-Pod that is interface for penetrator.

3.5. Gland for entry of umbilical into WET-NZ dry box

All umbilical conductors will enter the WET-NZ dry box through a single gland to be provided by the umbilical supplier. Umbilical supplier will propose the specific gland. The dry box is above waterline during normal operation but is always subject to splash and is sometimes subjected to submersion (during severe seas).

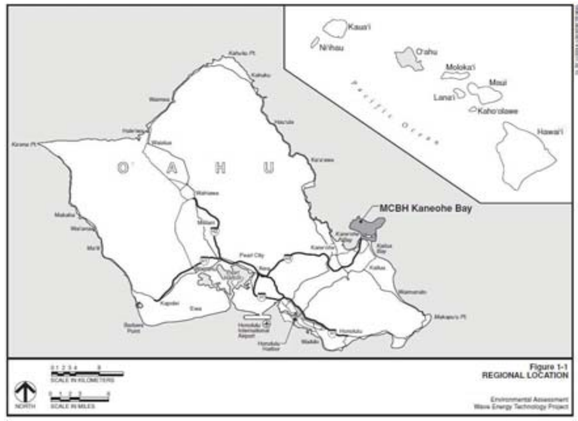
3.6. Flotation

Type	6.5-inch diameter
Spacing	TBD
Location	See table in Section 2

Appendix C – Mooring Drawings

WET-NZ Multi-Mode Wave Energy Converter
Hawaii Shallow Range (30m) Mooring Assessment

Prepared for:
Northwest Energy Innovations, LLC



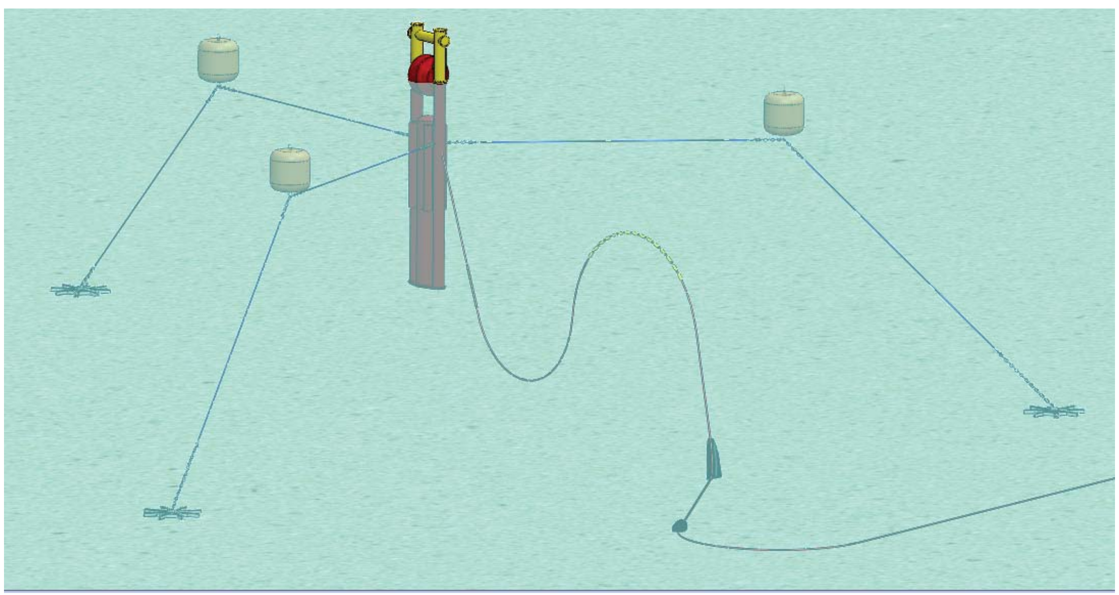
PROJECT LOCATION

NOTES:

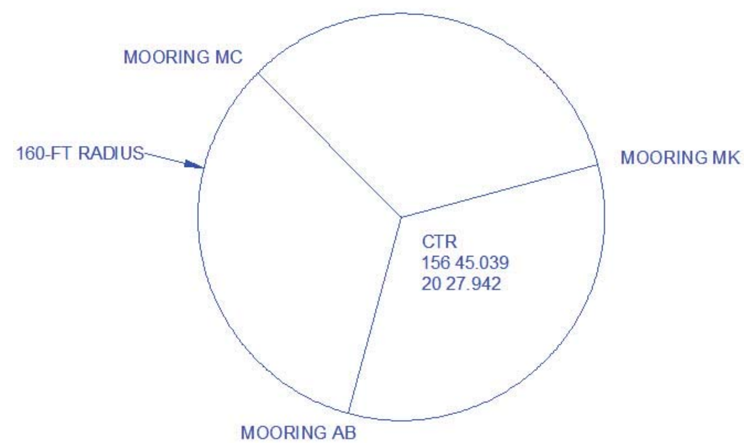
1. PROVIDED ARE DESIGN DRAWINGS FOR HALF SCALE WET-NZ DEVICE AT KAEHOHE, HI IN A WATER DEPTH OF ~30 M (100 FT).
2. DETAILED DESIGN ANALYSES ARE PROVIDED IN SST REPORT 2013-008 V1.0.
3. DESIGN ENVIRONMENT FOR THE SITE INCLUDES:

   SIGNIFICANT WAVE HEIGHT = 5.30 M TO 5.53 M
   WIND SPEED = 26.1 M/S (51 KNOTS)
   CURRENT SPEED = 1.044 M/S (2 KNOTS)
4. PEAK LOADING WITH 2.50" NYLON AND A F.S. OF 3.29:

   HORIZONTAL LOAD (ANCHOR MK) = 55.7 KIPS
   VERTICAL LOAD (ANCHOR MK) = 28.5 KIPS
5. PRETENSION HAWSER ON ANCHOR MC AND MK TO 13 KN.
6. PROOF LOAD MOORING LEGS AFTER INSTALLATION.
7. PROVIDE AS-BUILT DRAWING AND PROOF LOAD RECORDS.



GENERAL MOORING DESIGN
BUOYS 3M - 4M BELOW SURFACE



MOORING PLAN VIEW

	NAME	
DRAWN	J. BELL	COVER SHEET
CHECKED	R. TAYLOR	TITLE:
ENG APPR.	B. CABLE	WETS MOORING DESIGN
MFG APPR.		
Q.A.		
COMMENTS:		SIZE D · DWG. NO. 1180-10-100 · REV 6
		SCALE: 1:1 · WEIGHT: · SHEET 1 OF 6

PROPRIETARY AND CONFIDENTIAL

OCEAN GUARD SUPPORT BUOYS

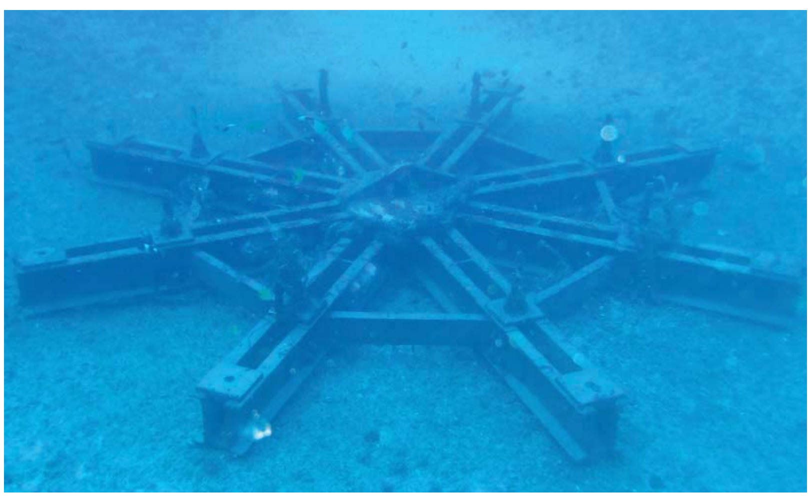
BUOY MODEL	BUOYANCY NET		BUOY WEIGHT		DIAMETER OVERALL		HEIGHT OVERALL		WORKING LOAD	
	LBS	KG	LBS	KG	FT	M	FT	M	LBS	TONS
SB-25	551	250	158	72	2.6	0.8	2.6	0.8	22,000	10
SB-50	1,102	500	285	129	3.2	1.0	3.2	1.0	22,000	10
SB-75	1,653	750	390	177	3.5	1.1	3.5	1.1	22,000	10
SB-100	2,205	1,000	475	215	3.8	1.2	3.8	1.2	40,000	18
SB-125	2,756	1,250	537	244	4.1	1.2	4.1	1.2	40,000	18
SB-150	3,307	1,500	584	265	4.3	1.3	4.3	1.3	40,000	18
SB-175	3,858	1,750	687	312	4.6	1.4	4.6	1.4	40,000	18
SB-200	4,409	2,000	819	371	4.8	1.5	4.8	1.5	40,000	18
SB-250	5,511	2,500	931	422	5.2	1.6	5.2	1.6	40,000	18
SB-300	6,614	3,000	1,200	544	5.5	1.7	5.5	1.7	45,000	20
SB-350	7,716	3,500	1,300	590	5.8	1.8	5.8	1.8	45,000	20
SB-400	8,818	4,000	1,612	731	6.0	1.8	6.0	1.8	45,000	20
SB-450	9,921	4,500	1,712	777	6.2	1.9	6.2	1.9	45,000	20
SB-500	11,023	5,000	1,945	882	6.4	2.0	6.4	2.0	45,000	20
SB-600	13,228	6,000	2,302	1,044	6.8	2.1	6.8	2.1	45,000	20
SB-700	15,432	7,000	2,500	1,134	7.2	2.2	7.2	2.2	45,000	20

* ACTUAL VALUES FOR ABOVE SIZES MAY VARY +/- 15% DUE TO VARIATIONS IN MATERIALS, AND TOLERANCES.

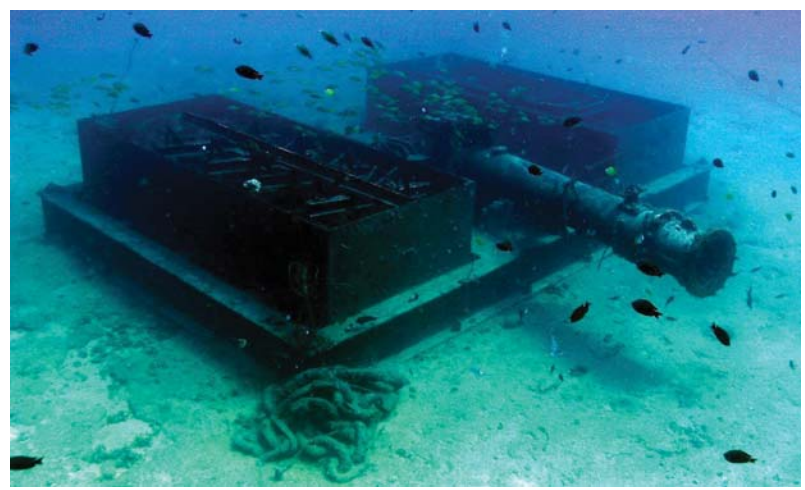
SB-300 MOORING BUOY

NOTES:

1. USE SB-300 MOORING BUOY FOR EACH MOORING LEG.
2. MC & MK ANCHORS ARE TESTED TO 50 KIPS.
3. ANCHOR AB HAS DESIGN CAPACITY OF 200 KIPS.



ANCHOR MC & MK

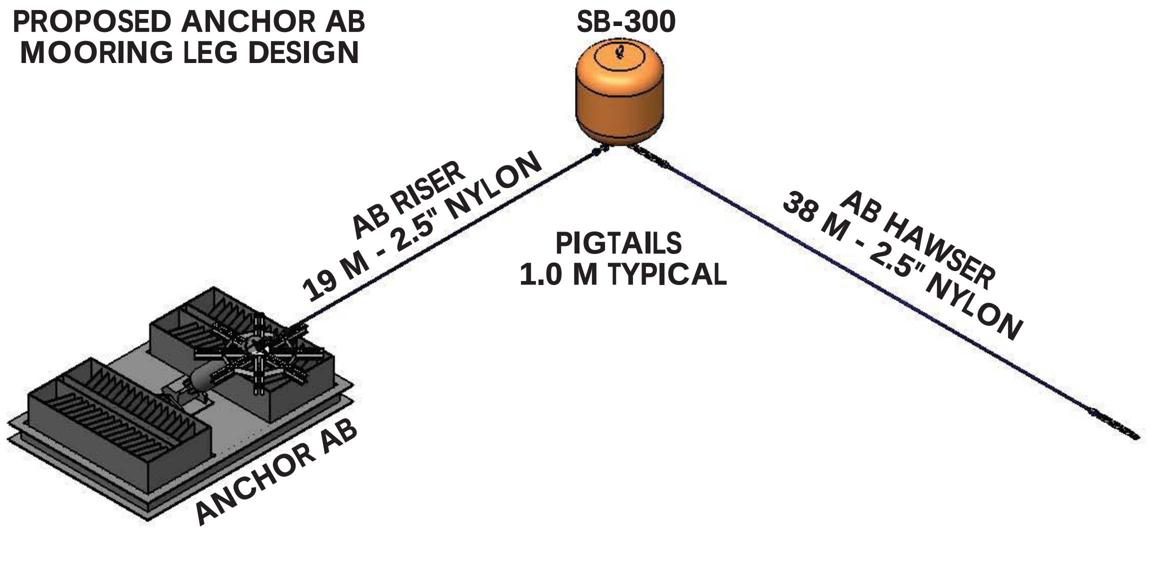


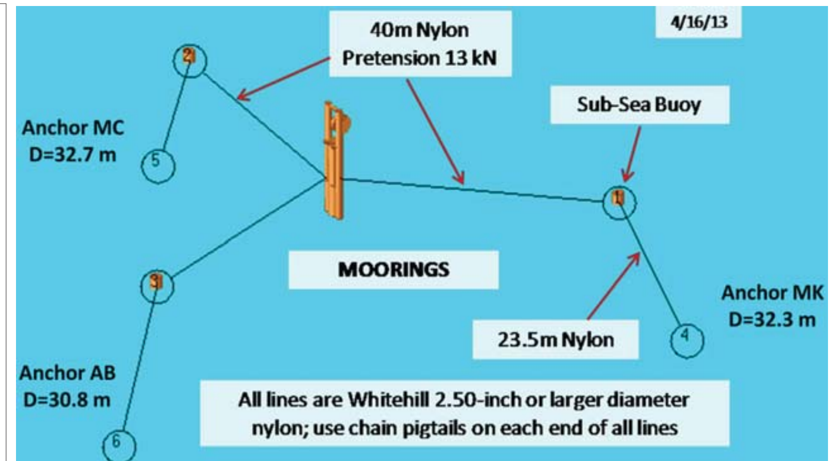
ANCHOR AB

	NAME	ANCHORS & BUOY
DRAWN	J. BELL	TITLE: WETS MOORING DESIGN
CHECKED	R. TAYLOR	
ENG APPR.	B. CABLE	
MFG APPR.		
Q.A.		
COMMENTS:		SIZE D — DWG. NO. 1180-10-200 — REV 6
		SCALE: 1:1 — WEIGHT: — SHEET 2 OF 6

NWEI northwest energy innovations

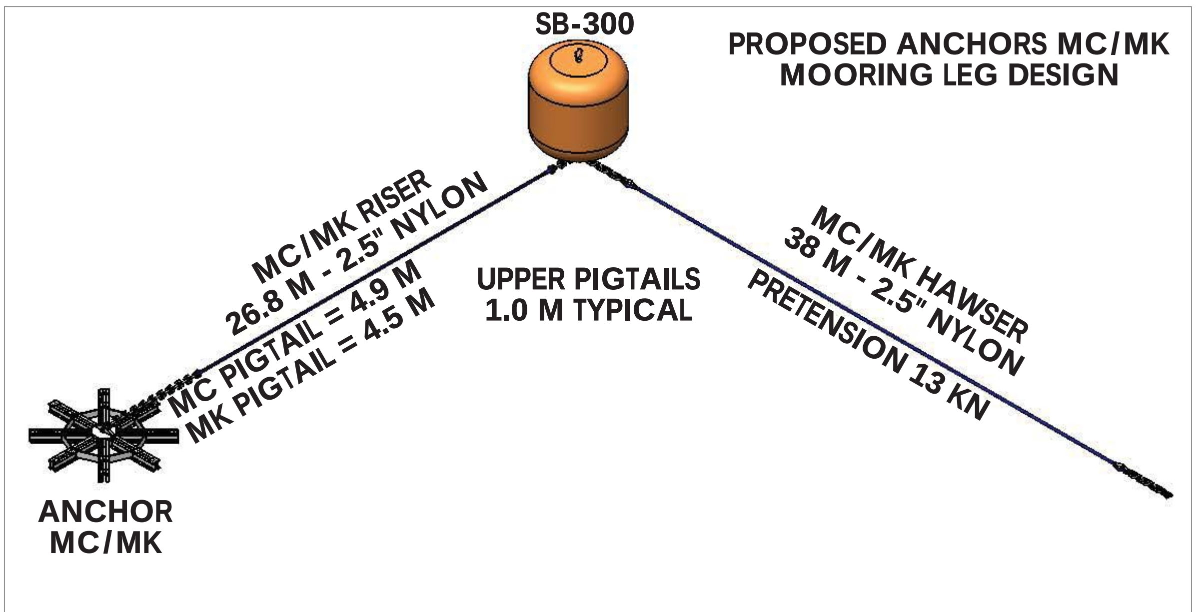
PROPOSED ANCHOR AB MOORING LEG DESIGN

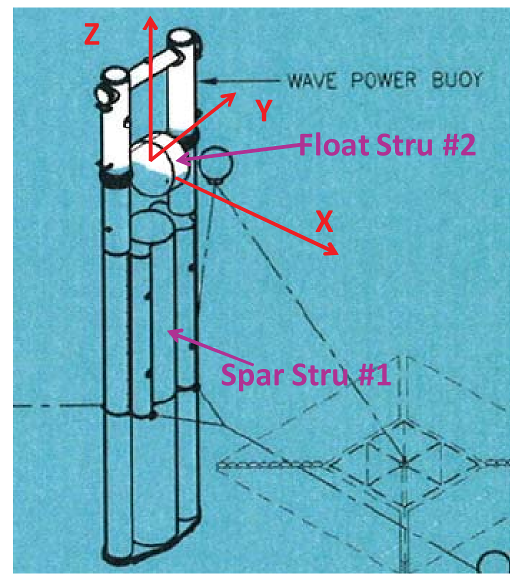




PROPOSED MOORING DESIGN

PROPOSED ANCHORS MC/MK MOORING LEG DESIGN



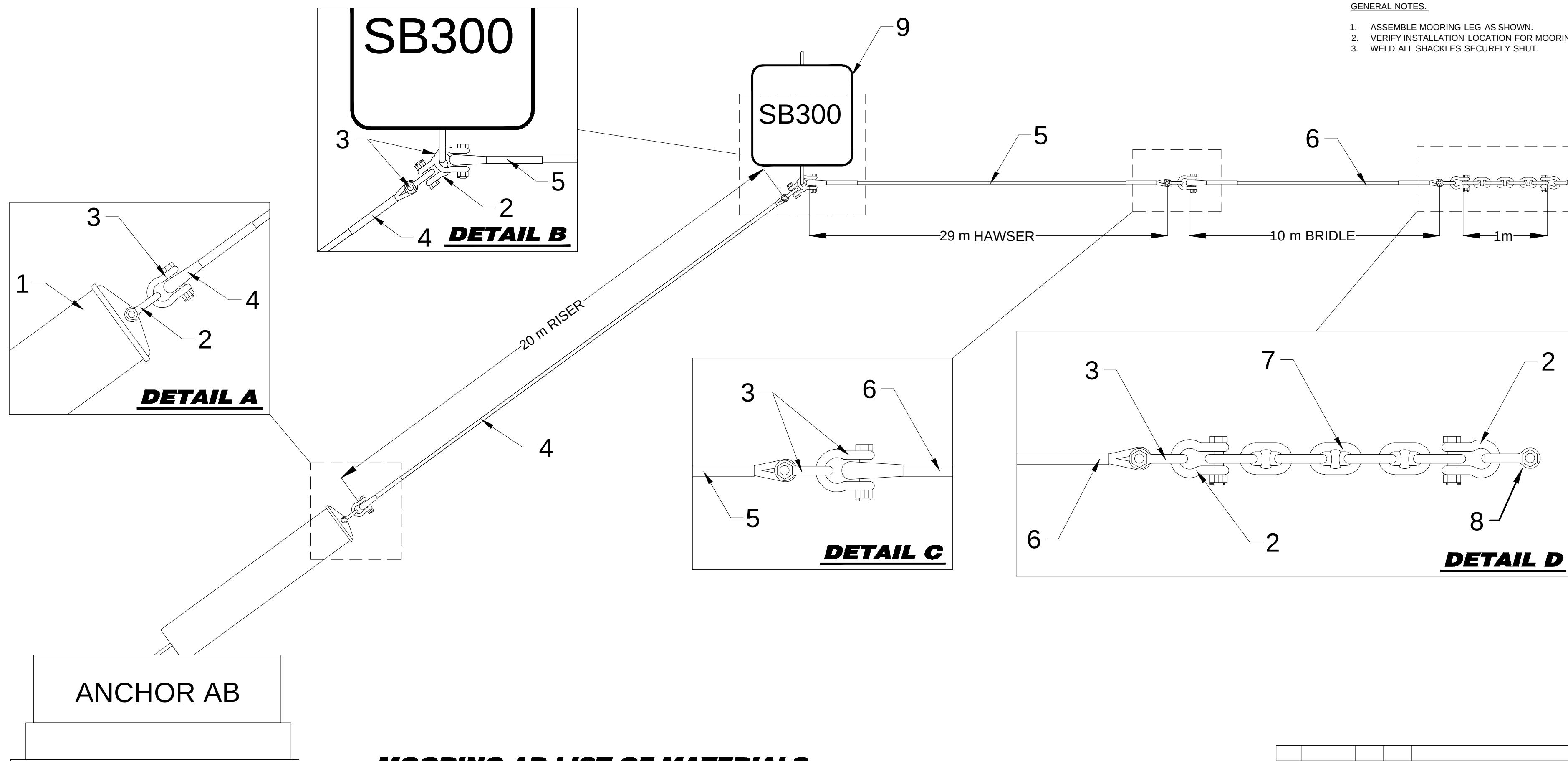


NWEI
northwest energy innovations

DRAWN	J. BELL	MOORING LEG DETAILS
CHECKED	R. TAYLOR	TITLE: WETS MOORING DESIGN
ENG APPR.	B. CABLE	SIZE D
MFG APPR.		DWG. NO. 1180-10-300
Q.A.		REV 6
COMMENTS:		SCALE: NTS WEIGHT: SHEET 3 OF 6

GENERAL NOTES:

1. ASSEMBLE MOORING LEG AS SHOWN.
2. VERIFY INSTALLATION LOCATION FOR MOORING.
3. WELD ALL SHACKLES SECURELY SHUT.



MOORING AB LIST OF MATERIALS

ITEM NO.	PART	PART	QTY/LENGTH	WEIGHT	REMARKS
1	ANCHOR AB	ROCK BOLTED ANCHOR FRAME	1	-	EXISTING ANCHOR
2	SHACKLE	1-3/4" SAFETY SHACKLE, 25 TON	6	33.91 LBS	USE AT MOORING AB & SB300 BUOY
3	TOW SHACKLE	22 TON WIDE JAW	8	53 LBS	BACK TO BACK SHACKLES AT NYLON LINES
4	NYLON LINE	SAMPSON HTP-12 W/THIMBLES EACH END	1@20m x 63.5mm	1.48 LBS/FT	RISER LINES FROM ANCHOR AB TO SB300 BUOY
5	NYLON LINE	WHITEHILL VETS 333-6 W/THIMBLES EACH END	1@29m x 63.5mm	1.48 LBS/FT	USE FROM SB300 BUOY TO BRIDLE
6	NYLON LINE	WHITEHILL VETS 333-6 W/THIMBLES EACH END	2@10m x 63.5mm	1.48 LBS/FT	USE AS BRIDLE FROM HAWSER TO WEC
7	CHAIN	2 INCH ABS GRADE 3 CHAIN	2 @ 1.0 m	37.33 LBS/FT	USE FROM BRIDLE TO WEC
8	LOAD CELL	25 TONNE	2		USE FROM BRIDLE TO WEC
9	BUOY	MARINE FENDERS SB 300 SUBSURFACE BUOY	1 @ 6FT X 6FT	1,200 LBS	

REV	DATE	DESIGN	DRAWN	REMARKS
	07/23/14	W.S.	B.C.	ADDED NYLON LINE PART NUMBERS
	07/22/14	W.S.	B.C.	UPDATED MATERIAL LIST
	07/03/14	W.S.	B.C.	LOAD CELLS ADDED
B	12/13/13	W.S.	J.B.	REVISED MOORING DESIGN
A	08/19/13	W.S.	J.B.	PRELIMINARY MOORING DESIGN

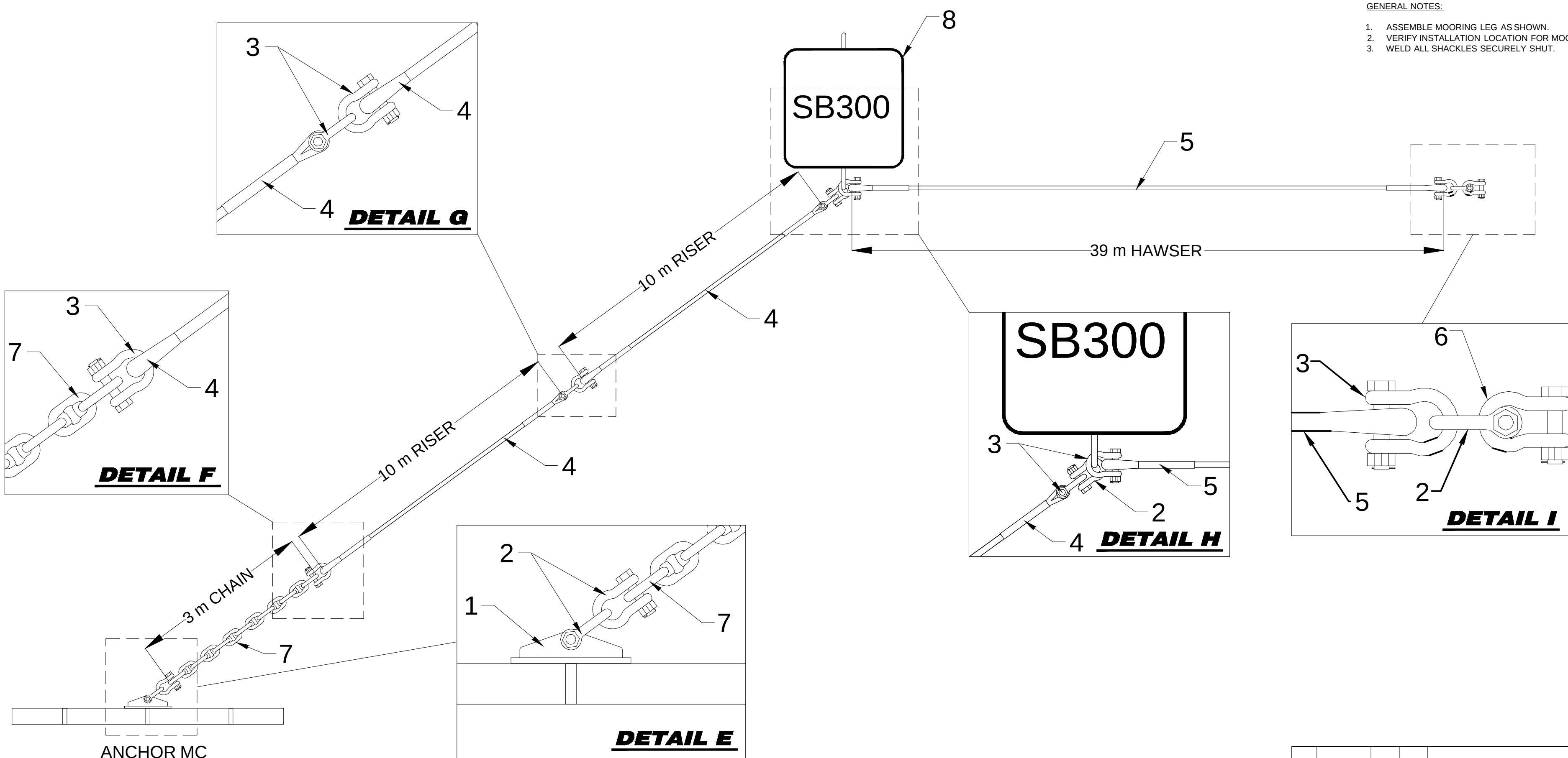
NAVFAC ENGINEERING & EXPEDITIONARY WARFARE CENTER
PORT HUENEME, CALIFORNIA 93043

NORTHWEST ENERGY INNOVATIONS
WETS MOORING DESIGN
MOORING LEG AB

SCALE	Drawing Number		Approved
AS NOTED		1180-10-400	

GENERAL NOTES:

1. ASSEMBLE MOORING LEG AS SHOWN.
2. VERIFY INSTALLATION LOCATION FOR MOORING.
3. WELD ALL SHACKLES SECURELY SHUT.



MOORING MC LIST OF MATERIALS

ITEM NO.	PART	PART	QTY/LENGTH	WEIGHT	REMARKS
1	ANCHOR MC	ROCK BOLTED ANCHOR FRAME	1	-	EXISTING ANCHOR
2	SHACKLE	1-3/4" SAFETY SHACKLE, 25 TON	4	33.91 LBS	USE AT MOORING MC & SB300 BUOY
3	TOW SHACKLE	22 TON WIDE JAW	6	53 LBS	BACK TO BACK SHACKLES AT NYLON LINE
4	NYLON LINE	WHITEHILL VETS 333-6 W/THIMBLES EACH END	2@10m X 63.5mm	1.48 LBS/FT	RISER LINES FROM ANCHOR MC TO SB300 BUOY
5	NYLON LINE	WHITEHILL VETS 333-6 W/THIMBLES EACH END	1@39m X 63.5mm	1.48 LBS/FT	USE FROM SB300 BUOY TO WEC LOAD CELL
6	LOAD CELL	25 TONNE	1		USE AT MOORING HAWSER WEC CONNECTION
7	CHAIN	2 INCH ABS GRADE 3	1 @ 3M	37.33 LBS/FT	USE AT MOORING CONNECTION
8	BUOY	MARINE FENDERS SB 300 SUBSURFACE BUOY	1 @ 6FT X 6FT	1,200 LBS	

REV	DATE	DESIGN	DRAWN	REMARKS
	07/23/14	W.S.	BC	ADDED NYLON LINE PART NUMBERS
	07/22/14	W.S.	BC	UPDATED MATERIALS LIST
	07/03/14	W.S.	BC	UPDATED MATERIALS LIST
	07/02/14	W.S.	BC	CHANGED LOAD CELL
B	12/13/13	W.S.	J.B.	REVISED MOORING DESIGN
A	08/19/13	W.S.	J.B.	PRELIMINARY MOORING DESIGN

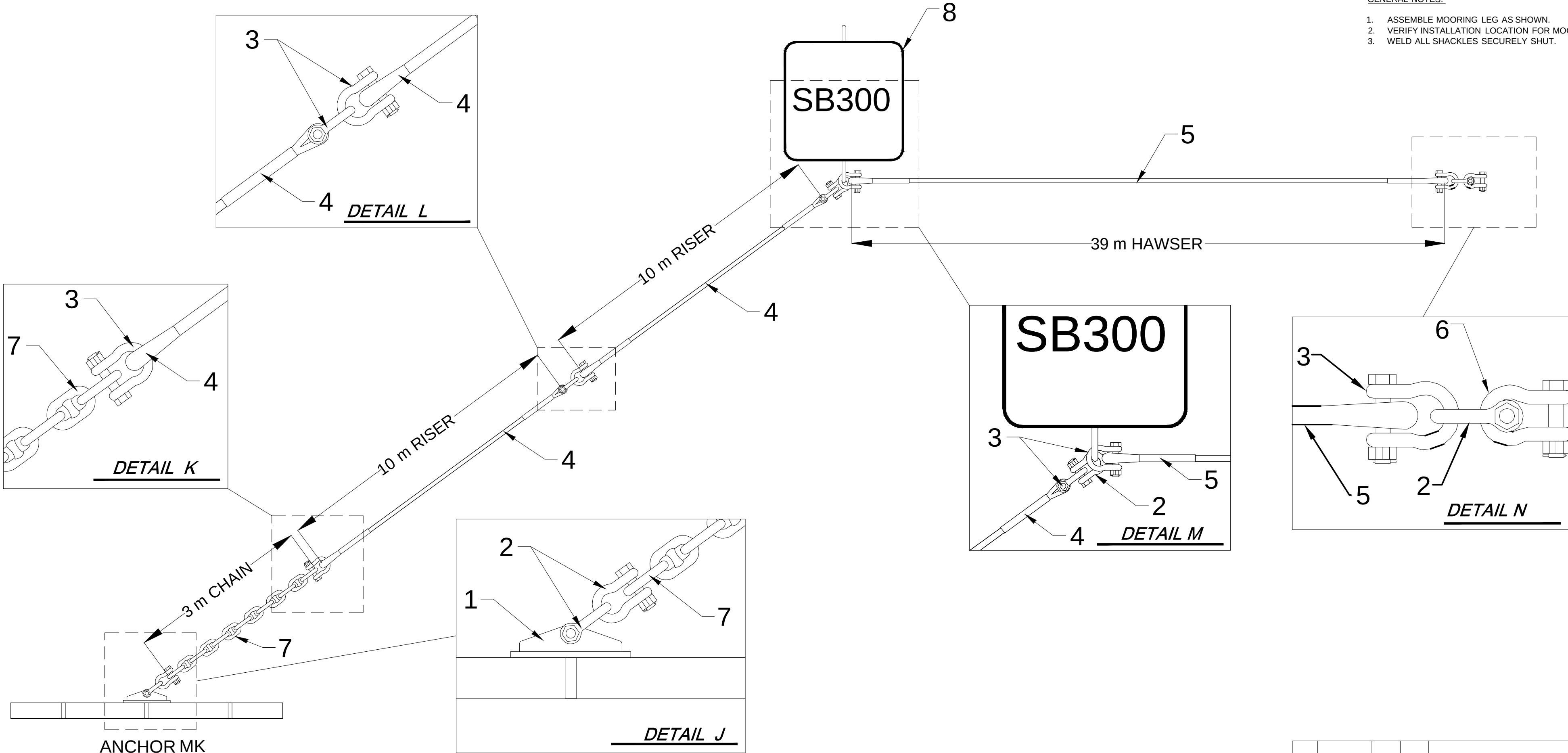
NAVFAC ENGINEERING & EXPEDITIONARY WARFARE CENTER
PORT HUENEME, CALIFORNIA 93043

NORTHWEST ENERGY INNOVATIONS
WETS MOORING DESIGN
MOORING LEG MC

SCALE	Drawing Number		Approved
AS NOTED		1180-10-400	

GENERAL NOTES:

1. ASSEMBLE MOORING LEG AS SHOWN.
2. VERIFY INSTALLATION LOCATION FOR MOORING.
3. WELD ALL SHACKLES SECURELY SHUT.



MOORING MK LIST OF MATERIALS

ITEM NO.	PART	PART	QTY/LENGTH	WEIGHT	REMARKS
1	ANCHOR MK	ROCK BOLTED ANCHOR FRAME	1	-	EXISTING ANCHOR
2	SHACKLE	1-3/4" SAFETY SHACKLE, 25 TON	4	33.91 LBS	USE AT MOORING MK & SB300 BUOY
3	TOW SHACKLE	22 TON WIDE JAW	6	53 LBS	BACK TO BACK SHACKLES AT NYLON LINES
4	NYLON LINE	WHITEHILL VETS 333-6 W/ THIMBLES EACH END	2@10m x 63.5mm	1.48 LBS/FT	RISER LINES FROM ANCHOR MK TO SB300 BUOY
5	NYLON LINE	WHITEHILL VETS 333-6 W/ THIMBLES EACH END	1@39m x 63.5mm	1.48 LBS/FT	USE FROM SB300 BUOY TO WEC LOAD CELL
6	LOAD CELL	25 TONNE	1		USE AT MOORING HAWSER WEC CONNECTION
7	CHAIN	2 INCH ABS GRADE 3	1 @ 3M	37.33 LBS/FT	USE AT MOORING CONNECTION
8	BUOY	MARINE FENDERS SB 300 SUBSURFACE BUOY	1 @ 6FT X 6FT	1,200 LBS	

REV	DATE	DESIGN	DRAWN	REMARKS
	07/23/14	W.S.	BC	ADDED NYLON LINE PART NUMBERS
	07/22/14	W.S.	BC	UPDATED MATERIALS LIST
	07/03/14	W.S.	BC	UPDATED MATERIALS LIST
	07/02/14	W.S.	BC	CHANGED LOAD CELL
B	12/13/13	W.S.	J.B.	REVISED MOORING DESIGN
A	08/19/13	W.S.	J.B.	PRELIMINARY MOORING DESIGN

NAVFAC ENGINEERING & EXPEDITIONARY WARFARE CENTER
PORT HUENEME, CALIFORNIA 93043

NORTHWEST ENERGY INNOVATIONS
WETS MOORING DESIGN
MOORING LEG MK

SCALE	Drawing Number		Approved
AS NOTED		1180-10-400	

Appendix D – Mooring Analysis

NWEI Wave Energy Demonstration at the Navy's Wave Energy Technology Test Site

Mooring Assessment for WETS Shallow (30m) Test Berth

Prepared for:
Northwest Energy Innovations, LLC

15 May 2013

Report 2013-008 V4.0

Prepared by:
Sound & Sea Technology, Inc.
3507 Shelby Road
Lynnwood, WA 98087

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Mooring Assessment

EXECUTIVE SUMMARY

Northwest Energy Innovations (NWEI) has been selected by the U.S. Department of Energy and the U.S. Navy to deploy a half-scale wave energy conversion (WEC) device (NWEI Device) at the Navy's Wave Energy Test Site (WETS) located at Marine Corp Base Hawaii, Kaneohe (MCBH-K). The NWEI Device is to be moored at the offshore shallow water (30-meter) test berth. An umbilical power cable from the NWEI Device will transmit electrical power to shore.

The NWEI Device was also tested for six weeks off the coast of Oregon in 2012.

This report documents the design of the NWEI Device mooring and provides a notional umbilical power cable configuration for the Hawaii site using the three existing anchors at the shallow water test berth.

The WETS 30-meter site is shallower and the anchors are closer together as compared to the Oregon test site. As a result, the selected design for the WETS project site is an "All Nylon" approach consisting of nylon risers and nylon hawsers. A small amount of chain will be used at the mooring line attachment points.

This report includes a Lazy-S umbilical configuration for the umbilical power cable that accommodates the winds, waves and currents at the WETS project site.

1.0 PURPOSE

The NWEI Device is an innovative WEC device that extracts wave energy and converts it to electrical power for transmission ashore. Deployment and test of a half-scale NWEI Device is being planned for the shallow water WETS test berth located at Marine Corp Base Hawaii, Kaneohe after a successful test in Oregon in 2012 (Figure 1).

The WETS 30 meter (m) test berth at MCBH-K is 1,220 m (4,000 feet) offshore at Mokapu Peninsula (Figures 2 and 3).

In preparation for this offshore test, NWEI tasked Sound & Sea Technology (SST) to conduct a mooring analysis and design for the NWEI Device half-scale device using the existing seafloor anchor infrastructure at the WETS shallow test berth. Analyses are to be conducted in a manner similar to those recently conducted for the Oregon deployment (1).

In this new study, the ANSYS AQWA numerical model developed in Reference 1 and design criteria from the original WETS 30m site anchor foundation design (2) is used to evaluate the NWEI Device with the existing 3-point anchor arrangement (Figures 4 and 5).

Figure 1. NWEI Device at the Oregon Test Site

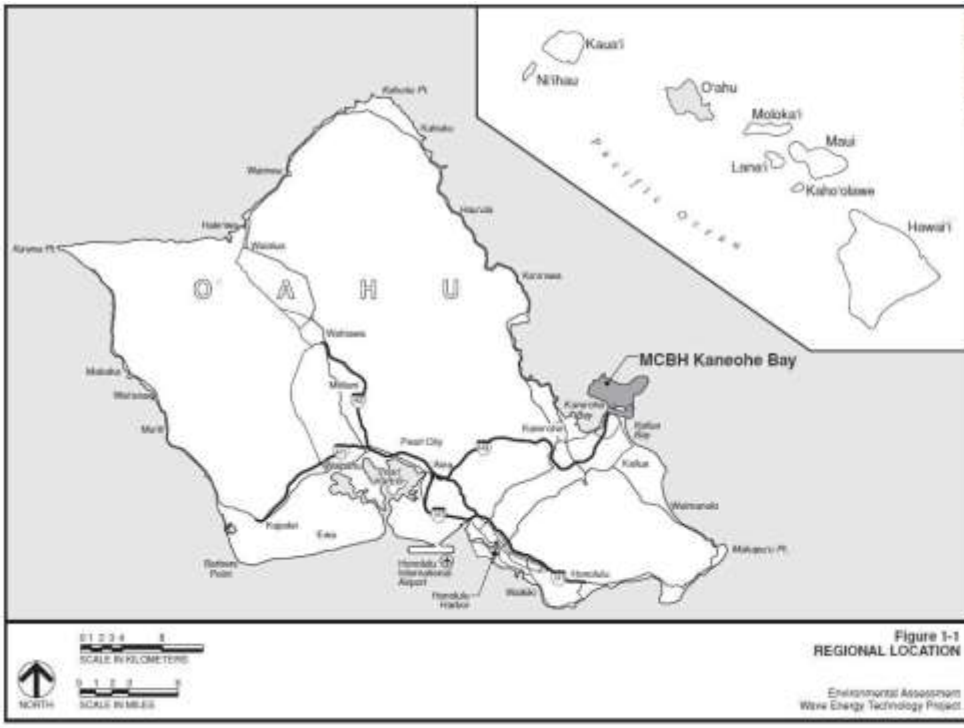


Figure 2. WETS Project Area

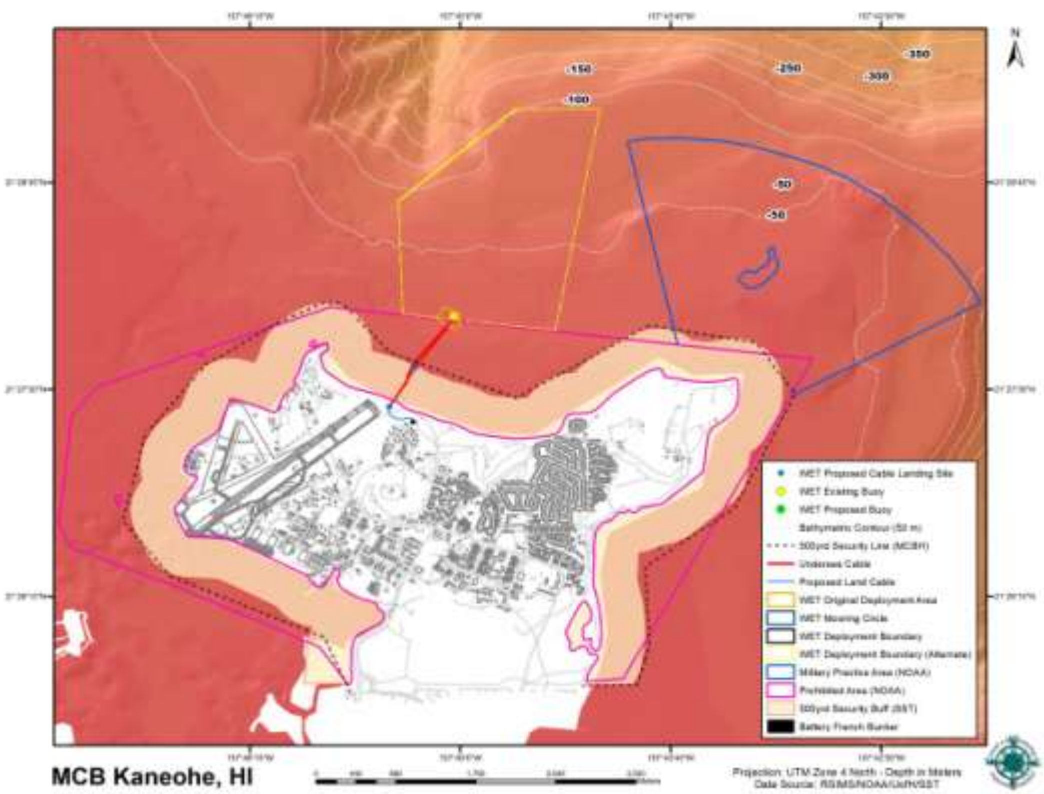


Figure 3. WETS Deployment Area

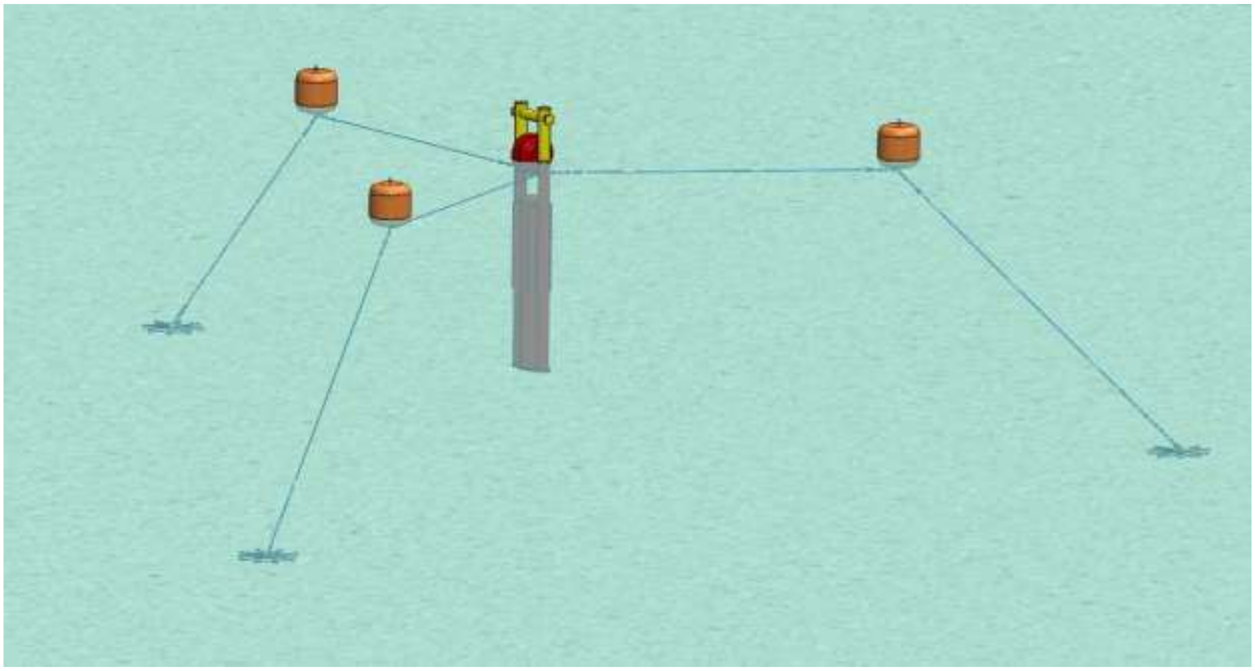


Figure 4. Example WEC Device at the WETS Shallow Water Test Berth

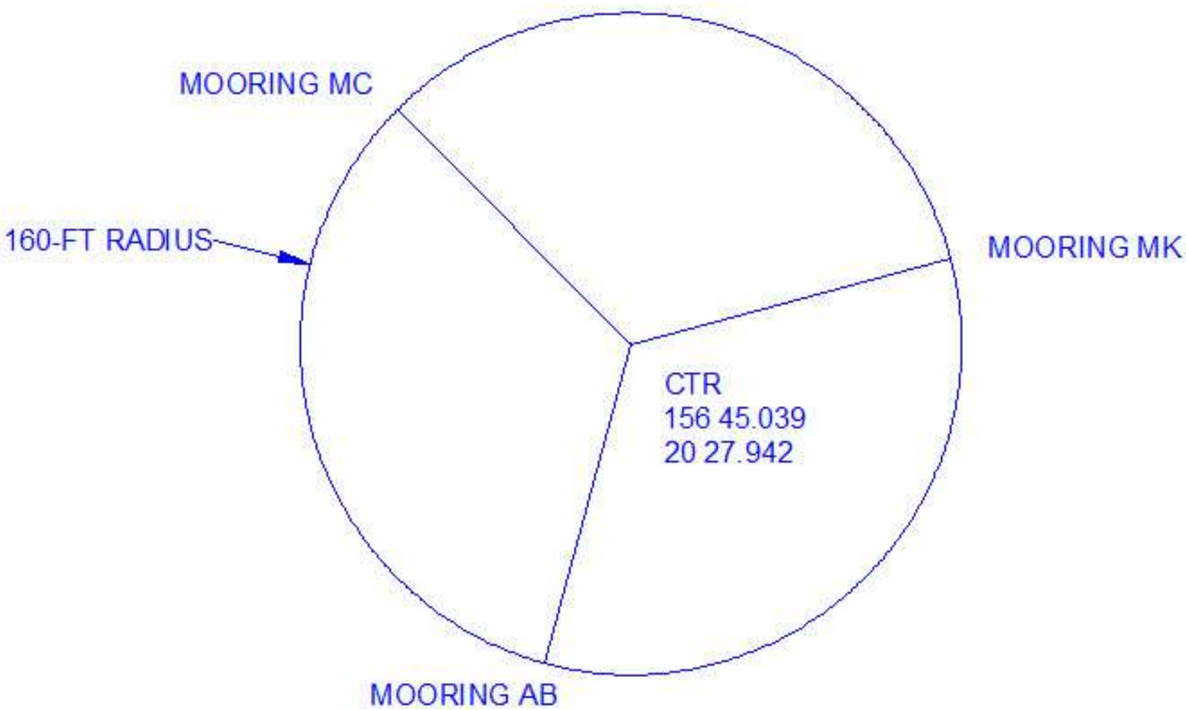


Figure 5. WETS Shallow Water (30m) Anchor Geometry

2.0 DESIGN CRITERIA

The existing shallow water test site has three main anchors: MC (rock bolted frame), MK (rock bolted frame, same as MC), and AB (gravity base with rock bolts) as shown in Figures 6 and 7. There are also several temporary vessel moorings in the area as shown in Figure 8 that can be used during installation. Anchors MK and MC were recently tested to 50 KIPS (25 tons) vertical load and anchor AB has a design capacity of 200 KIPS (100 tons).

Table 1 provides the basic design criteria for this project. Tables 2 through 6 and Figure 9 provide details of the NWEI Device half-scale engineering properties. The subsurface floats (Figure 10) with 6,614 pounds (lbf) net buoyancy and the 2.5-inch diameter nylon hawsers (Figure 11) from the Oregon test will be used for the Hawaii deployment.

Environmental design criteria for the site are given in Tables 7 through 9 and Figure 12. Note that there is considerable variability in the extreme design wave conditions for the Kaneohe site. Table 8, taken from Reference 3, reflects 10 years of wind data for the area with wave hindcast and 100 year significant wave heights in the range of 5.30m to 5.53m for the project site. The associated wave period (Tp) has a peak energy density at 15.79 seconds. For the larger waves, the deep water steepness would be $Hs/Lo = 5.53m / (1.56 * (15.79\ sec)^2) = 0.014$.

One approach to determining design wave conditions is to assume a "worst case" hurricane. However, storms with hurricane intensity rarely pass directly north of the Hawaiian Islands. The most recent historical hurricane passing north of the islands was Hurricane Hiki in 1950. In order to demonstrate a direct hurricane wave attack in the project area, Sea Engineering Inc. (SEI) used a Hawaiian scenario hurricane model, which was defined in the report *Hurricane in Hawaii* (Haraguchi, 1984) prepared for the U.S. Army Corps of Engineers following Hurricane Iwa. The model hurricane is defined as the probable hurricane that will strike the islands, based on the characteristics of the hurricanes Dot and Iwa. SEI chose a hurricane that approaches from a directional sector between the east and the southeast. The results indicate that the largest deepwater significant wave height that moves toward the project area during the model hurricane is 8.4m with significant wave periods of 11.5 seconds. The resultant waves in 30m of water were calculated to be 7.7m during the model hurricane and the associated wave period is Tp = 11.5 seconds. For these waves, the deep water steepness would be $Hs/Lo = 7.7m / (1.56 * (11.5\ sec)^2) = 0.037$.

The hindcast hurricane waves are considerably larger and steeper than the hindcast waves based on 10 years of observed winds. The initial analysis will use the larger hindcast hurricane waves for analysis and then other design wave conditions will be considered.

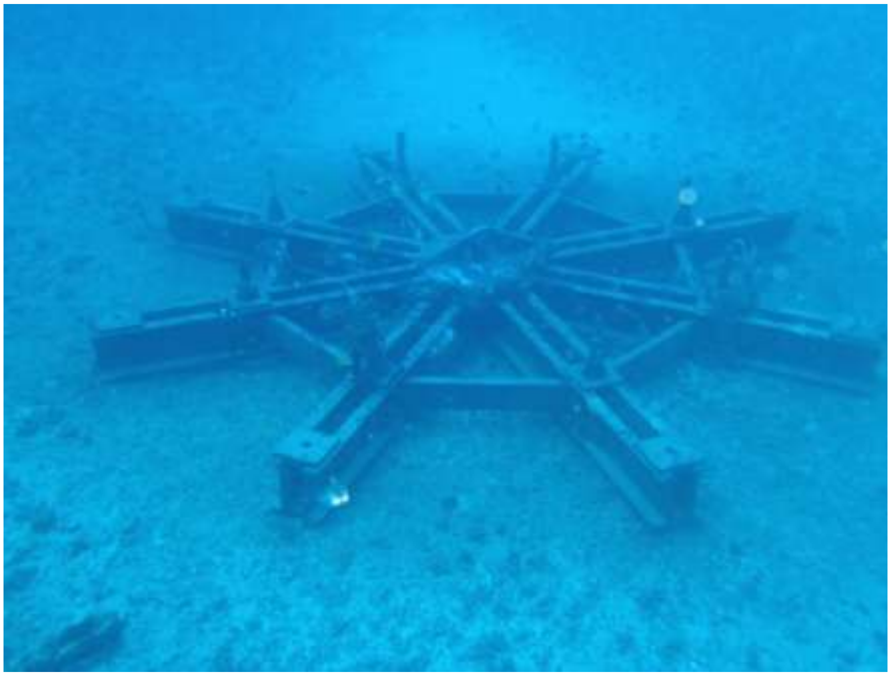


Figure 6. WETS Rock Bolted Anchor Frame MC

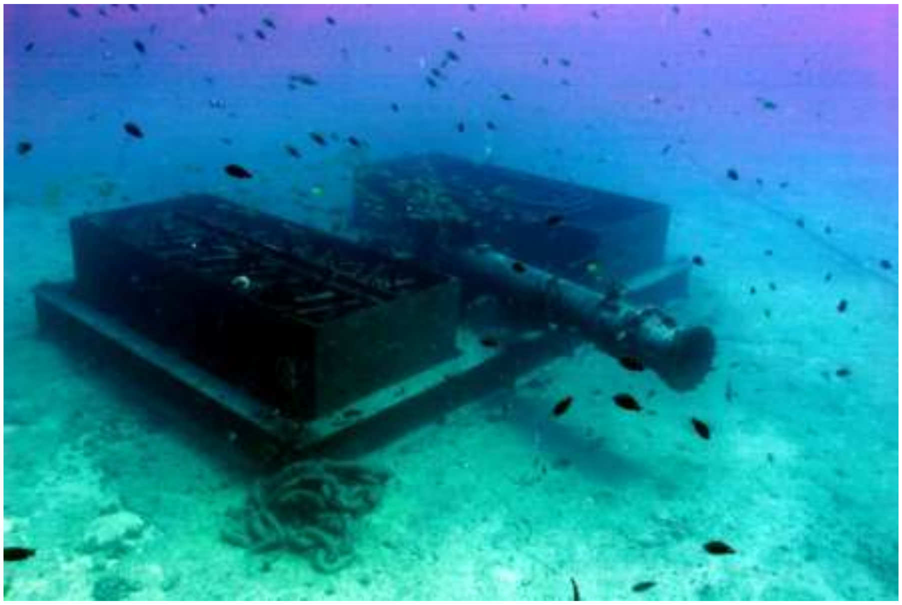


Figure 7. WETS Gravity Anchor Base AB

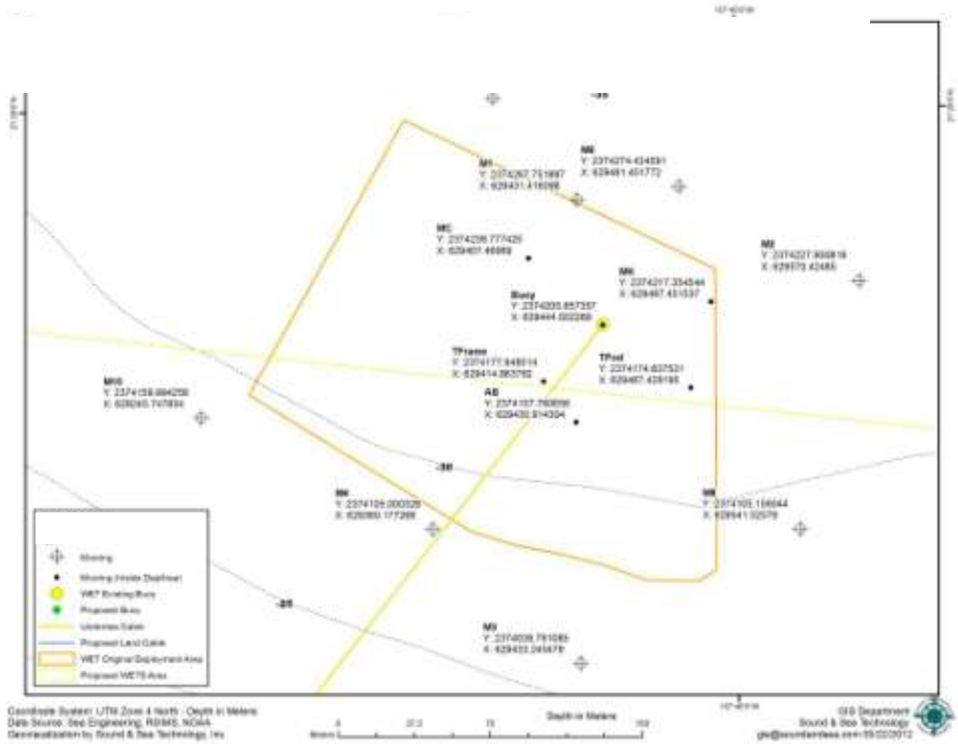


Figure 8. Shallow Water (30m) Site Showing Mooring Locations

Table 1. NWEI Device Design Criteria - General

Item	Value	Notes
Test period	TBD	Likely < 1 year
Scale	1 / 2	Test unit is a ½ Froude scale
Installation site	Kaneohe	~0.66 n.m. offshore
Orientation	Into waves	Angle not very critical
Water depth	~30 m	Anchors: AB = 30.8m MK = 32.3m MC = 32.7m
Mooring type	3-point	Use existing anchors
Net buoyancy of system	Very low	Mooring must not exert vertical forces on the NWEI Device
Wave tank test data	1/30th scale	Froude model
Factor of safety of nylon mooring lines	3.1	On peak load for breaking strength assuming the system is intact
Anchor factor of safety	1.5 or higher	Against drag, etc.

Table 2. Design Criteria - NWEI Device Half-Scale Active Float (AQWA #2)

Item	Value	Notes
Type	Cylinder type	See sketch below
Width	1.730 m	
Diameter	2.750 m	
Pivot point	1.028 m	Off center
Center of gravity	1.36 m	Distance from shaft center
Mass	4,025 kg	Based on the AQWA Model Rev0 to get the correct waterline
Rxx	0.923m	
Ryy	0.771m	
Rzz	0.771m	
Drag coefficient	Cd = 1.0	Ref 4
Added mass coefficient	Cm = 1.58	Ref 4

Local x-axis for this structure is taken as in the direction of the cylinder

Table 3. Design Criteria - NWEI Device Half-Scale Spar (AQWA #1)

Item	Value	Notes
Type	Cylinders	See sketch below
Thickness of main body	1.500 m	
Beam of main body	3.500 m	Width
Draft	-15.000 m	Bottom distance below water level
Center of buoyancy	-5.970 m	Based on the AQWA Model Rev0
Center of gravity	-7.970 m	-2.0 Below center of buoyancy
Mass	50,400 kg to get correct waterline	Based on the AQWA Model Rev0
Waterplane area	0.5 m^2	
Rxx		To be determined
Ryy	4.9m	
Rzz		To be determined
Drag coefficient	Cd = 1.0	Ref 4 surge & sway
Added mass coefficient	Transverse Cm = 5.0	Ref 4; this value seems high because a cylinder typically has an added mass coefficient of ~2

Table 4. Center-of-Buoyancy Location

NET-NZ-Rev0.xls W. Seelig 2/24/2012

DETERMINE CENTER-OF-BUOYANCY LOCATION BASED ON AQWA MODEL Rev0

Item	Z start (m)	Z stop (m)	Zbar (m)	Dia (m)	Area (m^2)	Length (m)	Vol (m^3)	Zbar*Vol
Side tube	0	-14.44	-7.22	0.9	0.6362	14.44	9.1863	-66.3253
Side tube	0	-14.44	-7.22	0.9	0.6362	14.44	9.1863	-66.3253
Center tube	-2.848	-14.55	-5.851	1.6	2.0106	11.702	23.5282	-137.6638
HDPE tube	-3.095	-9.182	-3.0435	0.6	0.2827	6.087	1.7211	-5.2380
HDPE tube	-3.095	-9.182	-3.0435	0.6	0.2827	6.087	1.7211	-5.2380
HDPE tube	-3.095	-9.182	-3.0435	0.6	0.2827	6.087	1.7211	-5.2380
HDPE tube	-3.095	-9.182	-3.0435	0.6	0.2827	6.087	1.7211	-5.2380
						Total =	48.7851	-291.2664
							COB (m) =	-5.970
							COG diff (m) =	-2.000
							COG (m) =	-7.970

Table 5. Design Criteria - Nylon Mooring Lines

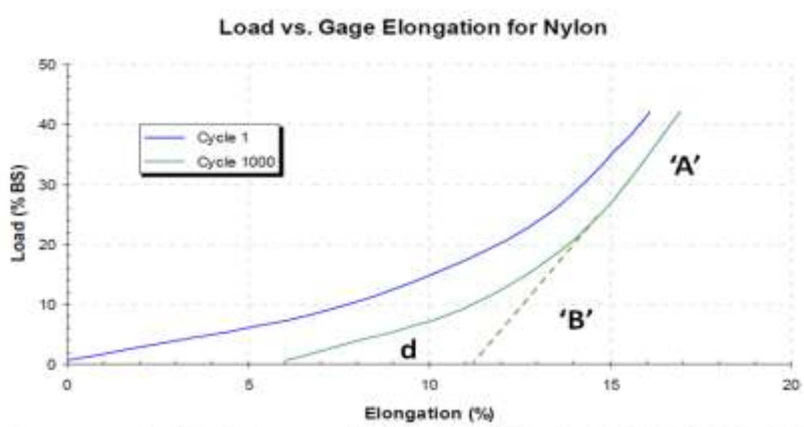
Item	Value	Notes
Nylon Mooring Lines	Fb=200,000 lbf Fb = 889.6 kN	Whitehill 2.5” 10m eye-to-eye 4-strand; 7 units

Table 6. Umbilical Cable

Item	Value	Notes
Power Cable	59.8 mm dia with a mass of 7.8 kg/m	Assumed representative power cable based on cable at the site

Figure 9. Local X-Axis

Figure 10. SB-300 Subsurface Float



Assume a nylon line has been cycled (curve to right; after Whitehill 10 Oct 2003):
For region 'A' EA~7.5*Fb, so asymptotic stiffness k=AE/L=7.5*Fb/L
where Fb=break strength, L=Length
For region 'B' at lower loads the asymptotic offset is d= 5% of L
This curve can be described by T=k(x-d(tanh(x/d))
where T=tension and x=extension of mooring line

Figure 11. Design Criteria - Load vs. Gage Elongation for Nylon

Swell and Sea Predominant Directions

Directional Rose: Mokapu Waverider **UH Model Hindcast**

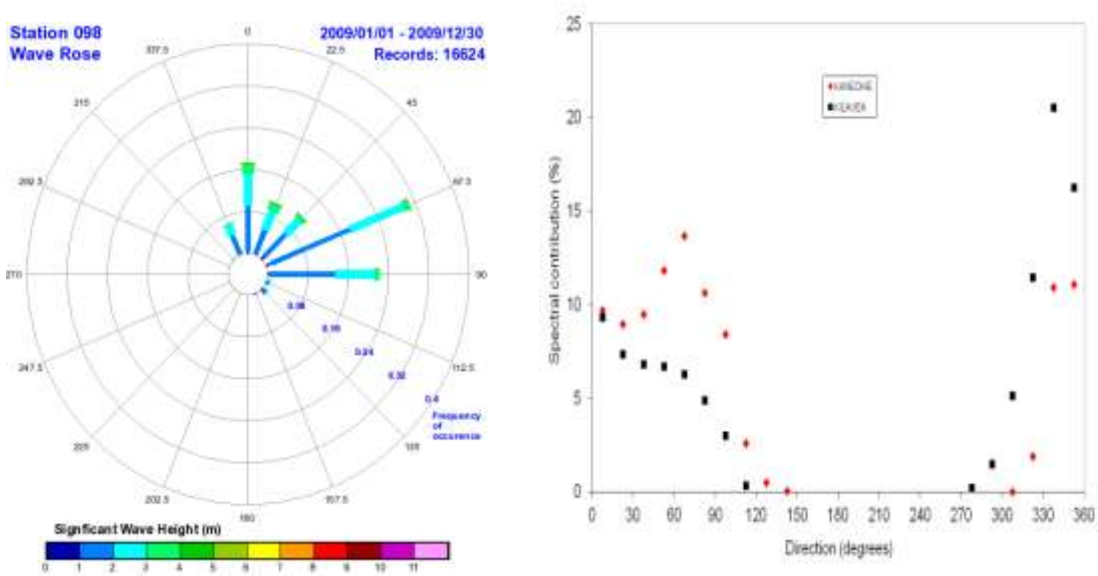


Figure 12. Kaneohe Wave Direction Data

A summary of “Worst” hindcast hurricane wave conditions from Reference (3) are provided in Table 7.

Table 7. Environmental Design Criteria for Kaneohe - Hurricane Wave Conditions

	Model Hurricane
Wave Period:	
Significant Wave Period (sec.)	11.5
Average Wave Period (sec.)	8.0
Deepwater Wave Height:	
Significant Wave (m)	8.4
Maximum Wave (m)	14.9
Wave Height at 30-Meter Water Depth:	
Significant Wave (m)	7.7
Significant Wave Crest Elevation (m)	4.5
Maximum Wave (m)	13.6
Maximum Wave Crest Elevation (m)	9.8

A summary of potential wave energy, significant wave heights and wave periods at selected locations in Hawaii is provided in Table 8.

Table 8. Wave Data

Site	Power Flux (kW/m)	Hs, 100yrs (m)	Tp, 100yrs (s)
Kaneohe	11.9	5.30	15.43
Kaneohe II	11.9	5.53	15.79
Pauwela	20.7	5.89	17.00
Upolu	11.4	5.11	14.76
South Point	14.2	2.70	12.68
Kilauea	19.0	6.16	17.96

A summary of MetOcean environmental data from Reference 3 is provided in Table 9.

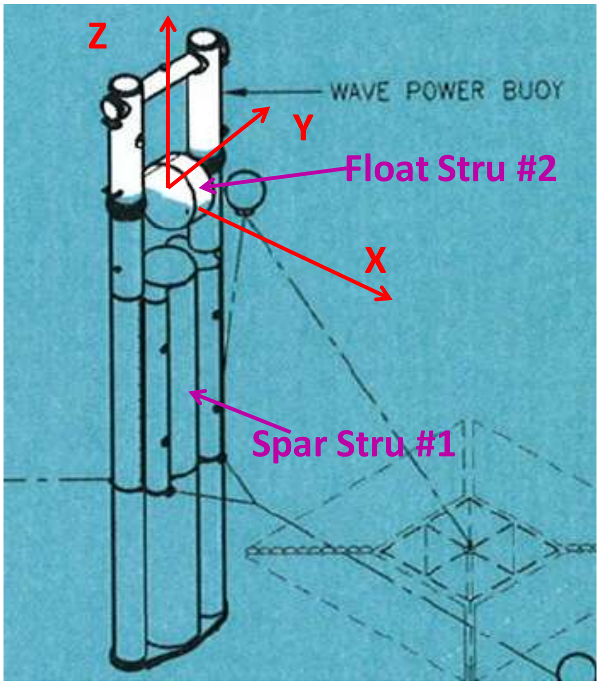
Table 9. Environmental Design Criteria for Kaneohe - Environmental Data

Design Parameter	Value
10-min wind speed	Vw = 26.1 m/s (51 knots)
Current speed	Vc = 1.044 m/s (2 knots)

3.0 MOORING CONCEPT

Several different alternatives were considered for mooring the NWEI half-scale device at the existing 30m Kaneohe offshore test site.

ANSYS AQWA software is used in these analyses and the units of kilogram, meters, seconds and degree are employed. Each structure is assigned its own local coordinate system. There is also a global right-handed coordinate assigned with X+ towards east, Y+ towards north and Z+ upward from the still water surface (Figure 13). The AQWA software uses a wave swell direction designation based on degrees where the direction in degrees is the direction the wave is traveling towards and not the direction the wave is generated from.



X=direction of waves, Y=parallel to wave crests, Z=positive upward from the still water level

Figure 13. Design Criteria - Spar (AQWA #1)

3.1 Plan 1 – Mooring Catenary Legs with Sinkers (Oregon Approach)

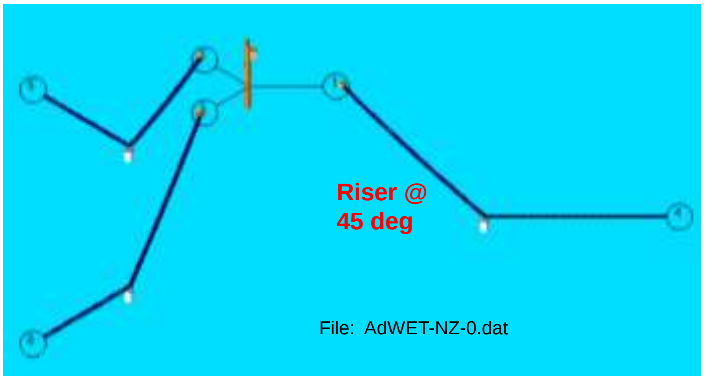
In this mooring design, we used an approach similar to that successfully used in the Oregon 2012 NWEI half-scale device test. There are two key differences at the Hawaii site:

a) In Hawaii the water depth is ~32m, while the Oregon water depth was ~45m. This means that the Hawaii design waves are shorter and steeper than they would be in deeper water.

b) The existing anchors at the WETS shallow site have a smaller spread than was used in the Oregon test. The smaller anchor spread and shallower water mean there is less compliance in the catenary portion of the mooring (i.e., Plan 1 at WETS has stiffer moorings than the Oregon test).

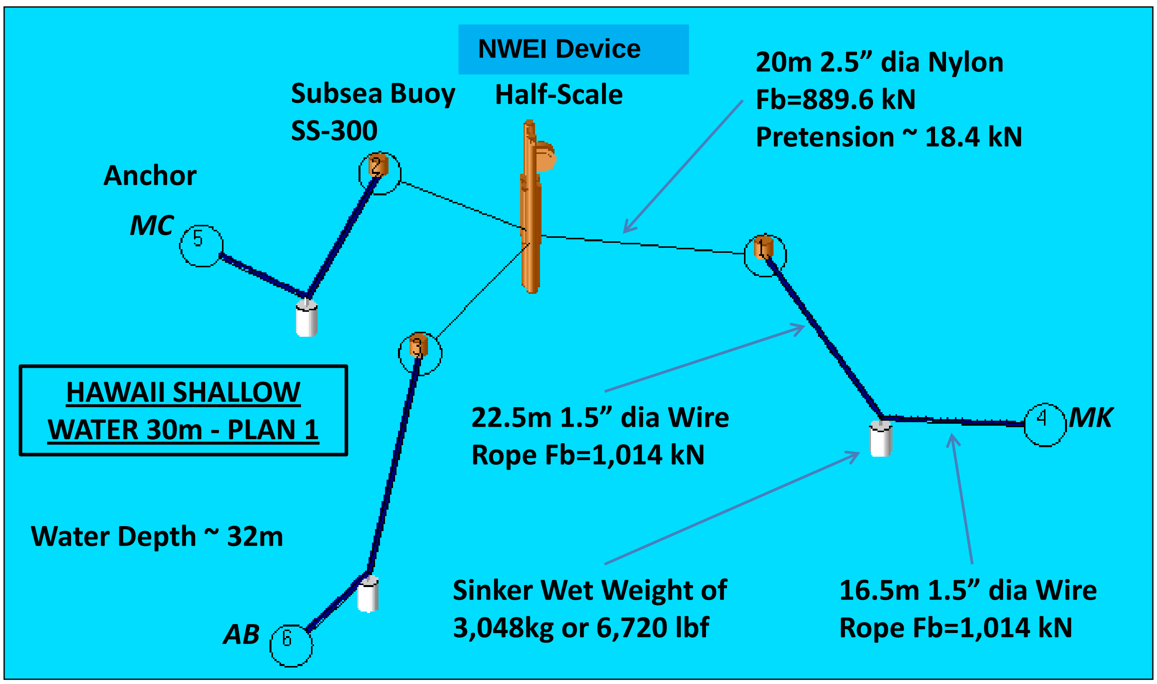
Therefore, in mooring Plan 1 the same hawsers, subsurface floats and sinkers as were used in Oregon are used. However, the riser and ground legs need to be shortened due to the shallower water and closer-in anchors.

Figure 14 shows Plan 1 and Figure 15 shows this mooring concept in plan view. Figure 16 shows results for the case of the survival wave environment from the NE (i.e. at an angle of 225 degrees). It turns out there can be high dynamic loads for Plan 1, which has the load/deflection curve illustrated in Figure 17.



(a) Oregon 2012 Test Mooring

(b) Hawaii 30m Range Plan 1



(c) Hawaii 30m Range Plan 1 (Perspective View)

Figure 14. Comparison of Oregon Mooring and Hawaii Mooring Plan 1

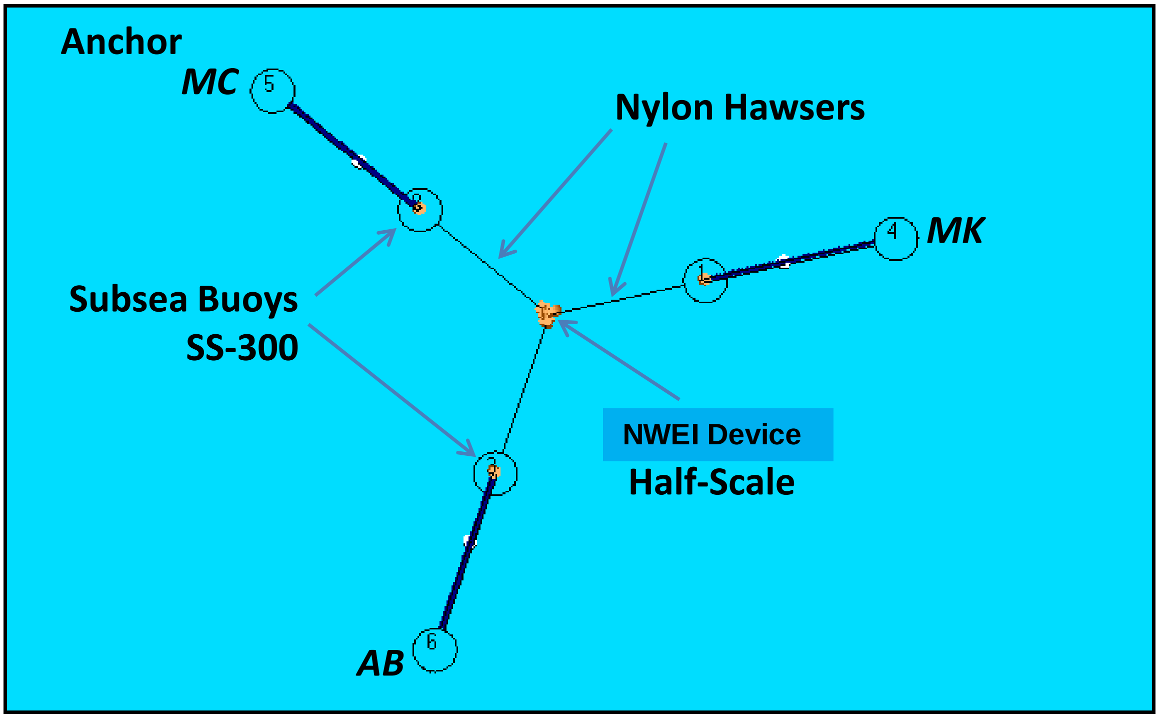
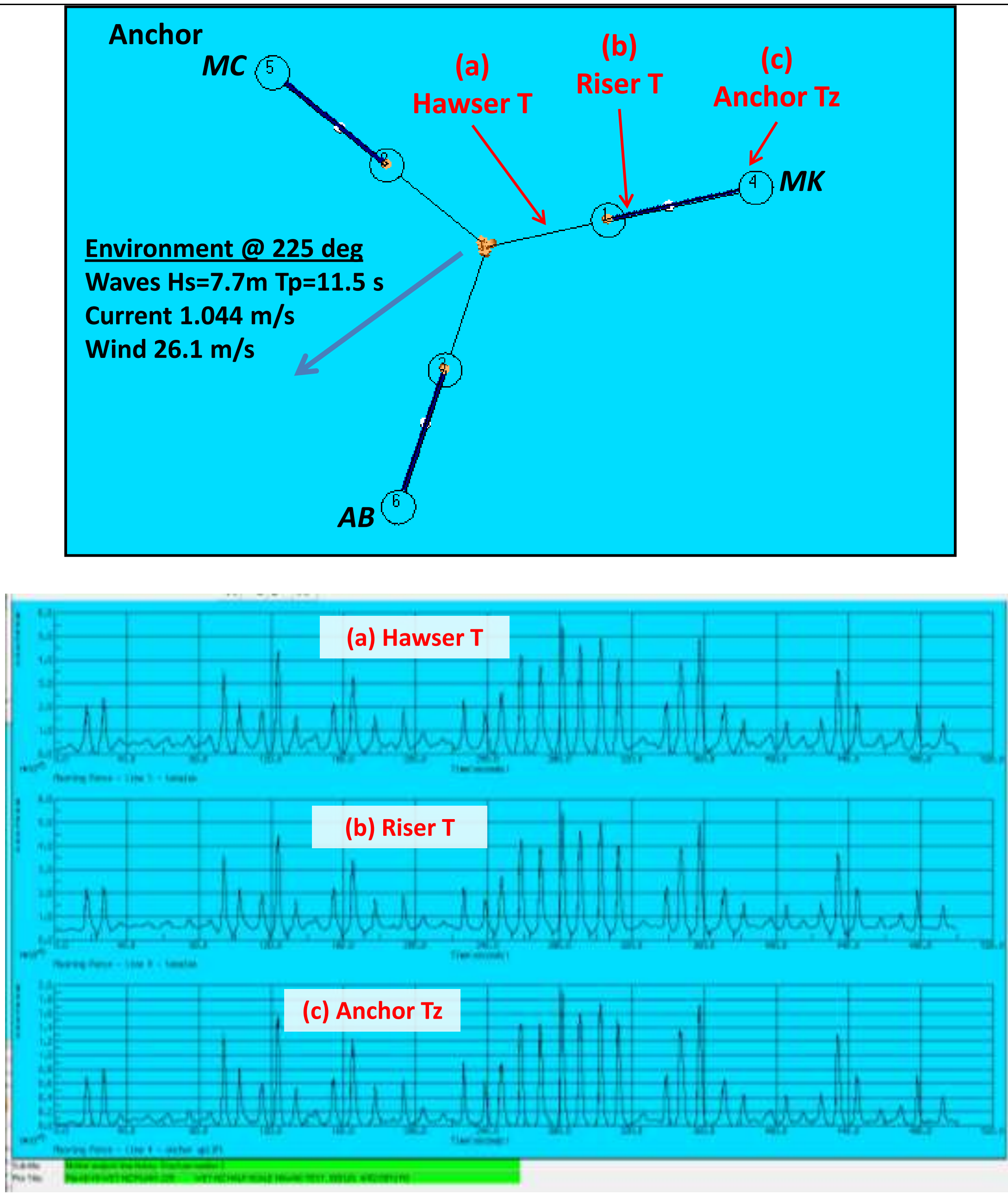


Figure 15. Mooring Concept Plan 1 View



Design Tensions for Plan 1, Environment Angle 225 Deg

Figure 16. Results Using Mooring Plan 1 for a Survival Environment From 225 Degrees

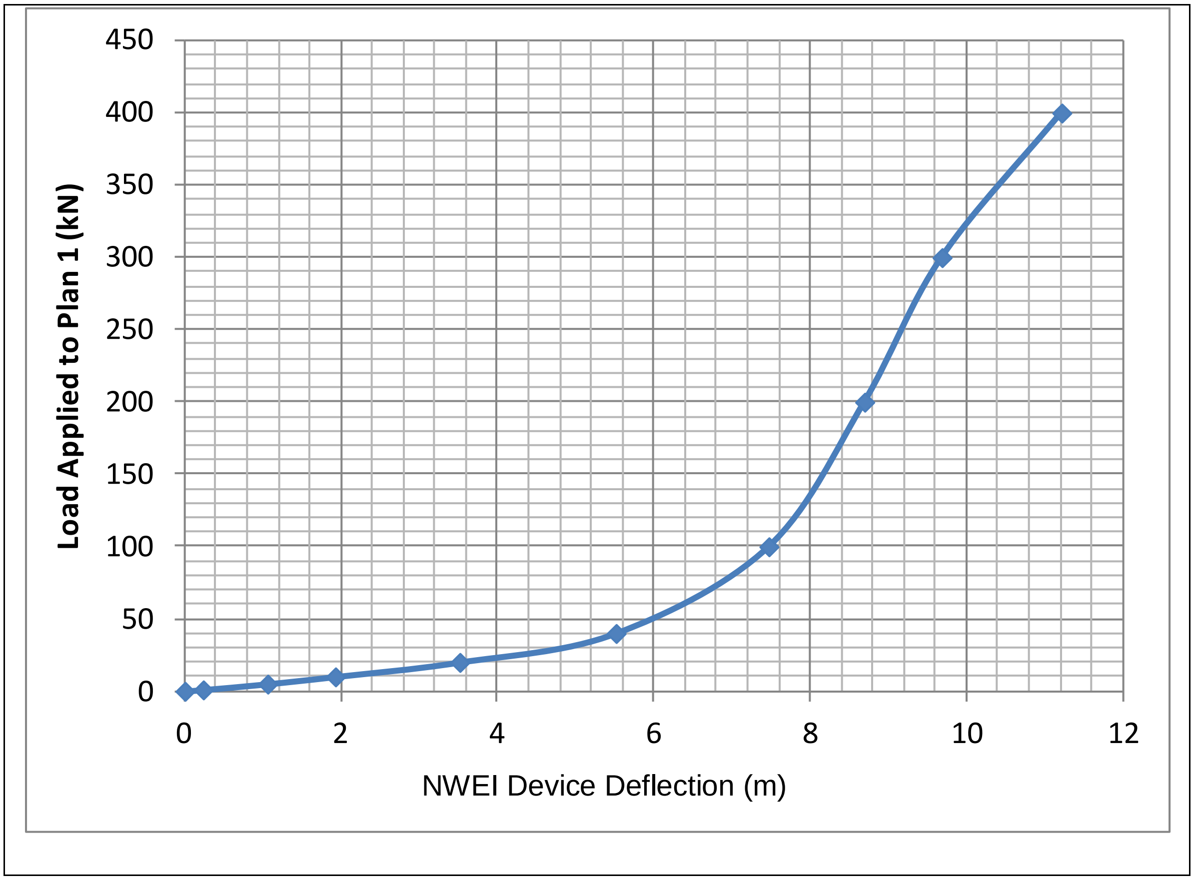


Figure 17. Load/Deflection Curve Using the Plan 1 Mooring Concept

A simulation of design conditions from the northeast (i.e. the wind, waves and current) have an AQWA angle of 225 degrees. Figure 16 shows that Plan 1 results in an unacceptable factor of safety (FS) for the hawser lines: The factor of safety on the 2.5-inch nylon hawsers is 1.64.

In addition, "snap loading" conditions occur as a group of high waves passes as illustrated in Figure 16 where the loading drops from high values to zero and back up to high tensions in a matter of seconds. The wire rope used in the risers and for the ground legs in Plan 1 is a poor choice of materials for "snap loading" conditions.

These results show that using the Oregon test mooring configuration (Plan 1) at the Hawaii site is not satisfactory.

3.2 Plan 2 – Mooring Catenary Legs with Chain, Sinkers and Nylon Risers

The Plan 1 results show that the NWEI half-scale system at the Hawaii site requires a mooring that is more compliant and that the wire rope should be eliminated. Therefore, a revised "Plan 2" configuration that uses a nylon riser and ground chain with a sinker was investigated (Figures 18, 19 and 20).

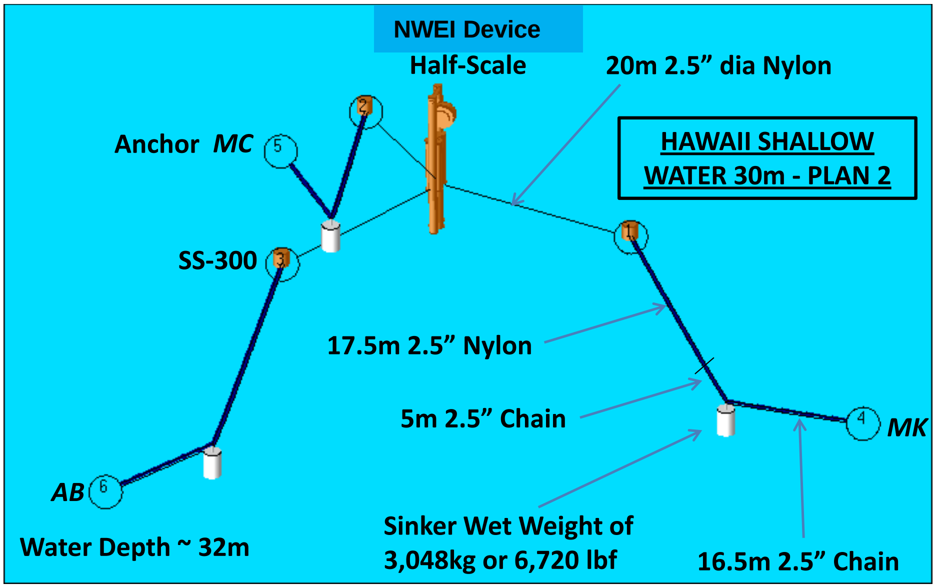


Figure 18. Mooring Plan 2 - System Concept

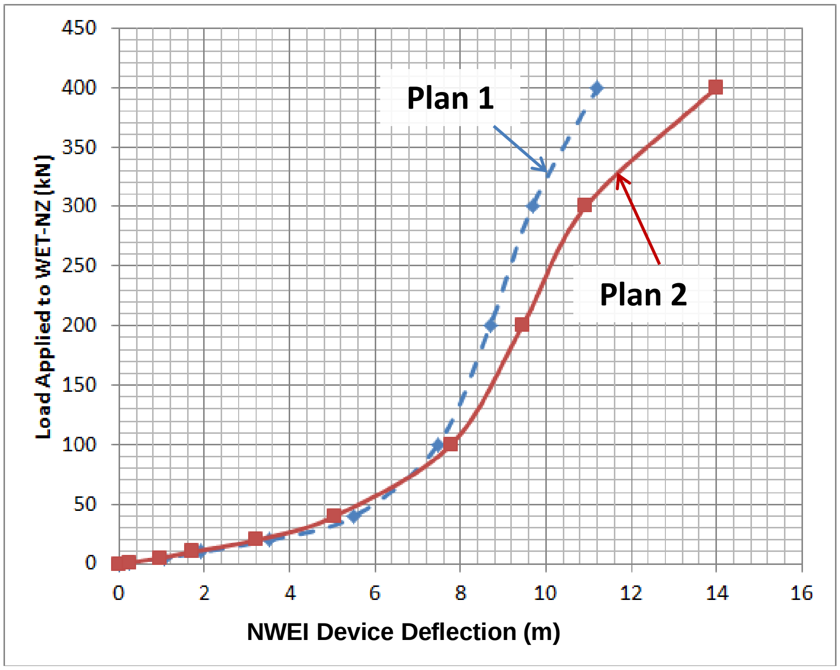


Figure 19. Plan 2 Mooring - Load/Deflection Curves

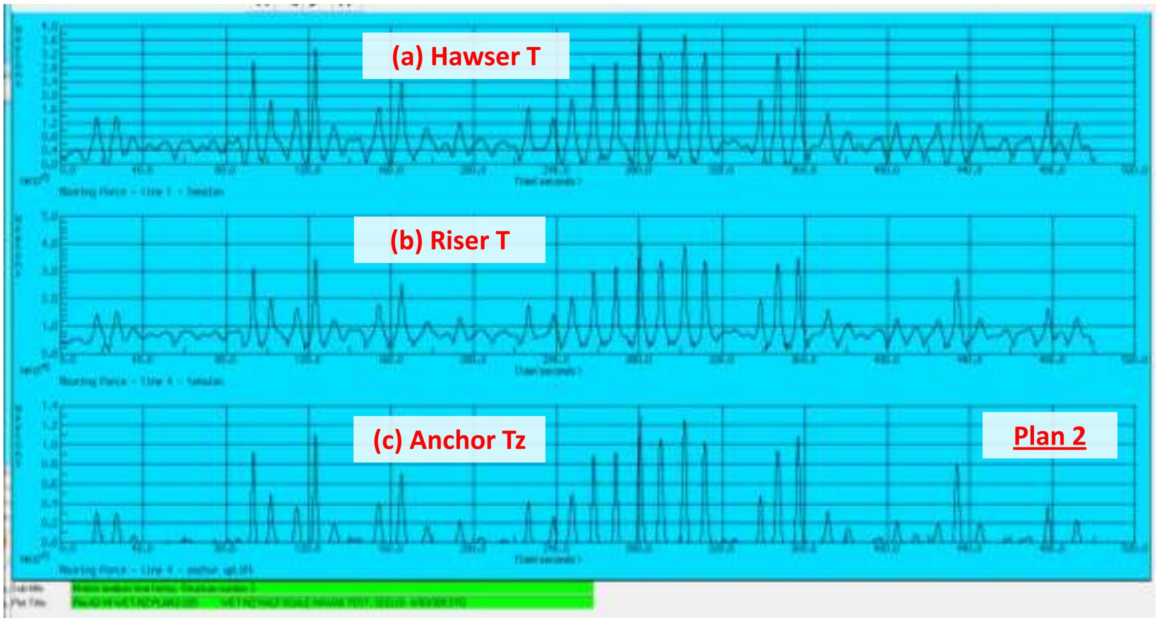


Figure 20. Plan 2 Design Environment from NE (225 deg)

The preliminary AQWA result (Figure 20) shows that Plan 2 is significantly improved with a nylon factor of safety FS ~ 2.26, as opposed to FS ~ 1.64 for Plan 1. However, there still are large lateral loads on the anchors.

3.3 Plan 3 – All-Nylon Mooring

The compliance of Plan 2 is an improvement, so a Plan 3 that includes both longer nylon hawsers and vertical nylon risers was investigated (Figure 21).

Preliminary results show Plan 3 is a "softer" mooring system (Figure 22) and has the lowest dynamic loads (Figure 23) of the configurations evaluated. This concept has the highest factors of safety on the mooring hawsers, and was therefore analyzed in more detail.

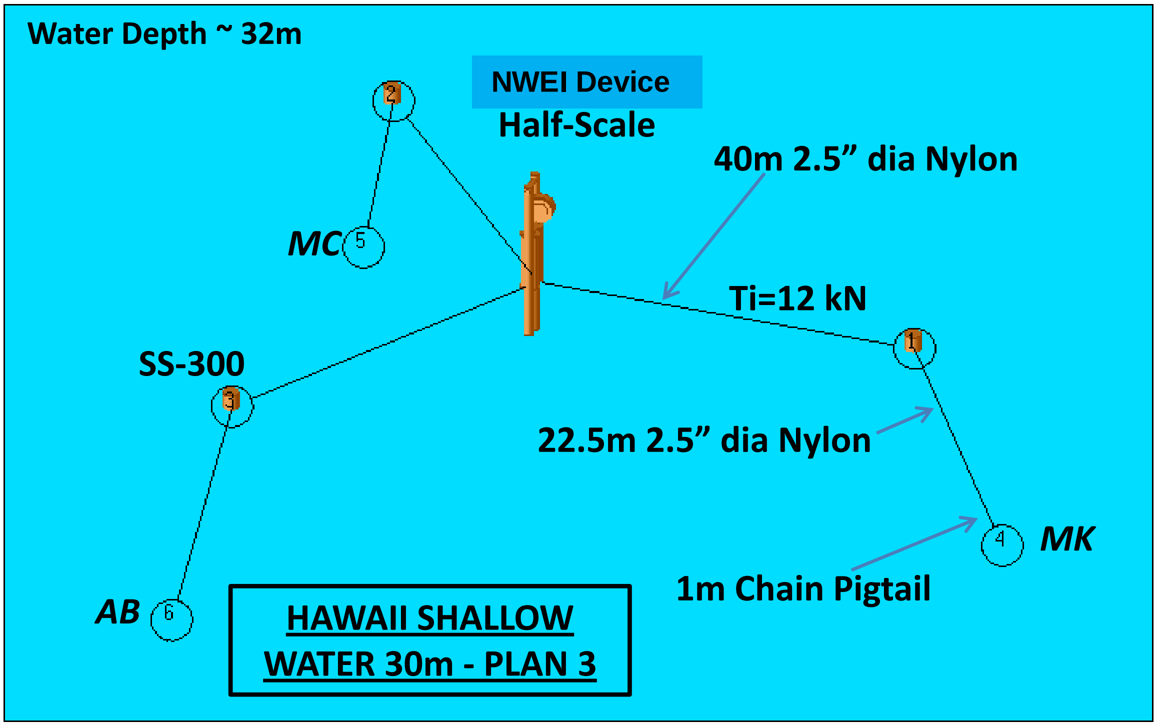


Figure 21. Arrangement for Mooring Plan 3

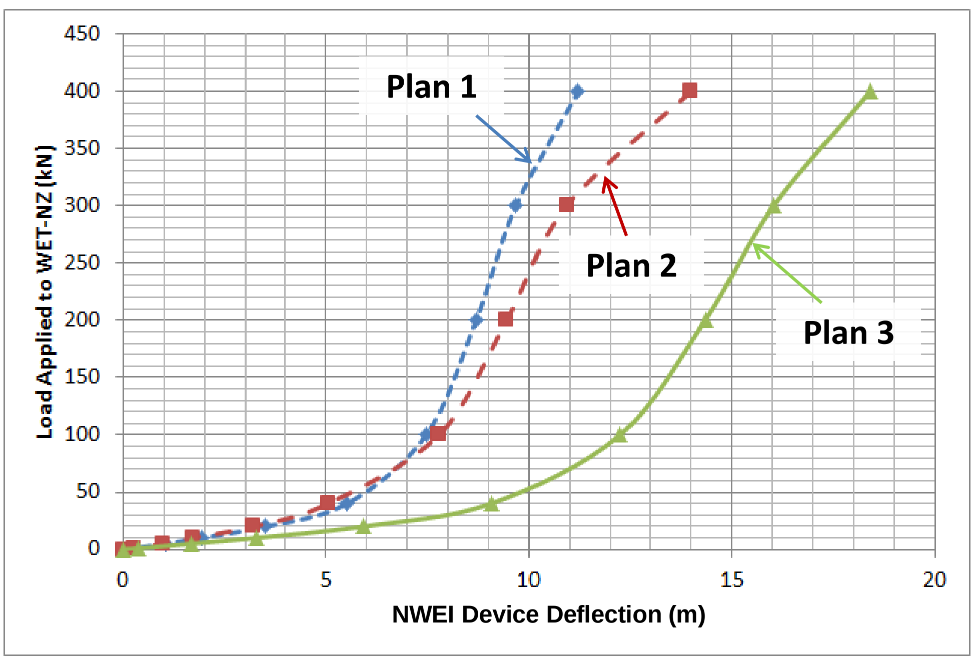


Figure 22. Comparison of Load/Deflection Curves

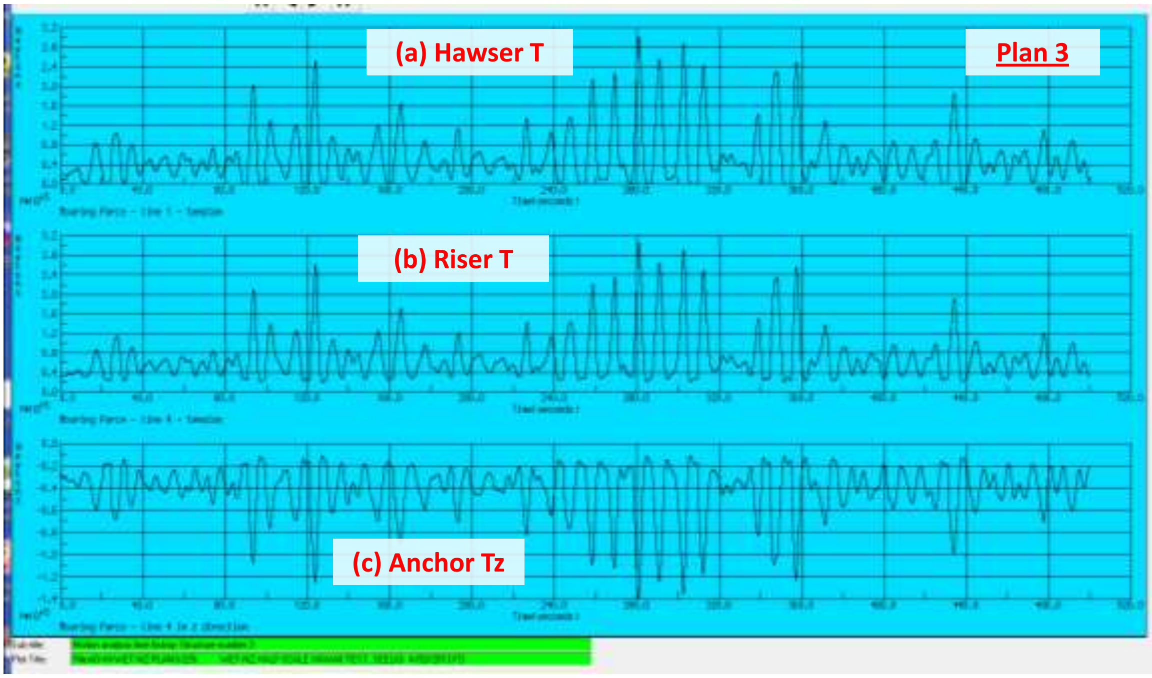
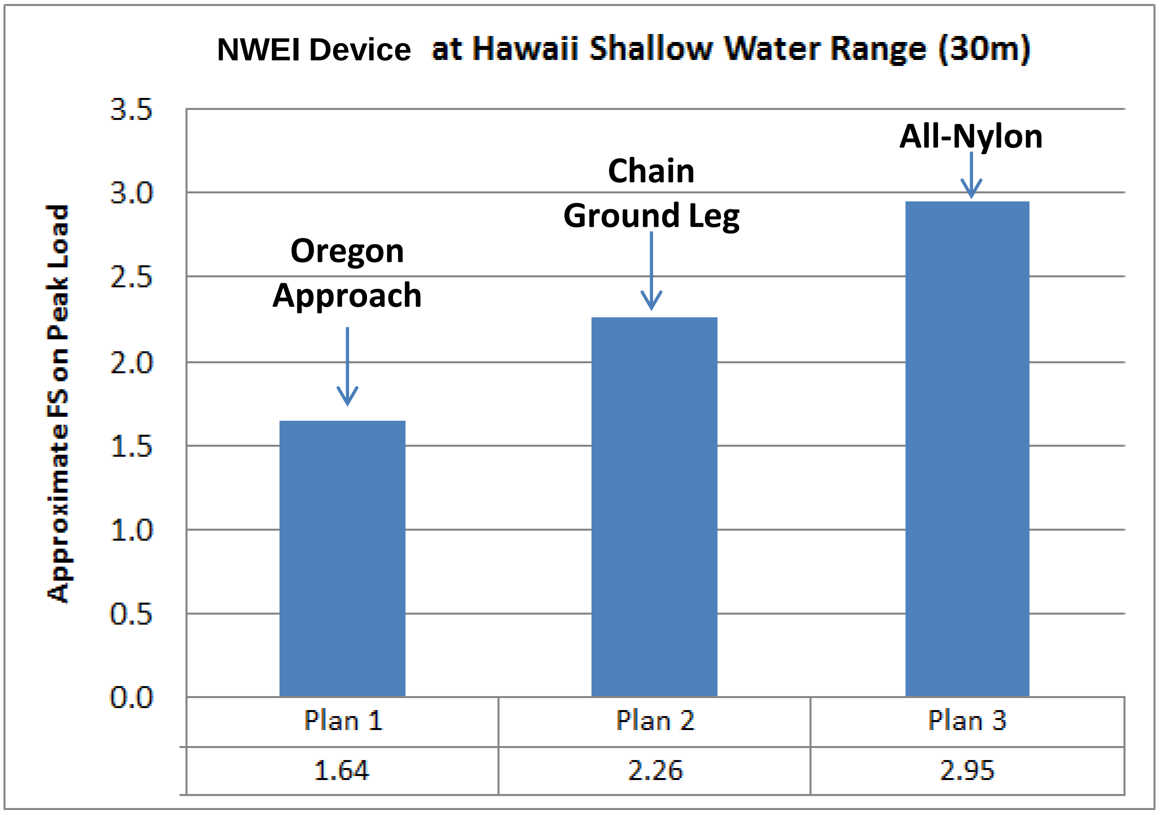


Figure 23. Results Mooring Plan 3 Design Environment for NE (225 deg)

3.4 Summary of Mooring Concepts

Preliminary simulations show that design conditions are sufficiently different at the Hawaii site that the Oregon mooring design (Plan 1) cannot be adapted for Hawaii. A modification of the concept (Plan 2) has some promise. The best option of those evaluated is Plan 3 with 40m nylon hawsers and nylon risers.

Figure 24 summarizes the mooring configurations considered and gives an indication of the factor of safety on hawsers for peak design loads.



Factor of safety based on 2.5" Diameter nylon lines

Figure 24. Approximate Factors of Safety of Peak Load for Various NWEI Device Moorings

Plan 3 has the advantages that it has the highest factor of safety and is also a configuration where assembly and installation are relatively straight forward.

4.0 ALL-NYLON MOORING DESIGN

Since the All-Nylon (Plan 3) approach looked promising, it was investigated further. Figure 25 illustrates the effect of current with one of the three mooring legs taking the load. A current of 1-knot causes a 3.4m NWEI Device offset from its static position and a 2-knot current produces a 10.7m offset. This response to currents seems quite reasonable. Since the largest design waves occur from the NE quadrant (Table 8), a significant wave height of Hs = 3m from this direction illustrates the predicted system behavior for an operational environment (Figure 26).

There are two sources of design wave data for the site:

a) 10-Year hindcast projected to give for R=100 years Hs=5.53m and Tp=15.79 sec and
b) Hindcast hurricane to give for R=100 years Hs=7.7m and Tp=11.5 sec

With the worst wave direction and the above design waves, it makes a substantial difference which source of design data is used. If the hindcast data is used, then the existing 2.50-inch nylon hawsers from the Oregon test have adequate factor of safety (Figure 27). If an assumed hurricane is used for design, then much larger hawsers are required, as summarized in Figure 28.

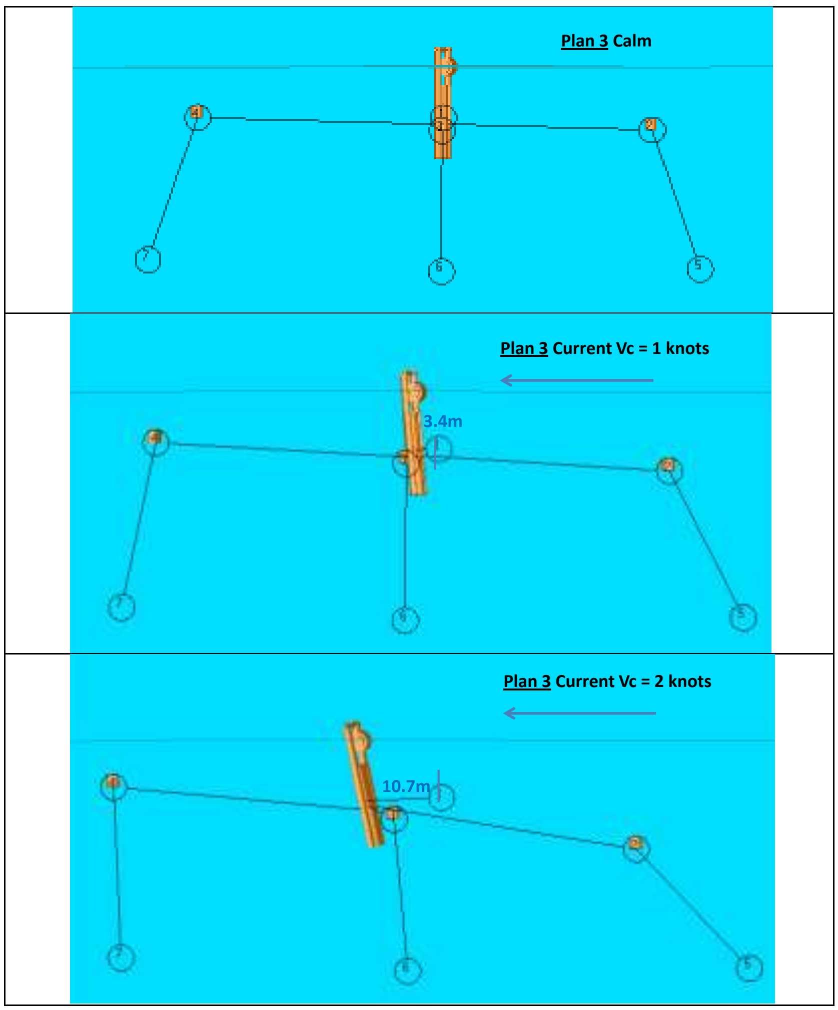
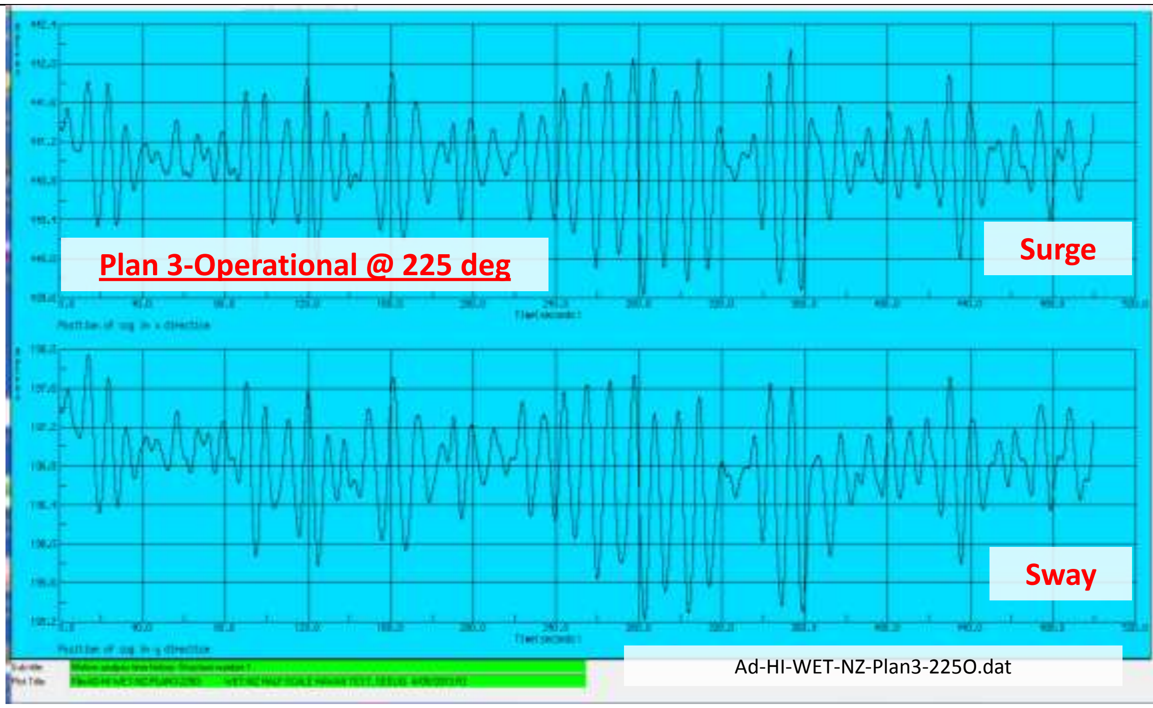
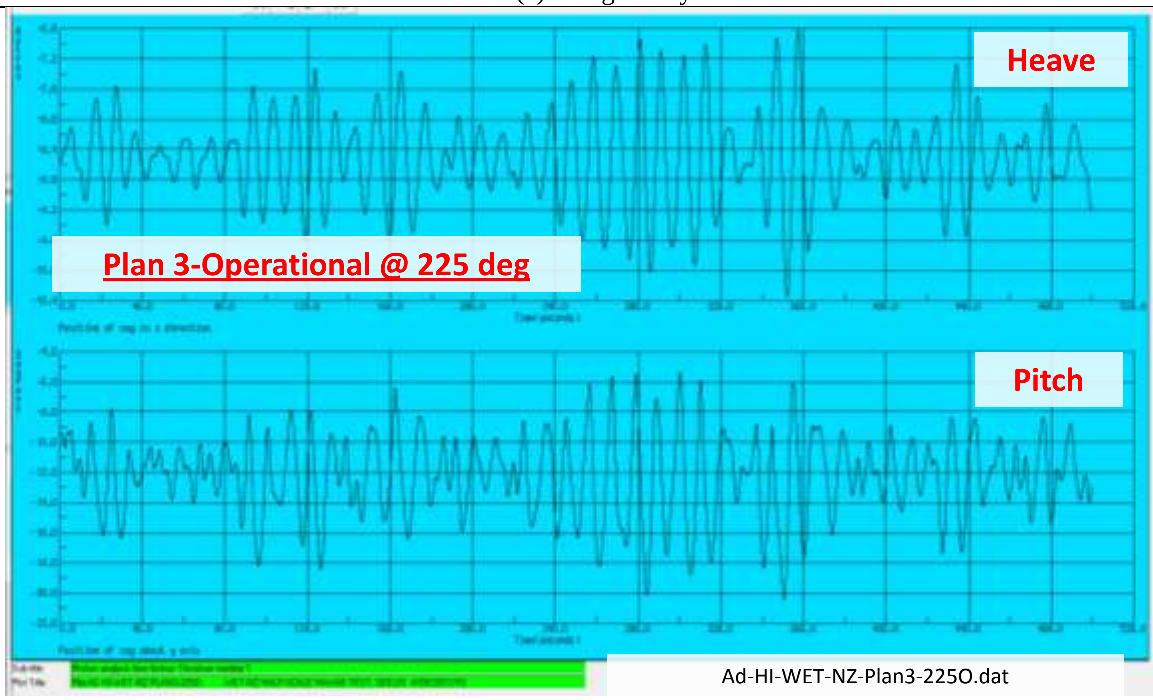


Figure 25. Current Effects on NWEI Device Plan 3 All-Nylon Mooring



(a) Surge/Sway



(b) Heave/Pitch

Figure 26. Operational Wave/Wind/Current Effects for Mooring Plan 3 (Hs=3m, Vc=2 kts)

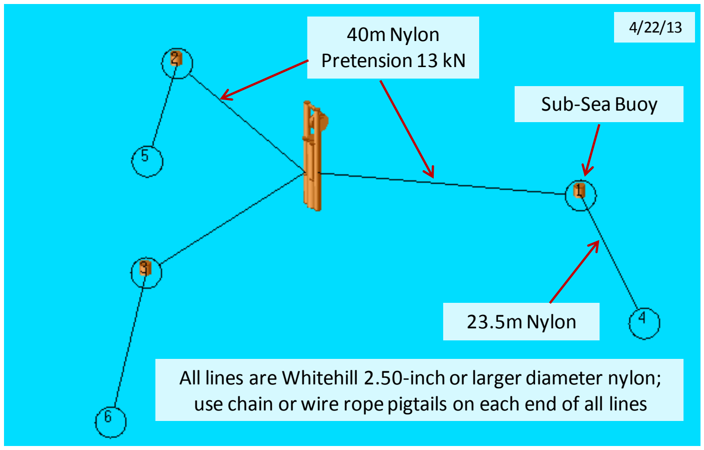
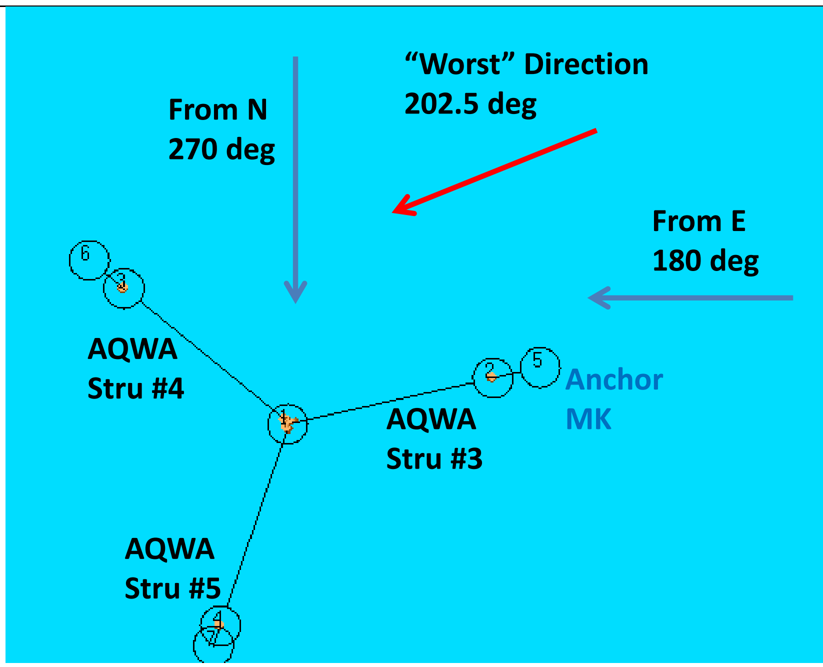
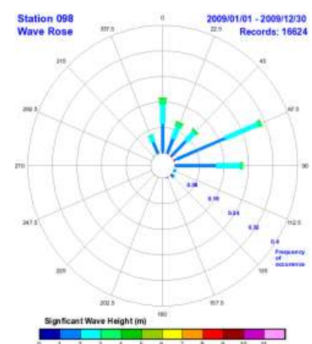


Figure 27. All-Nylon (Plan 3) Arrangement Based on Hindcast Waves with Hs=5.53m



(a) Site Arrangement



(b) Wave Rose

R=100 yr Design Waves	*Peak Mooring Results*
HINDCAST WAVES Hs=5.53m Tp=15.79 sec	<u>2.50-Inch Nylon F.S.=3.29</u> Horz Load on Anchor MK = 55.7 kips Vert Load on Anchor MK = 28.5 kips
HURRICANE WAVES Hs=7.7m Tp=11.5 sec	<u>3.0-Inch Nylon F.S.=2.87</u> Horz Load on Anchor MK = 95.1 kips Vert Load on Anchor MK = 44.6 kips

(c) Peak Loading

Figure 28 All-Nylon Arrangement for Mooring Plan 3

5.0 POWER CABLE

The dynamic umbilical power cable from the NWEI Device must be designed to run safely from the device to the seafloor touchdown point T-frame (Figure 29). Various analyses of hindcast R=100 year waves with Hs=5.53m and Vc=2 knots are shown in Figure 30 to show the motions of the NWEI half-scale device where (0,0) on this figure is the easting/northing of the device compared to the case where there are no wind/waves/current. The watch circle of the wave energy device is ~20m or less in the All-Nylon (Plan 3) mooring design.

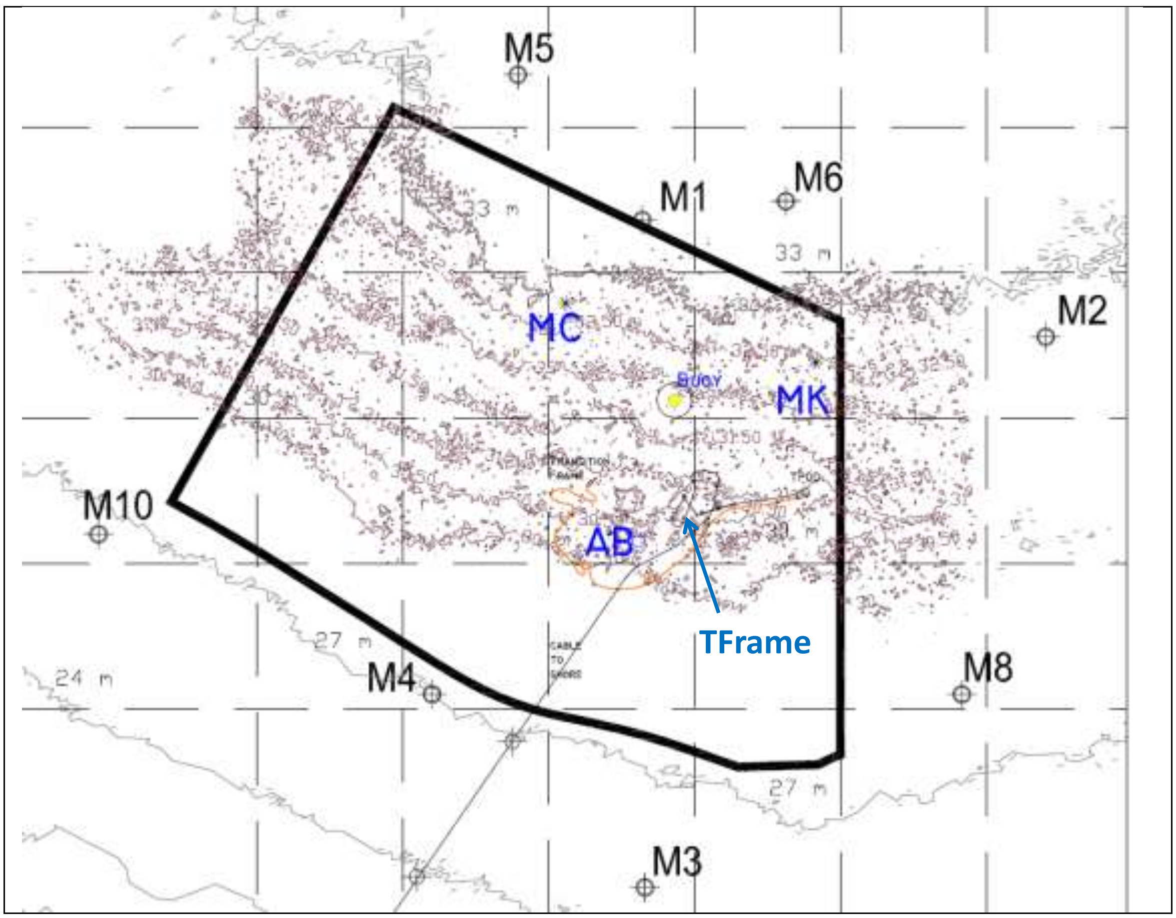


Figure 29. WETS Shallow Site Geometry

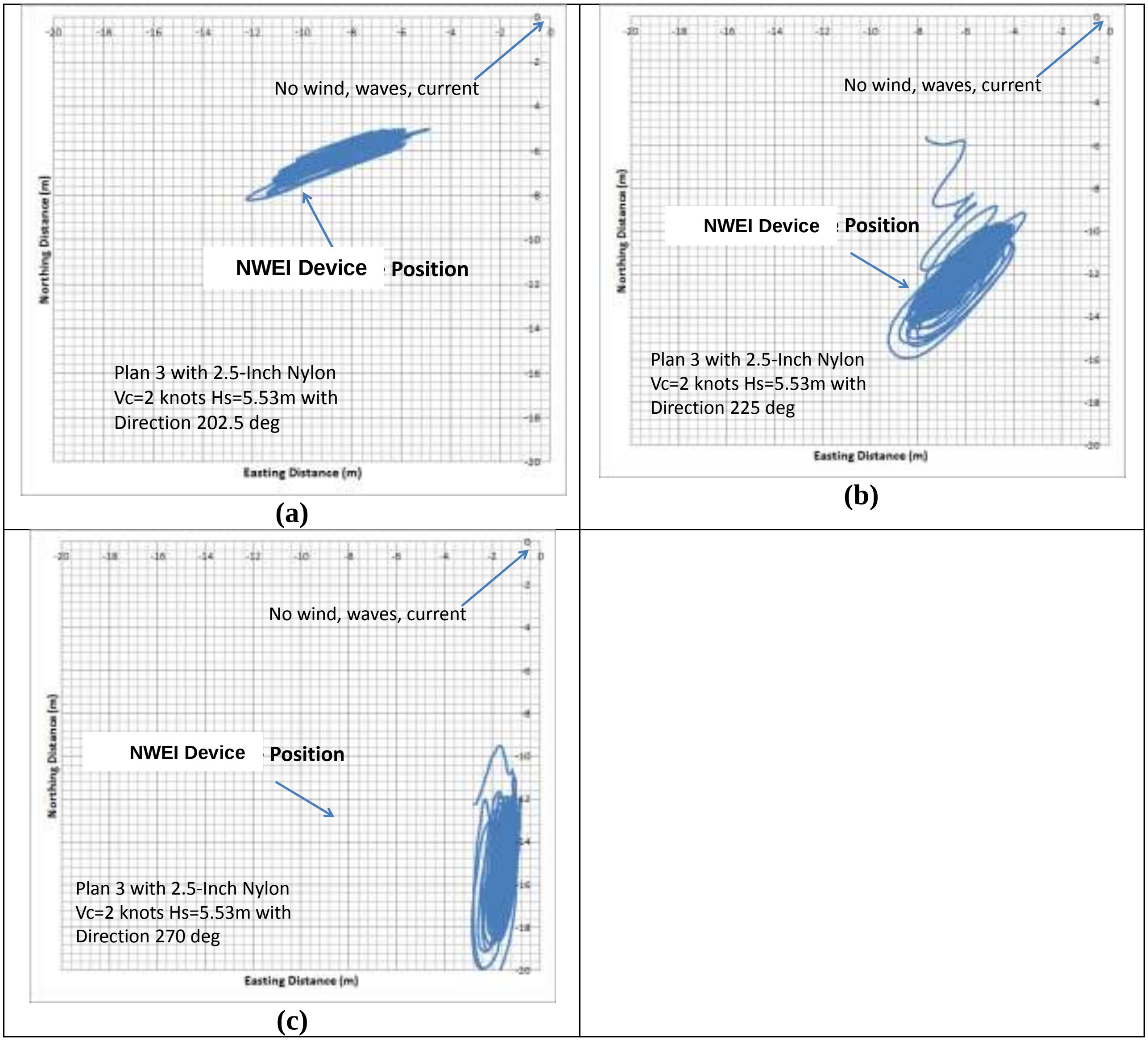


Figure 30. NWEI Device Half-Scale Positions for Various Wave/Current/Wind Directions

The existing submarine trunk cable to shore was fabricated by Olex Cables, Tottenham, Victoria, Australia. The notional dynamic umbilical cable is assumed to have similar properties and is a three (3) conductor double armored submarine cable incorporating optical fibers. Properties of the subsea cable are presented in Tables 10 and 11. Figure 31 shows the cross section view of the notional umbilical subsea cable.

Table 10. Subsea Power Cable Properties

Physical Properties:			
	Net mass of cable:		7800 kg/km
	Cable dimensions:		
		Overall cable diameter	59.8 mm nom ± 1.6 mm
		Diameter over armor:	45.1 mm
		Diameter under armor:	38.8 mm
		Diameter over laying-up:	30.6 mm
		Conductor Diameter:	4.7 mm
	Recommended minimum internal bending radius:		
		Pulling In:	1500 mm
		Set in Position:	900 mm
	Recommended maximum safe pulling/working tension:		
		Conductors:	1.9 kN
		Armor:	30.0 kN
Electrical Properties:			
	Maximum conductor dc resistance:		1.16 ohm/km
	Minimum insulation resistance:		12500 megohm/km
	Capacitance of main conductor:		0.23 µF/km
Despatch Parameters:			
	Length:		1250 m
	Internal drum size		2700 mm x 1500 mm B x 1400 mm
	Overall drum size		2850 mm x 1620 mm (Steel drum)
	Gross mass per drum:		11500 kg

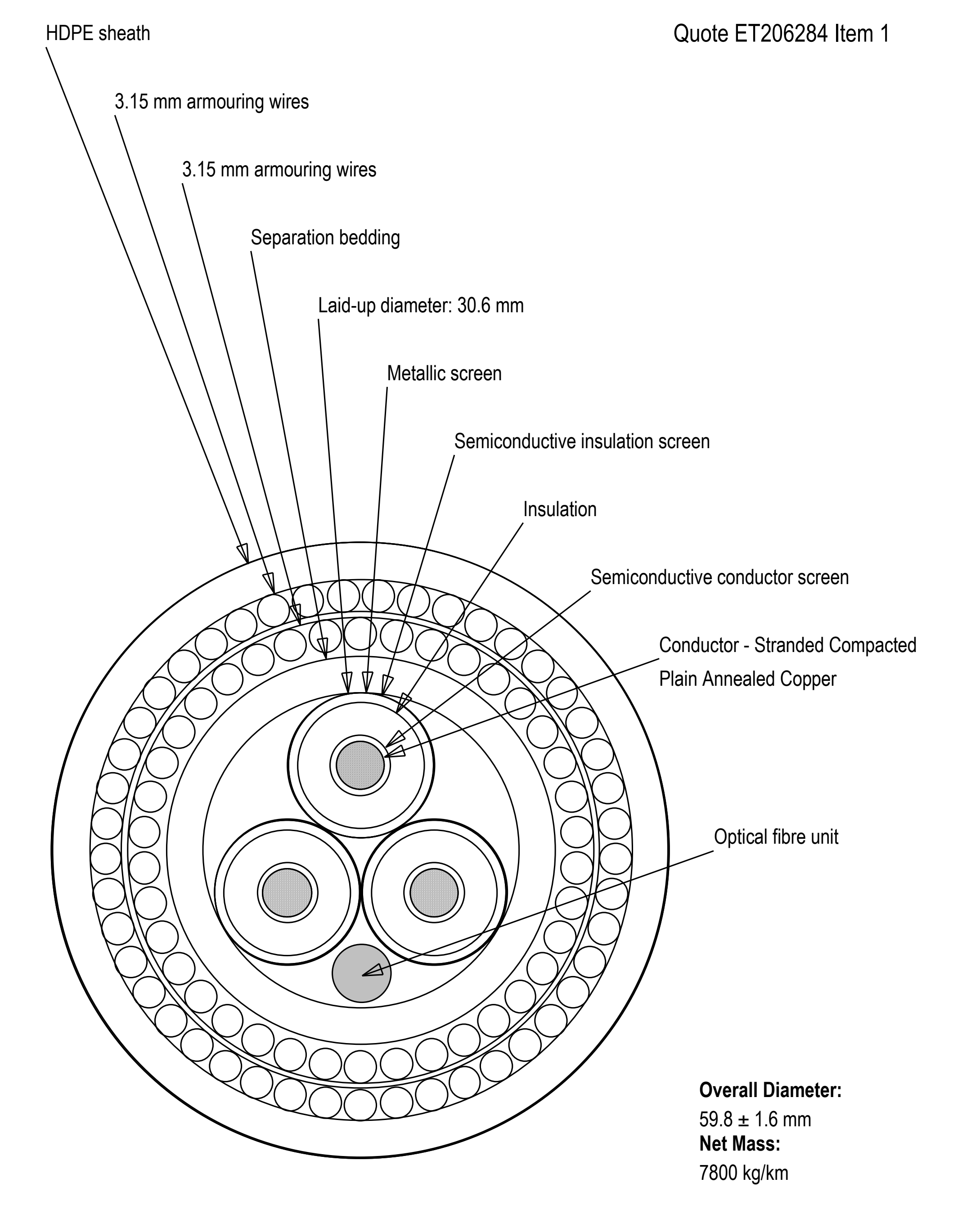
Table 11. Power Cable Properties Assumed for the Notional Umbilical

Power-Cable.mcd
W. Seelig
4/19/2013

NWEI Device POWER CABLE

The cable used on the seafloor at Hawaii is assumed for the umbilical:

$L := 1m$	Unit length	
$Dia := 59.8mm$	Diameter	$Dia = 0.0598m$
$A := \pi \cdot \left(\frac{Dia}{2}\right)^2$	Cross-sectional area	$A = 0.002809m^2$
$W := 7.8kg \cdot g$	In-air weight	$W = 76.5N$
$Mass := \frac{W}{g}$	Mass	$Mass = 7.8kg$
$V := L \cdot A$	Volume	
$\rho C := \frac{Mass}{V}$	Cable density	$\rho C = 2777.2 \frac{kg}{m^3}$
$\rho := 1024.4 \frac{kg}{m^3}$	Water density	
$Wsub := W - V \cdot \rho \cdot g$	Submerged weight	$Wsub = 10.9lbf$ $Wsub = 48.3N$
$MassUnit := \frac{Mass}{L}$	Mass per length	$MassUnit = 7.8 \frac{kg}{m}$
$WaterUnit := V \cdot \frac{\rho}{L}$		$WaterUnit = 2.877 \frac{kg}{m}$



DESCRIPTION: 3 Conductors 16 mm² Stranded Compacted Plain Annealed Copper, Semiconductive EPR Conductor Screen (0.6 mm nom wall), 3.8/6.6 kV R-EP-90 Insulated (3.0 mm min av wall), Strippolex Insulation Screen (0.6 mm min wall), Individually Helical Copper Tape Screened, Laid up with non-hygroscopic fillers, PE Bedded (3.0 mm min av wall), Brass Taped, Double Wire Armoured (3.15 mm nom diam), HD Polyethylene Sheathed (3.0 mm min av wall), Submarine cable incorporating Optical Fibres.

OLEX CABLES
A Division of Australian Cables Pty Limited
207 SUNSHINE ROAD, TOTTENHAM

Prepared: R Piechota	16 May 02
Approved:	Scale: 2.0 x full size

IDENT: 5499,000016,00,3572

Figure 31. Cross Section of Subsea Power Transmission Cable

The best place to terminate the power cable from NWEI Device is on the seafloor at a point exactly half-way between anchors MK and AB to minimize the chance of any interference of the mooring legs and power cable. The original “T-Frame” location is not recommended because it is too close to anchor AB.

The distance from NWEI Device to the recommended seafloor cable termination point is ~34m. Meanwhile, the device has a watch circle about its calm static position of ~20m. Therefore, the power cable segment running from the NWEI Device to the seafloor termination device is formed into a Lazy-S shape, as shown in Figures 32 and 33 to accommodate NWEI Device survival motions.

One approach to creating the Lazy-S shape is by adding a flotation collar of foam at selected locations on the power cable segment from the seafloor to the wave energy device. Figure 34 shows one possible configuration. In this approach, the suspended cable is 51.5m long and comprised of four segments (a, b, c and d) as follows:

a) 20m of cable starting at the seafloor termination point; this segment is shorter than the water depth to keep the cable from contacting and chafing on the seafloor as much as practical

b) 12m of cable with an ~6.5-inch diameter foam collar; this helps hold the power cable up and forms an inverse-catenary

c) 16m of cable; this forms a sagging catenary

d) 3.5m of cable with a ~6.5-inch diameter foam collar to keep the cable approximately horizontal where it attaches to the NWEI Device. Attachment devices, such as a tapered rubber collar, should also be considered to reduce cable bending where it attaches to the NWEI Device

Figure 35 illustrates the system in calm water, while Figure 36 shows the effect of a 2-knot current with a direction of 202.5 deg. These simulations indicate there is adequate slack in the Lazy-S and the power cable is well clear of the mooring hawsers.

If we then apply the R=100 year design waves of Hs=5.53m the system is observed to behave well (Figures 37 and 38) with maximum tension in the Lazy-S where it attaches to the NWEI Device of < 5 kN.

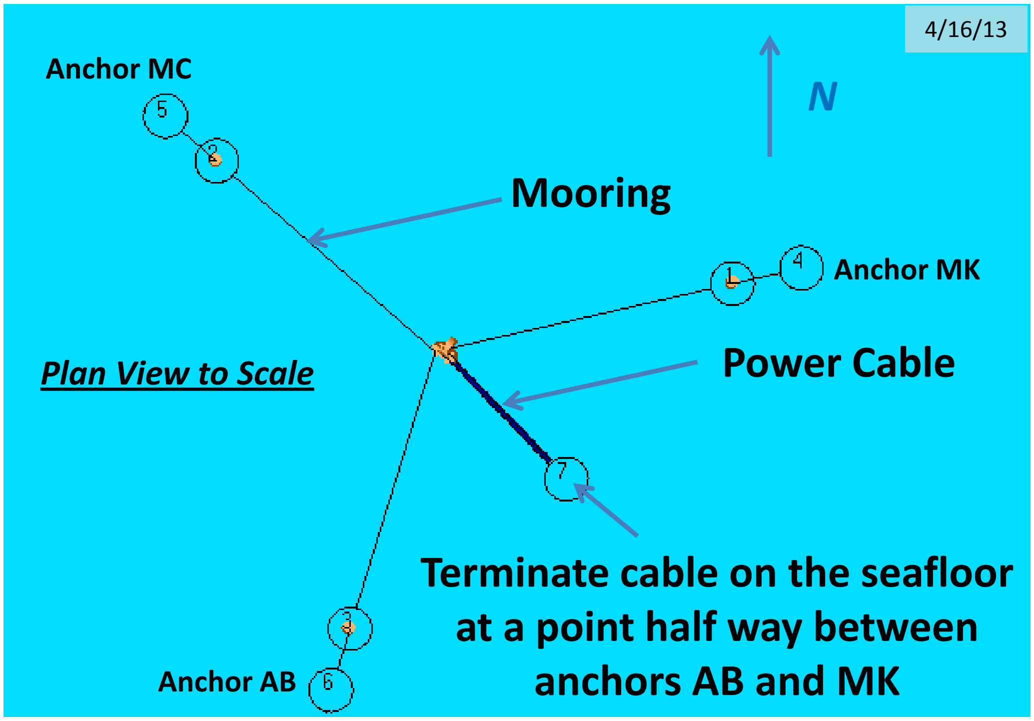


Figure 32. WEC Plan View

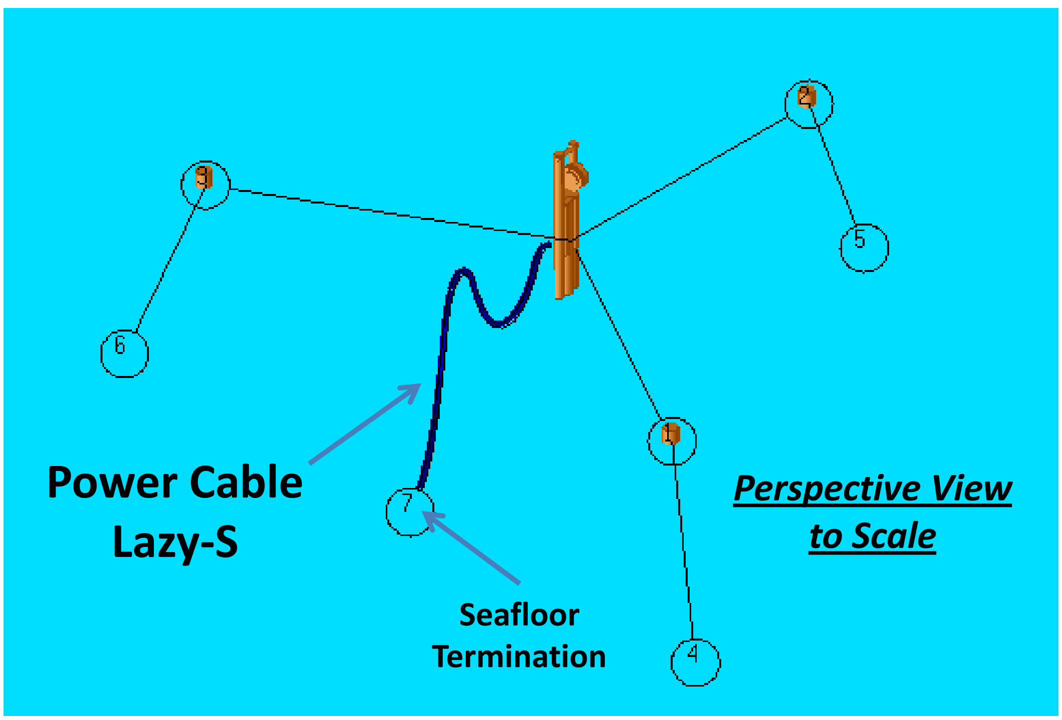


Figure 33. WEC Perspective View

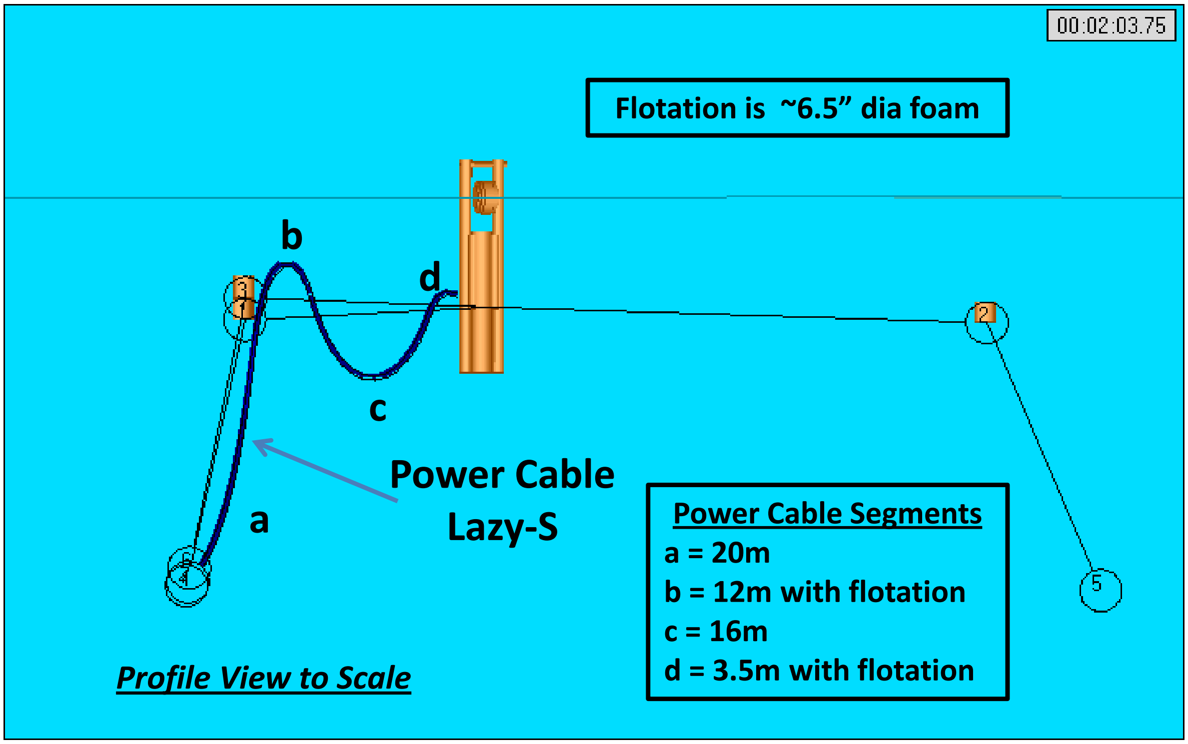


Figure 34. Umbilical Cable Lazy-S Design in Profile View

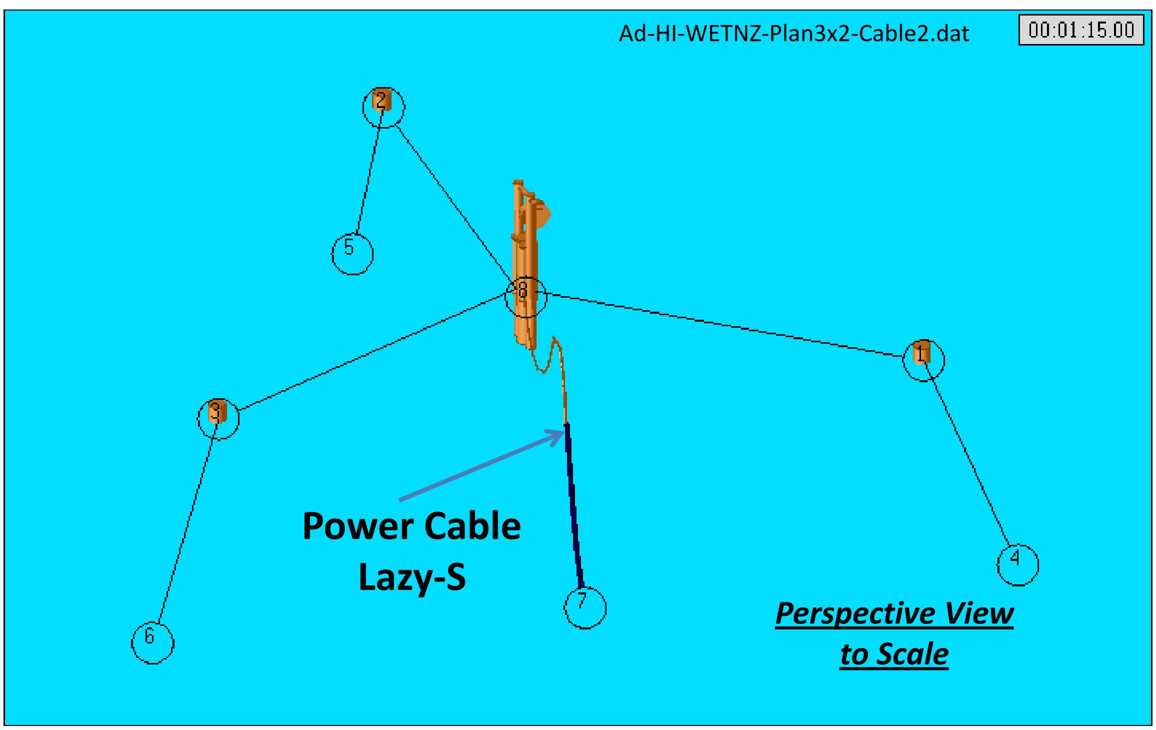


Figure 35. Umbilical Calm Water Position

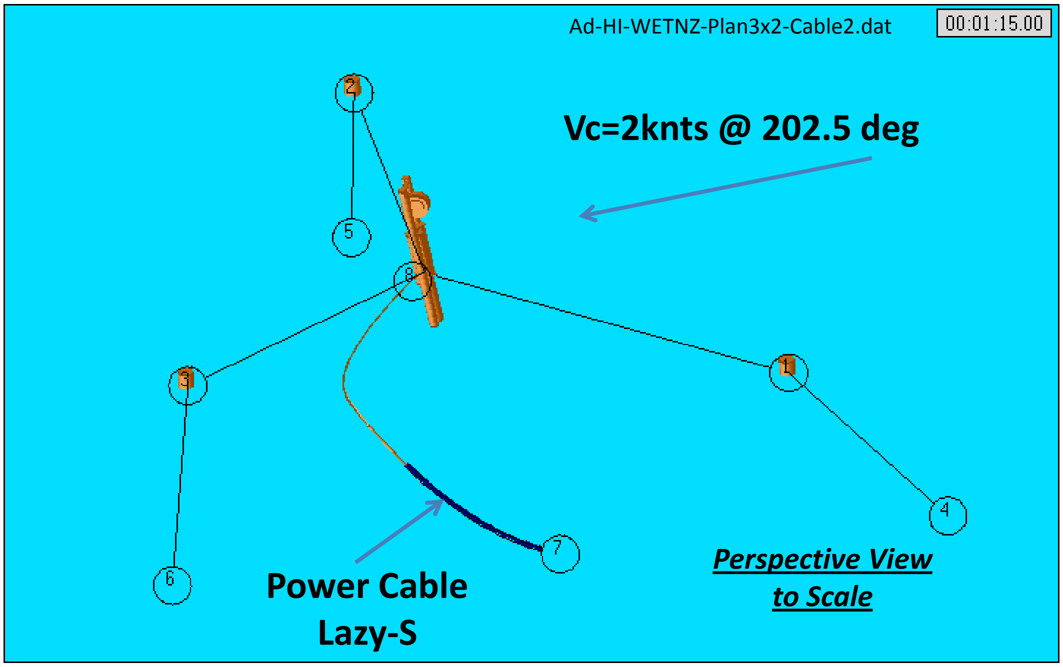


Figure 36. Umbilical Position with Current Speed of 2 knots and a Direction of 202.5 Degrees

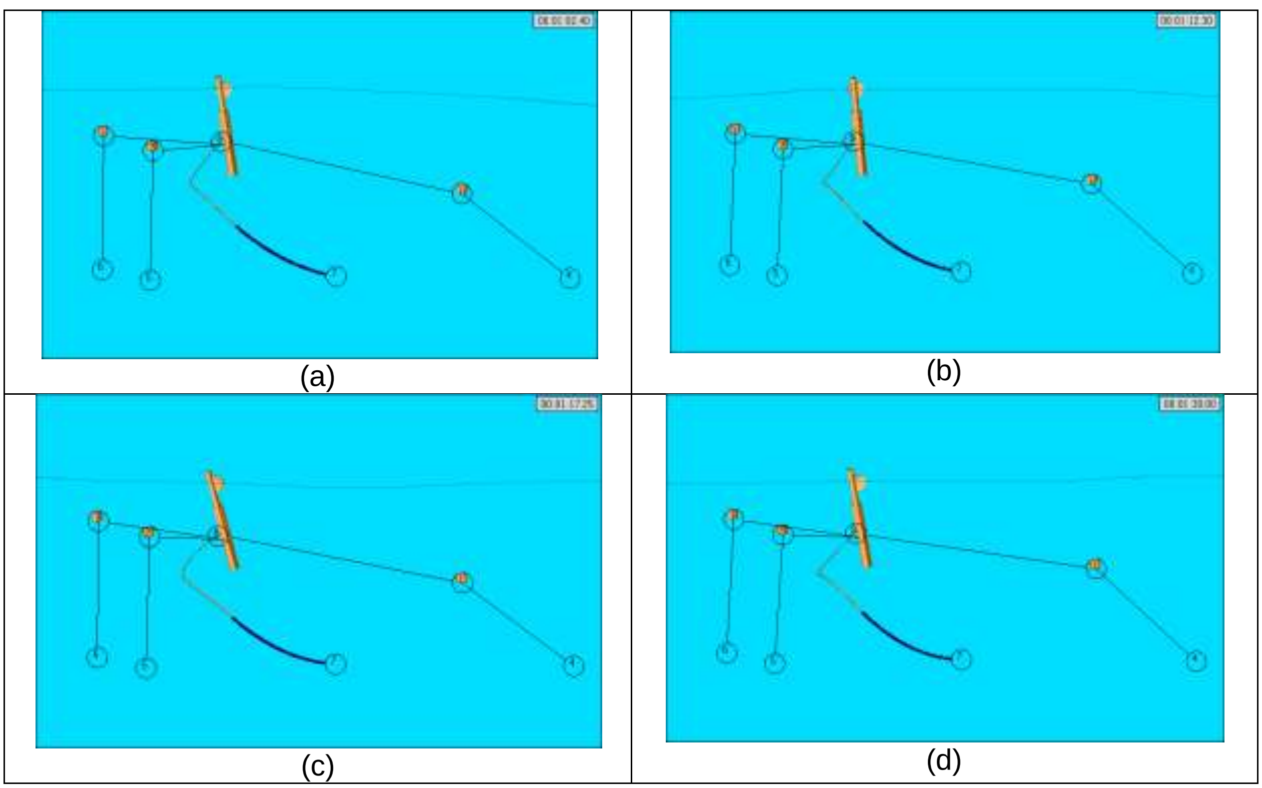
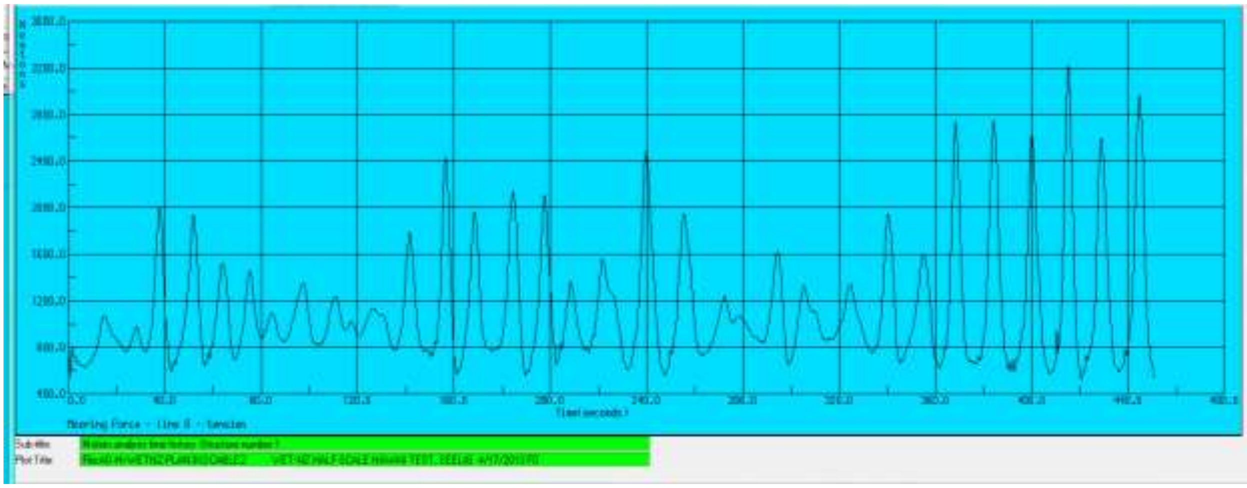


Figure 37. Profile Views at Various Times

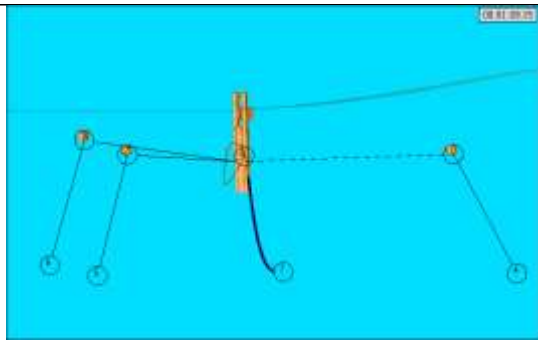


Tension Where Power Cable Attaches to NWEI Device

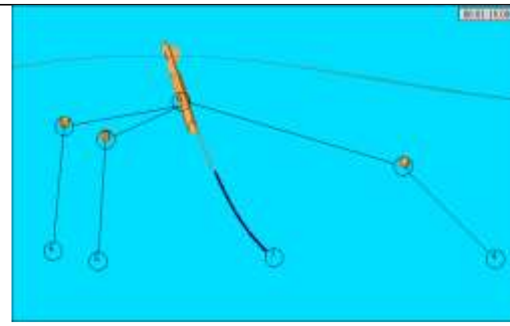
Figure 38. System Behavior in R=100 yr Hs=5.53m and Vc=2 knot Conditions Irregular Waves

Further analysis indicates if a storm occurs with a 10m swell (H) with a wave period of 15 seconds and Vc = 2 knots, the system moves a great deal as illustrated in Figure 39, and yet the maximum mooring hawser tension is 140 kN (i.e. a factor of safety of 6.3 for 2.5-inch diameter line) and the maximum Lazy-S tension at the NWEI Device is 0.8 kN.

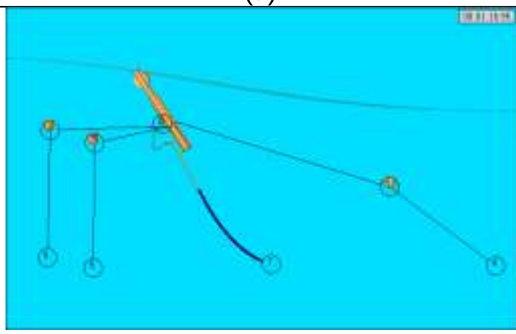
The initial umbilical cable is assumed to have a diameter of ~60mm and an in-air unit weight of 7.8 kg/m. The umbilical Lazy-S design that works well with this cable is shown in Figure 34. If another cable is considered for the umbilical, then a promising approach would be to use the same lengths called out on Figure 34, but with the diameter of the flotation collar adjusted accordingly. For example, if another cable has a unit weight of 3.9 kg/m (i.e. half the initial assumption) then the initial flotation collar to consider would have half the buoyancy of the initial model or a diameter of 6.5 inches / SQRT(2) = 4.6 inches.



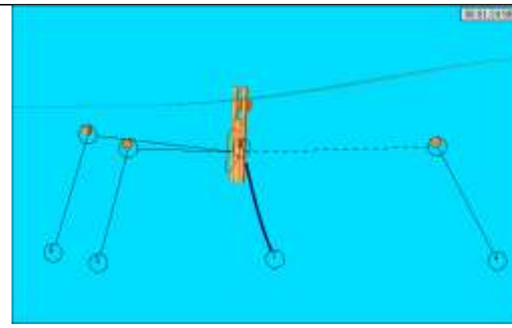
(a)



(b)

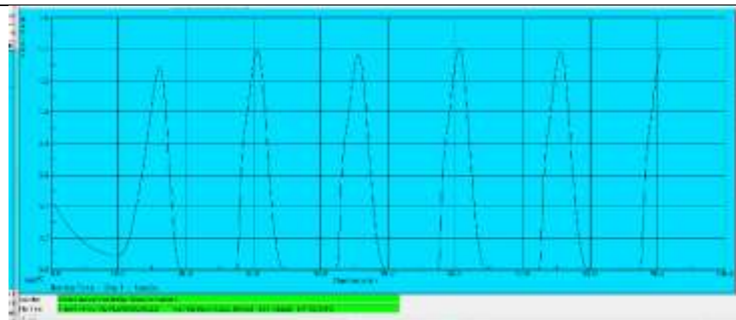


(c)

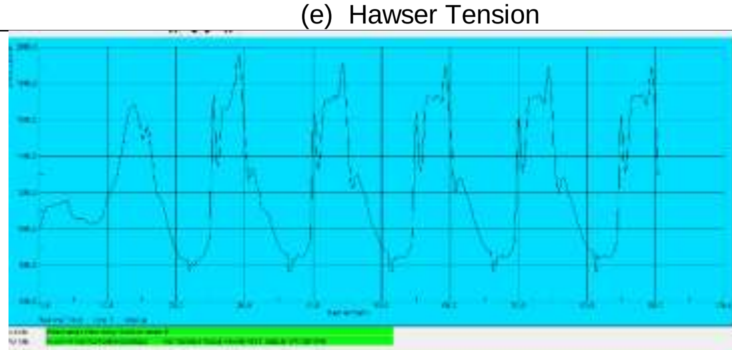


(d)

Profile Views at Various Times



(e) Hawser Tension



(f) Power Cable Tension at NWEI Device

Figure 39. System Behavior in Swell Waves of H=10m, T=15sec and Vc=2 knot

6.0 MOORING INSTALLATION CONCEPT

The following is one approach that could be considered for installation:

- Divers clamp temporary sheaves to each of the existing anchors. A haul-down line runs from the surface, through the sheave and back to the surface.
- Assemble a riser, sub-sea buoy and hawser.
- Secure the haul-down line to the sub-sea buoy.
- Pull the sub-sea buoy down with the haul-down line. Note that each sub-sea buoy has a net buoyancy of ~6,900 lbf.
- The riser is slack at this point, so divers can secure the lower end of the riser to the existing anchors.
- Tension is let off the haul-down line so the riser holds the tension caused by the sub-sea buoy.
- The haul-down line is now slack, so divers can remove the temporary haul-down line from the sub-sea buoy.
- After all three of the mooring legs are installed, the NWEI half-scale device can be towed to the site, up righted and the three mooring hawsers secured to the device. Note that the hawser lengths are selected to give ~13 kN of hawser pretension.
- The power cable Lazy-S is meanwhile installed and the termination end of the power cable attached to device.

The above steps are reverse at the end of testing to remove the system.

7.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This report documents the design of the NWEI Device mooring using a notional power cable umbilical configuration at the WETS shallow test berth using the three existing anchors at the site. The water is shallower and the anchors closer together at WETS as compared to Oregon, so the Hawaii mooring design is an “All Nylon” approach consisting of nylon risers and nylon hawsers.

The previously used Whitehill 2.50-inch diameter nylon line size is adequate for design R=100 year Hs=5.53m survival conditions at the site. The 2.50-inch lines are also adequate if a storm (H=10m Tp=15sec) wave condition were to occur. Larger 3-inch diameter would be recommended for the two north legs if the rare design hurricane were to locally occur to the north of Hawaii with Hs=7.7m irregular waves. However, the last time any hurricane was north of the islands was 1950. Chain pigtails are recommended on the ends of risers and hawsers where they attach to the anchors, subsurface floats and the NWEI Device.

The former "T-Frame" location is too close to Anchor AB, so it is recommended that the umbilical cable be anchored at a new T-Frame location at a point mid-way between anchors MK and AB. This cable termination point provides adequate room to help minimize the possibility of any conflict between the power cable Lazy-S and the mooring legs.

A power cable Lazy-S concept is developed that accommodates the winds, waves and currents at the Hawaii site. This Lazy-S uses a combination of extra cable and foam collars arranged in a manner so the umbilical cable from the NWEI Device to the seafloor behaves well in operational and survival design conditions. The size of the flotation collar depends on the umbilical cable. For example, if a ~60mm cable with a unit weight of 7.8 kg/m were to be used, the flotation collar would be approximately 6.5-inches placed at key sections along the umbilical. Lighter umbilical power cables could uses smaller diameter flotation collars.

8.0 POINTS OF CONTACT

Points of contact for this study are listed in Table 12.

Table 12. Points of Contact

Name	*Phone*	*Email*
Steven Kopf	503-475-2999	skopf@nwenergyinnovations.com
Brian Cable (SST)	805-612-5986 cell	bcable@soundandsea.com
Bob Taylor (SST)	805-910-9912 cell	rtaylor@soundandsea.com
Bill Seelig (SST)	240-753-2796 cell	wseelig@soundandsea.com

9.0 REFERENCES

1. Seelig, W. and Taylor, R., "WET-NZ Multi-Mode Wave Energy Converter, Oregon Mooring Assessment, SST Report, 27 Feb 2012.

2. MMI Engineering/Ocean Power Technologies, Inc., "PB40 HI Buoy 2, Wave Energy Converter, Mooring System and Power Takeoff Cable, Design Basis for Storm Conditions", Report: MMH067PH3-R-001 of 7/12/2006.

3. Wave Power Analysis for Select Sites around the Hawaiian Islands, Hawaii National marine Renewable Energy Center, August 2, 2011.

APPENDIX A - MOORING DESIGN NOTES

The mooring design for the NWEI half-scale device consists of:

- Three existing anchors at the Shallow Water (30m) site.
- The three existing sub-sea foam buoys from the Oregon test.
- Whitehill nylon 2.5-inch diameter risers at three places.
- Whitehill nylon 38m long 2.5-inch diameter hawsers at three places.
- Pigtails of chain on each end of each nylon line.

Note that anchors MK and MC are simple frames rock-bolted to the seafloor. However, the nearshore anchor AB is a frame with a 21.4-foot (6.53m) high articulated 2-foot (5cm) diameter column, as shown in Figure A-1. Table A-1 shows line and chain lengths needed for the mooring.

Table A-1. NWEI Device Half-Scale at Shallow Water (30m) Mooring

Mooring Leg	First or Upper Chain Pigtail (m)	Hawser Length (m)*	Second or Lower Chain Pigtail (m)
AB Nearshore Riser	1m	20.0m 2.5” Nylon	1m
AB Nearshore Hawser	1m	38m 2.5” Nylon	1m
MC Riser	1m	26.8m 2.5” Nylon	4.9m
MC Hawser	1m	38m 2.5” Nylon	1m
MK Riser	1m	26.8m 2.5” Nylon	4.5m
MK Hawser	1m	38m 2.5” Nylon	1m

* Whitehill lines

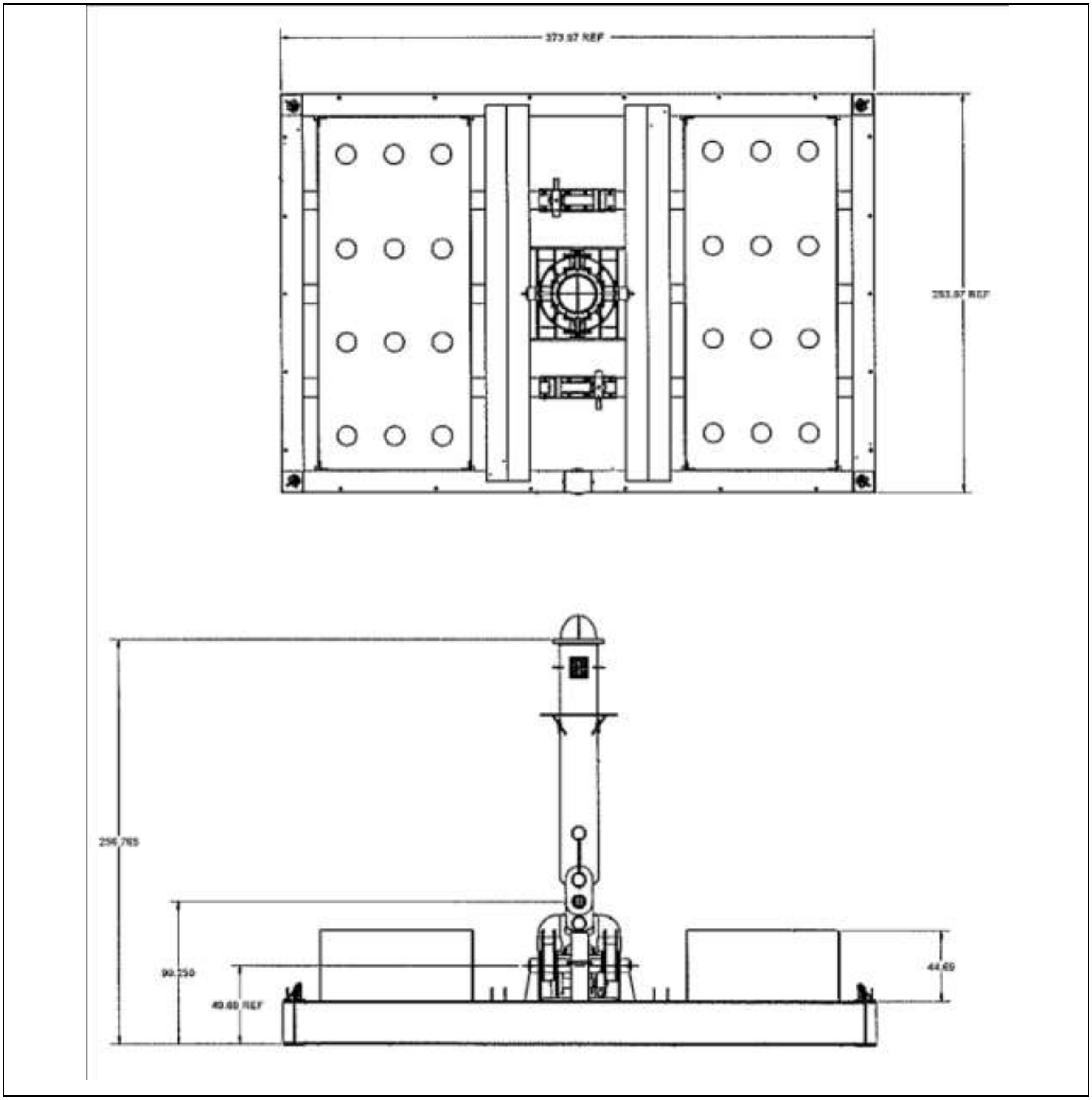


Figure A-1. Existing Anchor AB

APPENDIX B - MOORING DRAWINGS

Appendix E – NREL cRIO Documentation

NREL Test Plan for the WET - NZ Wave Energy Converter Test at the Wave Energy Test Center in Kaneohe Bay, Hawaii

DISTRIBUTION

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VERSION

Date	Version	Name	Comments
03/27/2013	1.0	AAH	Draft

1 Introduction

Northwest Energy Innovations (NWEI), Naval Facilities Command (NAVFAC), University of Hawaii's Hawaii National Marine Renewable Energy Canter (NNMREC) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) have partnered to deploy and test the ½ scale WET-NZ wave energy converter at the Wave Energy Test Site (WETS) at Kaneohe Bay, Hawaii. The proposed project involves deploying the WET-NZ device with the NREL MOISyt instrumentation system in an open-water setting to characterize the performance in a grid setting. The purpose of the WET-NZ project is to deploy an innovative marine hydrokinetic device, collect data for performance validation, and collect data for model validation. Additional benefits of testing the WET-NZ device include using the data and experiences to information IEC device design and testing standards and for the development of a robust and flexible data acquisition system.

WETS is located at the Kaneohe Marine Corps Base Hawai'i on the northeast cost of the island of O'ahu. The site is in water depth of about 30 m with exposure to unobstructed ocean waves. Testing is expected to occur from mid August to September 30, 2012.

The WET-NZ WEC has been tested in New Zealand and Oregon. After each testing deployment the device has been modified for improvement. The overall goal of the project is to deploy the WET-NZ device at WETS for one year and to collect performance and Tier 2 data. The data will be used to validate wave energy converter device design calculations, validate structural and performance models, and improve design and test standards. Over the one year test the instrumentation system will be evaluated so that a comprehensive monitoring system can be developed to support future deployments.

1.1 Objectives

- Demonstrate the operation and performance of the WET-NZ WEC
- Collect data to characterize the performance of the WET-NZ WEC using the NREL MOISyt instrumentation

1.2 Role and Responsibilities

NWEI will provide the WET-NZ WEC and be responsible for WEC deployment, operation, and monitoring of system health and performance including the power, hydraulic and system health, along with float location and draft.

Electro Hydraulic Limited and Sea Engineering will provide assistance to NWEI including WEC modifications and deployment.

NREL will provide the MOISyt instrumentation that includes a bottom node. NREL will be responsible for developing, installing and operating MOISyt and collecting data. Measurements will include WEC motion, mooring loads, water velocity profile and directional wave spectra.

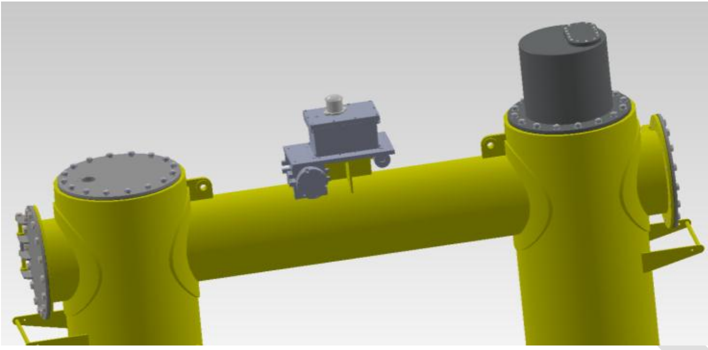
1.2.1 Roles of Personnel

Person	Organization	Responsibility
Justin Klure Steve Kopf	NWEI, Northwest Energy Innovations	Overall project management Logistics and schedules
Derrick Shotbolt	EHL, Electro Hydraulic Limited	Modifications to the WET-NZ WEC
	Sea Engineering	Deployment of the WET-NZ WEC
Arlinda Huskey	NREL, National Renewable Energy Laboratory	NREL project management and operations
Eric Nelson	NREL, National Renewable Energy Laboratory	Design, configuration and operation of MOISyt
Alex Devisser	NAVFAC, Naval Facilities Command	WETS Permitting

Luis Vega	HNMREC, Hawaii National Marine Renewable Energy Center	WET-NZ WEC inspections during testing

2 Description of Test Article and Site

The overall at sea testing consists of the WET-NZ WEC and the MOISyt instrumentation system. The WEC is connected by an underwater cable with transmits the power produced by the WEC to shore. MOISyt is mounted to the top of the WEC and directly interfaces with the WET-NZ.



2.1 WET-NZ WEC

The WET-NZ is a point absorber wave energy conversion buoy that is designed to harness both kinetic and potential energy from passing waves. The buoy consists of a long narrow main structure that supports a rotary float. When operating, the structure is vertically oriented with most of its length submerged. The rotary float is held near the surface. A hydraulic PTO connected to an electrical generator is used to harness the relative motion between the float and the main structure. The WET-NZ DAS consists of 2 fully redundant data acquisition systems with internal storage and that utilize cellular networks for communication with shore. These systems are used to measure the power output, the float position, the health of the PTO hydraulics, generator RPM and temperature, and the voltage of the battery banks. One of WET-NZ's DASs is connected to MOISt. The WET-NZ device will have a three-point mooring system. For this test, a ½ scale device will be used with the following characteristics:

Dimensions (feet)	13.8' (length) x 10.7 '(width) x 61.6' (height)
Height Above the Mean High Water Line (feet)	15'
wet mass of hull	110,231 lbs. (50 tons)
wet mass of float	8,818 pounds (4 tons)
Displacement Volume (%)	Hull: 95% Float: 50

2.2 MOISyt

The NREL system is called the modular offshore instrumentation system (MOISyt) and uses the LabVIEW cRIO hardware and software for this deployment. The current configuration provides measurements that compliment the measurements of WET-NZ with little overlap. MOISyt consists of two separate systems, a buoy mounted module for measuring motion and loads and a bottom module for measuring waves, currents and water properties. Through a feed from the WET-NZ SCADA systems, MOISyt is able to record power, float position and hydrostatic pressure at two points along the hull.

2.2.1 WET-NZ Mounted Module

The buoy mounted module consists of a 4 slot cRIO chassis mounted inside a self contained pressure vessel. Data is stored both onboard the cRIO on a memory stick and transmitted back to shore via a 4G/3G cell modem. The MOISyt software is also able to be reconfigured using the cell modem. Direct measurements include the 6 DOF motion of the platform, platform heading and geodetic position, and tension in 2 mooring lines

2.2.2 MOISyt Bottom Node

The bottom module will be deployed at a depth of about 30 m and consists of an AWAC, CT (conductivity and temperature) sensor and a battery can mounted on a sea-spider tri-pod. The AWAC measures the water velocity profile, directional wave spectra and time series of sea surface height and ambient pressure. The AWAC also interfaces with the CT sensors and stored the combined AWAC and CT data stream internally. The sea-spider also has two acoustically actuated pop-up buoys for recovery.

Dimensions (feet)	Triangular, 3 ft radius from center
Height Above the Mean High Water Line (feet)	N/A – completely submerged
Wet mass of buoy	TBD
Displacement Volume (%)	TBD

2.3 Test Site

The project site is located at the Wave Energy Test Site at the Marine Corps Base Hawaii (MCBH) in Kaneohe Bay. MCBH is located on the east coast of Oahu. The base is located on the windward side of Oahu approximately 12 miles northeast of Honolulu and occupies the Mokapu Peninsula. The test site is approximately 1200 m from the shore. The water depth is approximately 30 meters; exposure to unobstructed ocean waves with high energy resources; comparatively low levels of marine traffic but highly visible to marine navigation. The power generated by the WET-NZ WEC would be transmitted to shore via an armoured and shielded undersea power cable connected to a land transmission cable and routed to the existing MCBH Kaneohe Bay electrical grid system.

The general Hawaiian wave climate can be described by four primary wave types: northeast tradewind waves, North Pacific swell, south swell and Kona storm waves. The project area is sheltered from south swell and Kona storm waves by the island of Oahu itself.

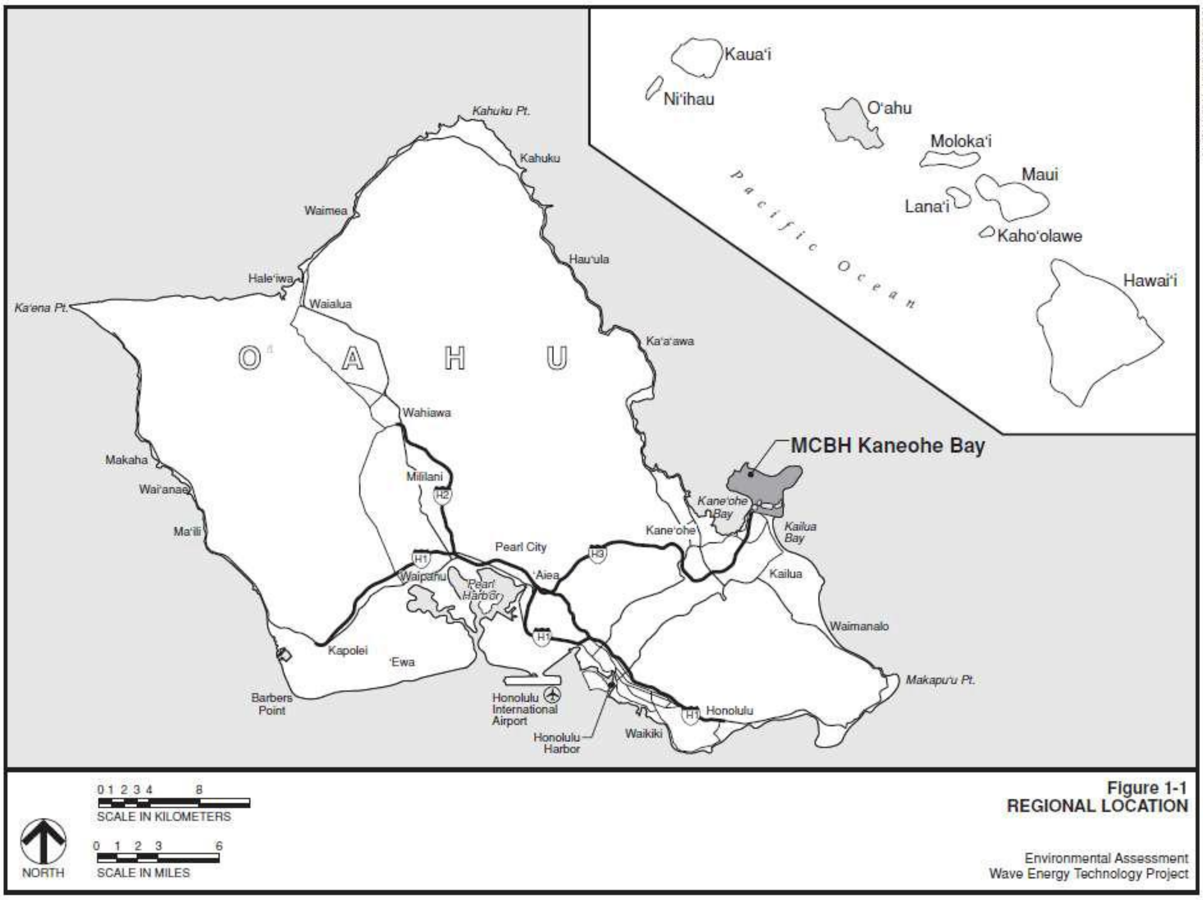


Figure 1-1
REGIONAL LOCATION

Environmental Assessment
Wave Energy Technology Project

3 Test Instrumentation and Readiness Verification

The data channels that will be collected by MOISyt are listed in the table below. The channel list includes most of the Tier 2 requirements.

Measurements Overview	Sampling rate Hz	Instrument	Location
Tier 1			
***Device Motion**			
Geodetic position (GPS)	1	GPS	Device, Navigation light mount
Heading	10	GPS	Device, Navigation light mount
Altitude above bottom	1	Altimeter	Device, Bottom of hull
Waterline	1	Derived channel	
***Device PTO - Drivetrain**			
Internal temperature	1	WET-NZ	Device, internal
Cycles	10	WET-NZ	Device, internal
Float Angle	10	WET-NZ	Device, internal
***System Health**			
Internal temperature	1	WET-NZ	Device, internal
***Device performance monitoring**			
Voltage	10	WET-NZ	Device, internal
Current	10	WET-NZ	Device, internal
***Device General**			
Fault status		WET-NZ, derived	
Tier 2			
***Device Motion**			
6 Degrees of Freedom - surge, sway, heave, roll, pitch, yaw and derivatives	10	Motion Reference Unit DMS-05	Device, Navigation light mount
***Device PTO - Drivetrain**			

Float shaft torque (added during modelling discussion)	10	WET-NZ, derived from hydraulic piston pressure	
***Device PTO - Generator**			
Generator temperature	1	WET-NZ	
Linear or rotational velocity	10	WET-NZ, derived	
***Device primary structure**			
Linear vibration/acceleration	10	Accelerometer	Device, MOIS enclosure mount
Loads (strain at single location, 2 gages)	10	Strain gage	TBD
***Device mooring**			
Line tension	10	Load cell	Device, at mooring line attachment
***Device/grid power quality**			
Device voltage	RMS	WET-NZ	Internal device, generator side
Device current	RMS		
Grid voltage - if applicable	1	From SEL meter	Data room (bunker)
Grid current - if applicable	1	From SEL meter	
***Video**			
Surface video	N/A	Security cam /w zoom	NAVFAC camera onshore on bunker
***Metocean measurements: Sea surface**			
Wave time histories (near device)	Spectra every 20 min	Wave rider and AWAC (redundant)	Buoy within 0.5mi of device and t-pod
Directional wave spectra	Spectra every 20 min	Wave rider and AWAC (redundant)	Buoy within 0.5mi of device and t-pod
Water depth	Once per 10 min	Wave rider and AWAC (redundant)	Buoy within 0.5mi of device and t-pod
***Metocean measurements: In-Flow**			
Current velocity profile	Once per 10 min	AWAC	Subsea, t-pod
***Metocean measurements: Water**			

Properties			
Temperature	Once per 10 min	AWAC	Subsea, t-pod
Salinity (conductivity)	Once per 10 min	AWAC	Subsea, t-pod

3.1 In-lab System Readiness Verification

Prior to shipping MOISyt to the test site system readiness verification will be conducted. Each channel on the system will be connected to the actual instrument or a proxy signal will be sent to verify functionality of the system and to verify data is being collected. MOISyt will operate in this state for at least a week to verify the software and hardware continue to operate without error.

3.2 Onsite System Readiness Verification

After shipping and installing on the WET-NZ WEC, another system readiness verification will be conducted but for a shorter duration of time to verify functionality of the system after shipping. Each channel on the system will be connected to the instrument or a proxy signal will be sent to verify functionality. In addition it will be verified MOISyt is sending data and the data is being received.

3.3 Measurements

The following measurements will be collected.

3.3.1 Met-ocean Measurements

Met-ocean parameters that affect the performance and response of the WET-NZ buoy will be simultaneous measured and these include the following per IEC 62600-100 TS:

- Spectral shape
- Directionality of waves
- Directional frequency spectrum
- Water depth including tidal effect.
- Tidal and Marine current, direction and velocity

HNMREC will measure the meteorological conditions. NREL will measure the wave parameters, current speed and direction and water properties from its bottom node.

3.3.2 Power Performance

The order and length of each test is dependent on wave conditions. It is required to cycle through all load cases and capture sufficient data (approximately one hour or longer for each load case) for each range of wave conditions.

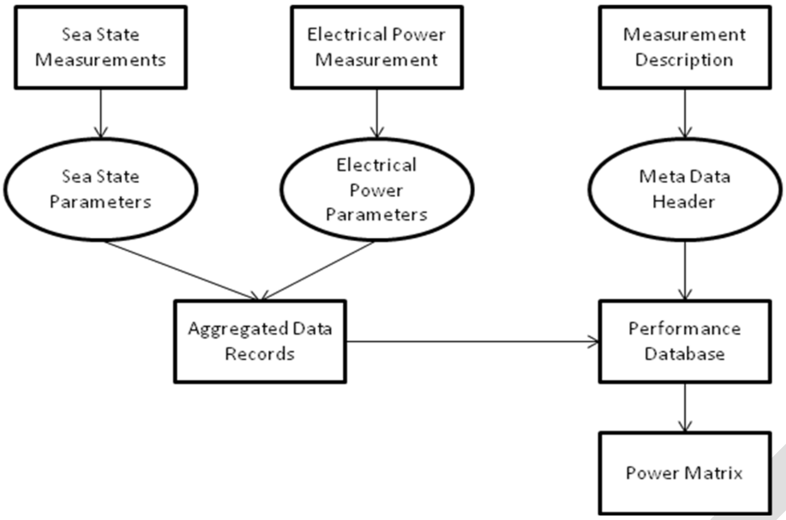


Figure 1. Data Flow Diagram per IEC 62600-100/DTS Power performance assessment of electricity producing wave energy converters

For each of the range of conditions below, the WEC load will be set to each of four nominal states: 2, 4, 8, 16 ohms per phase (wye connected).

Tests 2.1 Log data for three Hs conditions: (0.5m<low<1.5m), (1.5m<medium<2.5m), (2.5m<large), ie in all 12 tests of minimum 1 hour duration each.

Tests 2.2 If possible under the available wave conditions, additional tests with different average periods should be undertaken so that a range of periods are also covered: (short<7s), (7s<medium<10s), (10s<long) will be undertaken ie potentially an additional 24 tests.

Tests 2.1 and 2.2 will be used to populate the power matrix below

Significant Wave Height	Energy Period		
	Short < 7s	7s < medium < 10s	10s < long
0.5m < low < 1.5m			
1.5m < medium < 2.5m			
2.5m < large			

3.3.3 System Stability and Seakeeping

In parallel to the power performance testing, the motions of the WET-NZ buoy will be measured to determine the response of the platform to waves, currents and wind. In this case, all testing will be passive – the buoy will not be loaded, actuated or disturbed. The goal is to characterize the buoy response in a range metocean conditions to develop RAOs and data sets to validate computer models. The following motion data will be collected for the WET-NZ buoy:

- Position (latitude and longitude)
- Heading
- Translational motion (surge, sway and heave – and their derivatives)
- Rotational motion (roll, pitch, yaw and their derivatives)
- Draft (via the hull mounted pressure sensors)

4 Schedule

Date	Event	Duration	Location
Mid-April	Meeting of partners	2-3 days	Test site in Hawaii

	Definition of roles and responsibilities		
Late April	Finalize channel list	1 week	NREL
Late April	Order hardware	2 weeks	NREL
May/June	Finalize software	2 weeks	NREL
July	Construct system	1 month	NREL
July	In-lab readiness verification	2 weeks	NREL
August	Ship to test site	2 weeks	NREL
August	Install on WET-NZ WEC	2 weeks	Hawaii
September	Onsite readiness verification	1 week	Hawaii
September/October	Deployment	1 week	Hawaii
October	Data collection	1 year	Hawaii

Appendix F – MSDS Hydraulic Oil

Safety Data Sheet

TOTAL

Section 1 - Identification of The Material and Supplier

Product Name:	**Elfolna DS 46**
Product Code:	GCL
Product Use:	Hydraulic oil.
Supplier:	**Total Oil Australia Pty Ltd (ABN 15 149 501 922)** **Suite 2, 415 Riversdale Road, Hawthorn East** **Victoria 3123** **AUSTRALIA** **Phone: +61 (03)9861 8600** **Fax: +61 (03) 9882 0447**
EMERGENCY TELEPHONE NUMBER:	**1800 033 111 (Australia), 0800 734 607 (New Zealand)**
Chemical nature:	Product containing mineral oil with less than 3% DMSO extract as measured by IP 346.
Creation Date:	**July, 2011**
This version issued:	**June, 2012** and is valid for 5 years from this date.

Section 2 - Hazards Identification

Statement of Hazardous Nature

This product is classified as: Not classified as hazardous according to the criteria of SWA.

Not a Dangerous Good according to the Australian Dangerous Goods (ADG) Code.

Risk Phrases: Not Hazardous - No criteria found.
Safety Phrases: S23, S24/25. Do not breathe mists. Avoid contact with skin and eyes.
SUSMP Classification: None allocated.
ADG Classification: None allocated. Not a Dangerous Good under the ADG Code.
UN Number: None allocated

Emergency Overview

Physical Description & Colour: Yellow coloured liquid.
Odour: Characteristic odour.
Major Health Hazards: no significant risk factors have been found for this product.

Potential Health Effects

Inhalation:

Short Term Exposure: Available data indicates that this product is not harmful. In addition product is unlikely to cause any discomfort or irritation. Inhalation of high concentration of aerosols may cause mild irritation of the throat.
Long Term Exposure: No data for health effects associated with long term inhalation.

Skin Contact:

Short Term Exposure: Available data indicates that this product is not harmful. It should present no hazards in normal use. In addition product is unlikely to cause any discomfort in normal use.
Long Term Exposure: oil blisters may develop following prolonged and repeated exposure through contact with stained clothing.

Eye Contact:

Short Term Exposure: This product may be mildly irritating to eyes, but is unlikely to cause anything more than mild discomfort which should disappear once product is removed.
Long Term Exposure: No data for health effects associated with long term eye exposure.

Ingestion:

Short Term Exposure: Significant oral exposure is considered to be unlikely. However, this product may be irritating to mucous membranes but is unlikely to cause anything more than transient discomfort.
Long Term Exposure: No data for health effects associated with long term ingestion.

Carcinogen Status:

SWA: No significant ingredient is classified as carcinogenic by SWA.
NTP: No significant ingredient is classified as carcinogenic by NTP.
IARC: No significant ingredient is classified as carcinogenic by IARC.

Section 3 - Composition/Information on Ingredients

Ingredients	CAS No	Conc,%	TWA (mg/m^3)	STEL (mg/m^3)
Oil, mineral	8012-95-1	>90	5 (mist)	not set
Zinc alkyl di thiophosphate	68649-42-3	<0.52	not set	not set
Aryl phenol		<0.17	not set	not set

This is a commercial product whose exact ratio of components may vary slightly. Minor quantities of other non hazardous ingredients are also possible.

The SWA TWA exposure value is the average airborne concentration of a particular substance when calculated over a normal 8 hour working day for a 5 day working week. The STEL (Short Term Exposure Limit) is an exposure value that may be equalled (but should not be exceeded) for no longer than 15 minutes and should not be repeated more than 4 times per day. There should be at least 60 minutes between successive exposures at the STEL. The term "peak "is used when the TWA limit, because of the rapid action of the substance, should never be exceeded, even briefly.

Section 4 - First Aid Measures

General Information:

You should call The Poisons Information Centre if you feel that you may have been poisoned, burned or irritated by this product. The number is 13 1126 from anywhere in Australia (0800 764 766 in New Zealand) and is available at all times. Have this MSDS with you when you call.

Inhalation: First aid is not generally required. If in doubt, contact a Poisons Information Centre or a doctor.
Skin Contact: Gently blot away excess liquid. Irritation is unlikely. However, if irritation does occur, flush with lukewarm, gently flowing water for 5 minutes or until chemical is removed.
Eye Contact: Quickly and gently blot material from eyes. No effects expected. If irritation does occur, flush contaminated eye(s) with lukewarm, gently flowing water for 5 minutes or until the product is removed. Obtain medical advice if irritation becomes painful or lasts more than a few minutes. Take special care if exposed person is wearing contact lenses.
Ingestion: If product is swallowed or gets in mouth, do NOT induce vomiting; wash mouth with water and give some water to drink. If symptoms develop, or if in doubt contact a Poisons Information Centre or a doctor.

Section 5 - Fire Fighting Measures

Fire and Explosion Hazards: The major hazard in fires is usually inhalation of heated and toxic or oxygen deficient (or both), fire gases. This product is classified as a C2 combustible product. There is no risk of an explosion from this product under normal circumstances if it is involved in a fire. Violent steam generation or eruption may occur upon application of direct water stream on hot liquids. Vapours from this product are heavier than air and may accumulate in sumps, pits and other low-lying spaces, forming potentially explosive mixtures. They may also flash back considerable distances.
Fire decomposition products from this product are likely to be irritating if inhaled.
Extinguishing Media: Suitable extinguishing media are carbon dioxide, dry chemical, foam, water fog.
Fire Fighting: If a significant quantity of this product is involved in a fire, call the fire brigade.

Flash point:	>200°C, Cleveland open cup.
Upper Flammability Limit:	No data.
Lower Flammability Limit:	No data.
Autoignition temperature:	No data.
Flammability Class:	C2

Section 6 - Accidental Release Measures

Accidental release: Minor spills do not normally need any special cleanup measures. In the event of a major spill, prevent spillage from entering drains or water courses. As a minimum, wear overalls, goggles and gloves. Suitable materials for protective clothing include nitrile, neoprene. Eye/face protective equipment should comprise as a minimum, protective glasses and, preferably, goggles. If there is a significant chance that vapours or mists are likely to build up in the cleanup area, we recommend that you use a respirator. Usually, no respirator is necessary when using this product. However, if you have any doubts consult the Australian Standard mentioned below (section 8). Stop leak if safe to do so, and contain spill. Absorb onto sand, vermiculite or other suitable absorbent material. If spill is too large or if absorbent material is not available, try to create a dike to stop material spreading or going into drains or waterways. Sweep up and shovel or collect recoverable product into labelled containers for recycling or salvage, and dispose of promptly. Can be slippery on floors, especially when wet. Recycle containers wherever possible after careful cleaning. After spills, wash area preventing runoff from entering drains. If a significant quantity of material enters drains, advise emergency services. This material may be suitable for approved landfill. Ensure legality of disposal by consulting regulations prior to disposal. Thoroughly launder protective clothing before storage or re-use. Advise laundry of nature of contamination when sending contaminated clothing to laundry.

Section 7 - Handling and Storage

Handling: Keep exposure to this product to a minimum, and minimise the quantities kept in work areas. Check Section 8 of this MSDS for details of personal protective measures, and make sure that those measures are followed. The measures detailed below under "Storage" should be followed during handling in order to minimise risks to persons using the product in the workplace. Also, avoid contact or contamination of product with incompatible materials listed in Section 10.

Storage: Note that this product is combustible and therefore, for Storage, meets the definition of Dangerous Goods in some states. If you store large quantities (tonnes) of such products, we suggest that you consult your state's Dangerous Goods authority in order to clarify your obligations regarding their storage.

Store packages of this product in a cool place. Make sure that containers of this product are kept tightly closed. Keep containers dry and away from water. Make sure that the product does not come into contact with substances listed under "Incompatibilities" in Section 10. Some liquid preparations settle or separate on standing and may require stirring before use. Check packaging - there may be further storage instructions on the label.

Section 8 - Exposure Controls and Personal Protection

The following Australian Standards will provide general advice regarding safety clothing and equipment:

Respiratory equipment: **AS/NZS 1715**, Protective Gloves: **AS 2161**, Occupational Protective Clothing: AS/NZS 4501 set 2008, Industrial Eye Protection: **AS1336** and **AS/NZS 1337**, Occupational Protective Footwear: **AS/NZS2210**.

SWA Exposure Limits	TWA (mg/m^3)	STEL (mg/m^3)
Oil, mineral	5 (mist)	not set

No special equipment is usually needed when occasionally handling small quantities. The following instructions are for bulk handling or where regular exposure in an occupational setting occurs without proper containment systems.

Ventilation: This product should only be used in a well ventilated area. If natural ventilation is inadequate, use of a fan is suggested.

Eye Protection: Eye protection is not normally necessary when this product is being used. However, if in doubt, wear suitable protective glasses or goggles.

Skin Protection: The information at hand indicates that this product is not harmful and that normally no special skin protection is necessary. However, we suggest that you routinely avoid contact with all chemical products and that you wear suitable gloves (preferably elbow-length) when skin contact is likely.

Protective Material Types: We suggest that protective clothing be made from the following materials: nitrile, neoprene.

Respirator: Usually, no respirator is necessary when using this product. However, if you have any doubts consult the Australian Standard mentioned above.

Section 9 - Physical and Chemical Properties:

Physical Description & colour:	Yellow coloured liquid.
Odour:	Characteristic odour.
Boiling Point:	Not available.
Freezing/Melting Point:	No specific data. Liquid at normal temperatures.
Volatiles:	Nil at 100°C.
Vapour Pressure:	Nil at normal ambient temperatures.
Vapour Density:	No data.
Specific Gravity:	0.880 at 15°C (ASTM D 1298)
Water Solubility:	Insoluble.
pH:	No data.
Volatility:	Nil at normal ambient temperatures.
Odour Threshold:	No data.
Evaporation Rate:	No data.

Coeff Oil/water Distribution:	No data.
Viscosity:	Kinematic viscosity at 40°C: about 46 mm^2/s (ISO 3104)
Autoignition temp:	No data.

Section 10 - Stability and Reactivity

Reactivity: This product is unlikely to react or decompose under normal storage conditions. However, if you have any doubts, contact the supplier for advice on shelf life properties.
Conditions to Avoid: This product should be kept in a cool place, preferably below 30°C. Keep containers tightly closed. Containers should be kept dry.
Incompatibilities: strong oxidising agents.
Fire Decomposition: Combustion forms carbon dioxide, and if incomplete, carbon monoxide, various hydrocarbons, aldehydes and smoke. Water is also formed. Small quantities of oxides of nitrogen, sulfur, zinc and phosphorus. Carbon monoxide poisoning produces headache, weakness, nausea, dizziness, confusion, dimness of vision, disturbance of judgment, and unconsciousness followed by coma and death.
Polymerisation: This product will not undergo polymerisation reactions.

Section 11 - Toxicological Information

Local Effects:
Target Organs: There is no data to hand indicating any particular target organs.

- **Skin contact:** Characteristic skin lesions (pimples) may develop following prolonged and repeated exposure through contact with contaminated clothing.
- **Sensitization:** Not classified as a sensitiser.
- **Carcinogenicity:** Not classified as a carcinogen.
- **Mutagenicity:** Not classified as a mutagen.

Used motor oils have been shown to cause skin cancer in mice following repeated application and continuous exposure. Brief or intermittent skin contact with used oil is not expected to have serious effects in human if the oil is thoroughly removed by washing with soap and water.

Classification of Hazardous Ingredients

Ingredient	Risk Phrases

No ingredient mentioned in the HSIS Database is present in this product at hazardous concentrations.

Section 12 - Ecological Information

Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment. This product is unlikely to be mobile in soils.
Experimental data on the finished product are not available. No information available for used product, however it is considered to present low danger for aquatic life.
Mobility:

- There is a slow loss by evaporation in air.
- Given its physical and chemical characteristics, the product generally shows low soil mobility.
- The product is insoluble; it spreads on the surface of water.

Zinc alkyl dithiophosphate

EC_{50} *Daphnia magna* (48h) 1 - 1.5 mg/L
LC_{50} *Pimephales promelas* (static) (96h) 1.0-5.0 mg/L
LC_{50} *Pimephales promelas* (semi-static) (96h) 10.0-35.0 mg/L

Section 13 - Disposal Considerations

Disposal: This product may be recycled if unused, or if it has not been contaminated so as to make it unsuitable for its intended use. If it has been contaminated, it may be possible to reclaim the product by filtration, distillation or some other means. If neither of these options is suitable, consider controlled incineration, or landfill.

Section 14 - Transport Information

ADG Code: This product is not classified as a Dangerous Good. No special transport conditions are necessary unless required by other regulations.

Section 15 - Regulatory Information

AICS: All of the significant ingredients in this formulation are compliant with NICNAS regulations.

Section 16 - Other Information

This MSDS contains only safety-related information. For other data see product literature.

Acronyms:

ADG Code	Australian Code for the Transport of Dangerous Goods by Road and Rail (7th edition)
AICS	Australian Inventory of Chemical Substances
SWA	Safe Work Australia, formerly ASCC and NOHSC
CAS number	Chemical Abstracts Service Registry Number
Hazchem Code	Emergency action code of numbers and letters that provide information to emergency services especially firefighters
IARC	International Agency for Research on Cancer
NOS	Not otherwise specified
NTP	National Toxicology Program (USA)
R-Phrase	Risk Phrase
SUSMP	Standard for the Uniform Scheduling of Medicines & Poisons
UN Number	United Nations Number

THIS MSDS SUMMARISES OUR BEST KNOWLEDGE OF THE HEALTH AND SAFETY HAZARD INFORMATION OF THE PRODUCT AND HOW TO SAFELY HANDLE AND USE THE PRODUCT IN THE WORKPLACE. EACH USER MUST REVIEW THIS MSDS IN THE CONTEXT OF HOW THE PRODUCT WILL BE HANDLED AND USED IN THE WORKPLACE.

IF CLARIFICATION OR FURTHER INFORMATION IS NEEDED TO ENSURE THAT AN APPROPRIATE RISK ASSESSMENT CAN BE MADE, THE USER SHOULD CONTACT THIS COMPANY SO WE CAN ATTEMPT TO OBTAIN ADDITIONAL INFORMATION FROM OUR SUPPLIERS

OUR RESPONSIBILITY FOR PRODUCTS SOLD IS SUBJECT TO OUR STANDARD TERMS AND CONDITIONS, A COPY OF WHICH IS SENT TO OUR CUSTOMERS AND IS ALSO AVAILABLE ON REQUEST.

Please read all labels carefully before using product.

This MSDS is prepared in accord with the SWA document "National Code of Practice for the Preparation of Material Safety Data Sheets" 2nd Edition [NOHSC:2011(2003)]

http://www.kilford.com.au/ Phone (02)9251 4532

Appendix G – Channel List for NWEI Offshore cRIO DAS

Channel List for Onboard Red DAS 6/26/2013

Channel	Measurement	Raw Unit	Offset	Gain	Physical Unit	Sensor
ADC01	Float Angle 1	4-20mA	9.45	21.815	Deg	
ADC02	Water Depth 1	4-20mA	4	4.2868	m	
ADC03	Gen Line Voltage Red A	0-30V	-0.016	34.6	Vrms	IRL VT and CT transducers. Custom PCB. See IRL drawing WED0020-411.
ADC04	Gen Line Voltage Red B	0-30V	-0.016	34.6	Vrms	
ADC05	Gen Line Voltage Red C	0-30V	-0.016	34.6	Vrms	
ADC06	Gen Current Red A	0-30V	0.002	8.342	Irms	
ADC07	Gen Current Red B	0-30V	0.002	8.342	Irms	
ADC08	Gen Current Red C	0-30V	0.002	8.342	Irms	
ADC09	Motor RPM	RPM	0	1	RPM	
ADC10	Gen Side Cyl(Closed)	4-20mA	4	21.56	bar	
ADC11	Gen Side Cyl(Rod)	4-20mA	4	21.56	bar	
ADC12	Motor Inlet	4-20mA	4	21.56	bar	
ADC13	Motor Outlet	4-20mA	4	21.56	bar	
ADC14	Gen Temp	mA	Non-linear (see note)	Non-linear	degC	
ADC15	Red Main Battery	0-30V	0	1	V	Direct V input
ADC16	Red Backup Battery	0-30V	0	1	V	Direct V input

Measurement = gain × (ADC reading – offset)

degC = 7.55e-5 mA5 - 0.0063 mA4 + 0.1979 mA3 - 2.9292 mA2 + 23.921 mA - 1.9795

Channel List for Onboard Blue DAS 6/26/2013

Channel	Measurement	Raw Unit	Offset	Gain	Physical Unit	Sensor
ADC01	Float Angle 2	4-20mA	9.45	21.815	Deg	
ADC02	Water Depth 2	4-20mA	4	4.2868	m	
ADC03	Gen Line Voltage Blue A	0-30V	-0.016	34.6	Vrms	IRL VT and CT transducers. Custom PCB. See IRL drawing WED0020-411.
ADC04	Gen Line Voltage Blue B	0-30V	-0.016	34.6	Vrms	
ADC05	Gen Line Voltage Blue C	0-30V	-0.016	34.6	Vrms	
ADC06	Gen Current Blue A	0-30V	0.002	8.342	Irms	
ADC07	Gen Current Blue B	0-30V	0.002	8.342	Irms	
ADC08	Gen Current Blue C	0-30V	0.002	8.342	Irms	
ADC09	Hyd tank level					
ADC10	Filter side extension	4-20mA	4	21.56	bar	
ADC11	Filter side retraction	4-20mA	4	21.56	bar	
ADC12	TTP pressure	4-20mA	4	21.56	bar	
ADC13	TP1 pressure	4-20mA	4	21.56	bar	
ADC14	Hyd tank temp					
ADC15	Blue Main Battery	0-30V	0	1	V	Direct V input
ADC16	Blue Backup Battery	0-30V	0	1	V	Direct V input

Measurement = gain × (ADC reading – offset)