CWPT Open Water Demonstration

DE-EE0008097.0000
Budget Period 2

Task 5.4 Comprehensive IO&M and Testing Plan

Comprehensive Installation, Operation, and Maintenance Plan

Version 5.3 - May 2020

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FURTHER CONVENTIONS

CalWave is using the following convention for the positioning and orientation of the global coordinate system. This convention is equal to the most common convention used in Naval Architecture and specifically in wave energy conversion related research & development:

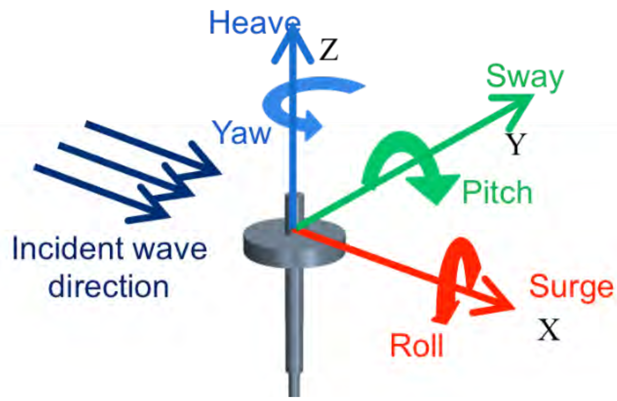


Figure 1: Global Coordinate System Position and Orientation used throughout this report. Picture / Scheme by WECSim - Theory section (https://wec-sim.github.io/WEC-Sim/theory.html)

Note on units:

Metric units have been maintained as standard for design purposes. However, many suppliers that were collaborated with in the process of the design and development of relevant systems work primarily in imperial units and therefore both sets of units appear throughout this document, largely depending on which suppliers were prominently involved in supporting the design evolution of various components. The term ‘ton’ in this document refers exclusively to U.S. tons. Metric tons are referred to as ‘MT’.

1 INTRODUCTION

The objective of the project is to advance the Technology Readiness Level (TRL) of the Wave Energy Converter (WEC) developed by CalWave Wave Power Technologies Inc (CalWave) through advanced numerical simulations, dynamic hardware tests, and ultimately a scaled open water demonstration deployment while continuing to exceed DOE's target ACE threshold of 3m/M$. The outcomes of Budget Period 1 were a detailed design of the scaled demonstration unit and bench testing of the critical hardware components. In Budget Period 2, the key outcomes are the deployment and operation of the demonstration unit at an open water site which replicates full scale ocean conditions, and performance and load measurements will be used to validate the high techno-economic performance (ACE) of the device full scale device, as measured by the "Average Climate Capture Width per Characteristic Capital Cost" (ACE) metric defined for the Wave Energy Prize.

This report focuses on the Installation and Operations Planning for the open water demonstration to be conducted in collaboration with University of California, San Diego (UCSD) near the Scripps Institute of Oceanography (SIO) pier, in a water depth of approximately 70 ft (21.3 m).

All operations are being coordinated with University of California, San Diego (UCSD) Scripps Institute of Oceanography (SIO) staff as well as local vessel operators and marine operations contractors. Several potential vessels have been identified for use during different aspects of the CalWave technology deployment and test period.

The details outlined in these procedures are contingent upon several factors, such as operation conditions, vessel ability, safety, efficiency, etc. Due to these factors, this plan is subject to change. Adjustments to sequences for the preset installation and connection can be made in the field with the use of Management of Change (MOC) process. The respective management personnel must be contacted and contribute to determining a safe and effective method of performing operations. The current and weather conditions must be deemed favorable before starting operations.

Before the start of any operations, all vessels and individuals involved will hold operational procedure review and safety meetings to prepare for upcoming operations. All equipment will be checked at this time and the equipment will be verified for availability for upcoming operations. Additionally, Hazard Identification (HAZID) reviews will be conducted with relevant parties well in advance of any planned operation, in order to provide adequate time to address any raised concerns.

The vessel captain and CalWave representatives will approve deviations that become unavoidable in the field during the installation process. VHF working channels will be identified at this time.

This document comprises of the overall methodologies of safe operations offshore, includes vessel specifics, and operations planning for the following planned evolutions:

Table 1: Planned Offshore Operations

Activity	Days
Dive Survey of Anchor Locations	1
CoastScout Deployment	1
Anchor Installation (including pre-dive markings)	2
Umbilical Lay	1
WEC Tow to Site & Deployment	1
WEC Inspections & Planned Maintenance Offshore	8
WEC Recovery & Decommissioning	1
Umbilical Cable & CoastScout Recovery	1
Anchor Recovery & Site Decommissioning	1
Total Planned Operational Days Offshore	17

2 Equipment, Vessels, and Personnel

2.1 Vessels

Table 2: Vessel List

Vessel	Operator	Website	Notes
R/V Beyster	UCSD	https://scripps.ucsd.edu/ships	Primary work vessel
BW1	UCSD	https://www.bostonwhaler.com/family-overview/outrage-boat-models/190-outrage/	Line handling vessel
DB San Diego	Pacific Maritime Group	https://www.pacificmaritimegroup.com/fleets/db-san-diego/	Anchor handling vessel
Coastal Tugs	Pacific Maritime Group	https://www.pacificmaritimegroup.com/fleet_categories/ocean-and-coastal-towing/	Towing and maneuvering of DB San Diego (multiple options)
M/V Cooper	C&W	http://www.cwdiving.com/CWVessels.htm	Backup vessel
Jag	Pacific Maritime Group	https://www.pacificmaritimegroup.com/fleets/jag/	Backup vessel
R/V Sproul	UCSD	https://scripps.ucsd.edu/ships	Backup vessel

2.2 Equipment

CalWave provided equipment vs equipment provided by vessel to be specifically identified in mobilization section of individual operations.

2.3 Personnel

To ensure safe, effective, and efficient operations, the following contact numbers are included for use by personnel connected to the deployment operations. Any external contractors working on-site as part of the CalWave project shall provide staff contact information to be included below.

Table 3: Contact List

CalWave Power Technologies				
Name	**Position**	**Phone**	**Mobile**	**Email**
Marcus Lehman	CEO	***Private information not included in submitted documents***		
Dan Petcovic	COO			
Nigel Kojimoto	Head of Design			
Bryan Murray	Head of Electronics			
Thomas Boerner	Technical PI; Hydrodynamics & Control			
Josiah Clark	Mechanical Engineering			

University of California, San Diego				
Name	**Position**	**Phone**	**Mobile**	**Email**
Christian McDonald	Scientific Diving & Small Boating Safety Officer	***Private information not included in submitted documents***		
Brett Pickering	Assistant Boating Safety Officer			

Pacific Maritime Group		
Bill Harju	VP Special Projects	***Private information not included in submitted documents***
Tom Ebner	Port Captain	
24-hour dispatch		

C&W Dive Services				
Name	**Position**	**Phone**	**Mobile**	**Email**
Elliott West	Commercial divers	***Private information not included in submitted documents***		

3 SAFETY

3.1 GENERAL SAFETY GUIDELINES

These procedures are written in part to provide for a safe and efficient operation. Before operations begin, the vessel operator and CalWave staff will hold a Hazard Identification (HAZID) meeting with to review the entire job, following these step-by-step procedures. As the site owner, UCSD staff will be invited to attend all safety and operational briefing, regardless of the inclusion of UCSD staff or vessels in the operations.

The following safety issues should also be addressed during this safety meeting:

- Hand awareness will be discussed in all pre-job meetings and HAZID reviews/discussions.
- Proper personal protective equipment (PPE) required.
- Unsafe conditions will be reported and will be corrected.
- Employees will identify and correct the unsafe acts of coworkers.
- All incidents, injuries, and illnesses, regardless of how minor, will be reported immediately.
- All employees must be aware of their appropriate muster list assignment.
- All tools must be stored and maintained when not in use.
- Fingers, arms, and legs must be kept clear of all pinch points.
- Proper tag lines will be used to position and control loads.
- Proper lifting techniques must be used when manually moving loads.
- All personnel are required to wear a full body harness any time they are working at height and whenever specified by the vessel captain.
- Good housekeeping increases the safety of any job. Work areas must be kept free of trip, slip, or fall hazards.
- Employees must inspect all lifesaving equipment upon arrival and prior to departure of the vessel. All discrepancies are to be reported to the vessel captain.
- Proper eye protection will be used during welding and cutting operations.
- Lightning and other adverse weather conditions must be taken into consideration, and operations must be suspended when meteorological or sea conditions pose a danger to personnel working aboard vessels.
- Contingency plans of the vessel will be followed to prevent pollution events should a hydraulic hose break or other equipment failures pose a danger to the environment.
- Selected hydraulic fluids selected with due regard to potential leaks and the consequences to the environment.
- Provisions for adequate communication between vessel crews, and pier side staff must be present to ensure coordination of all parties in their assigned duties. One designated radio channel required to be selected and reserved for use by the parties involved in the marine operation.
- Crew fatigue factors must be considered. The crew will be adequately sized to offer ample rest periods on long duration jobs by rotation of crewmembers.
- Consideration of extremely hot or cold weather conditions must be made and crewmembers rotated in work assignments to keep exposure to excess environmental factors within tolerable limits. This is essential in preventing cases of heat exhaustion or hypothermia.
- In the event that variance from these written procedures becomes necessary, all supervisory personnel are to be made aware of the change and be in agreement with the new procedure.

<u>The safety of personnel and the environment are the first considerations during any operation.</u>

3.2 Employee Accountability

Employee acceptance and compliance with company health, safety, and environmental procedures is the key to the success of the overall program. The employee will assume the responsibility to assist in the development of his coworker's positive attitude regarding health, safety, and the environment. Employees must be allowed to freely express their responsibility to suggest improvements, caution coworkers, and interrupt work tasks when conditions pose a health, safety, or environmental threat. The employee will:

- Understand and comply with health, safety, and environmental procedures.
- Be competent to perform assigned tasks in a safe manner.
- Comply with the use of safety equipment.
- Report all unsafe conditions.
- Identify and correct unsafe acts of coworkers.
- Assist in the training of coworkers by being a mentor.
- Report all incidents, injuries, and illnesses.

3.3 Hazard Identification and Operations Briefings

Every operation will be preceded by a formal hazard identification (HAZID) and operations briefing with all parties involved in the operation. Briefing material and operations plans will be circulated with stakeholders prior to briefings. In addition to the HAZID conducted far enough in advance of the operation to allow for any identified hazards to be addressed and operations planning updated; a operations briefing will occur immediately preceding any offshore operation. The following procedure will be followed to ensure a properly conducted operations briefing.

1. Define the task.
    - Define the task to be performed in detail
    - Explain the reason for the task
    - Explain the expected results
    - Explain the consequences of failure
2. Designate resources.
    - Who will be in charge of coordinating the procedure?
    - Designate the other members of the team
    - List the materials or tools that will be needed
    - Determine the methods of communication
3. Lay out the procedure.
    - List the steps to be performed in the order in which they will occur
    - Designate the person in charge of each step
    - Define the timing of the procedure
    - Start time

- Expected duration
- Stop time

4. Analyze the procedure.
   - On a step-by-step basis, identify all known hazards
   - Determine methods to eliminate the hazard
   - Develop procedures to control the hazard
   - Define the risks involved
   - Determine the methods to decrease the risks
   - Ensure all parties are aware of the risks and mitigation procedures
   - If the hazard cannot be eliminated or controlled, change the procedure
   - On a step-by-step basis, determine what can go wrong that may create hazards
   - List the possible hazards that could be created
   - Develop procedures to compensate for mistakes
5. Record any additionally identified hazards and collect signatures documenting that all parties are in agreement conducting safe operations per the discussed plan.
6. Review the with all parties that are involved.
   - Poll the participants to ensure their understanding of the process
   - Have each member explain their duties and responsibilities
   - If possible, take the team to the site and complete a walkthrough
   - Adjust the plan if necessary
7. After-job critique.
   - Did everything match the plan?
   - Were the results expected?
   - What went wrong?
   - What improvements were identified during the PAUSE?
   - Revise the HAZID based on the results

<u>Responsibility</u>

- Supervisory Staff
  - Plan each work task element with consideration of health, safety, and environmental impact factors as an integral part of the process.
  - Issue orders in a clear and concise manner so as to be understood by all affected crewmembers.
  - Orient employees in reference to:
    - Responsibilities and accountabilities
    - The employee’s team
    - Personal protective equipment required
    - Reporting standards
    - General and job specific hazards

        - The work area and potential hazards that exist
    - Assign personnel to a task only for which they are competent.
    - Lead by example.
    - Conduct safety meetings and monitor/critique the review of plans and materials.
    - Report all incidents, near hits, injuries, and illnesses immediately.
    - Communicate hand awareness to all crewmembers.
- Safety/Operations Staff
    - Ultimately responsible for ensuring that all personnel adhere to the plan as detailed in the HAZID. In charge of supplying personnel and resources to successfully and safely complete the job task.
- All Staff Performing Work On-Site
    - Actively participate in briefings development and review discussions. Perform the duties required by the task in a safe manner. Ensure that any changes are communicated to the supervisor. Use Stop Work Authority when any uncontrolled hazard is identified.
    - Recognize the importance of briefly as a serious process to reduce risk and plan Delmar business that requires participation from the whole team. Simply reading of the HAZID prior to the job does not provide the feedback that everyone understands the risks and their role in conducting the task safely.

4 Personnel Responsibilities

CalWave Power Technologies Representative

- Will be the designated operator representative on board the vessel and as such is the sole point of contact through which all project notifications/exterior communications will pass, including daily progress reports.
- Will liaise between contractor and hirer in all matters other than specified below.
- Will be responsible for authorizing commencement of operations following consultation with requisite parties.
- Will perform all operations with regards to controls of the Wave Energy Converter (WEC), including coordination with shore-based staff.
- Provides final approval for any operational or project changes, per MOC procedure, unless safety related and determined by Vessel Captain to be immediate in nature.
- Submit and/or review and approve change requests per MOC procedure.

Vessel Captain

- Will be responsible for the safety of their crew and vessels, and, when towing, for the safety of the equipment under tow.
- Will liaise closely with CalWave representative during project operations to ensure the procedures are followed as closely as circumstance permits.
- Will ensure that the appropriate navigation warnings are issued at regular intervals.
- Will coordinate and be responsible for directing the vessel crew during operations, as agreed with CalWave representative.
- Submit and/or review and approve change requests per MOC procedure.

UCSD Supervisory Staff

- Will be responsible for the safety any UCSD personnel, pier side facilities and maintain supervisory authority over the test site
- Will be informed of all operations, including commencement and completion of all work.
- Will be invited to attend any pre-briefings or other operational meetings for which UCSD staff are not directly involved in.
- Submit and/or review change requests per MOC procedure.

5 TRIGGER POINTS

The following trigger points are to be monitored during the operations. Trigger points are pre-defined points of review for the operation and not a defined condition for cessation of operations. The listed events are not exhaustive, and it is paramount that the STOP WORK OBLIGATION persists in conjunction with trigger points.

- Prevailing Weather
  - Wind speed
  - Sea (swell, current)
  - Visibility
- A reduction, during operations, in the function of the vessel navigation system.
- The experience of periods of onerous current and/or tide stream that impact the vessel's capacity to hold the required position.
- The degradation in the status of critical personnel during the operation due to illness or fatigue.
- Tensions, higher than anticipated, are experienced at the vessel.
- Technical faults with the vessel equipment.

Trigger points are reference aids only in so far as vessel design, operator's boat handling skills and vessel orientation to tide and sea states precludes the establishment of any definitive conditions. Notwithstanding the above, the vessel's Captain can stop the operation at any time.

During operational pre-briefings contingency plans shall be agreed by all parties for best practices related to actions taken in the event of a stop work trigger to ensure safety of crew and equipment.

6 PROJECT LOCATION

6.1 AREA OF OPERATIONS

The specific area for the WEC deployment is approximately 540 meters from the Scripps Institute of Oceanography (SIO) pier, at a heading of 276.9 (SEE), with an average depth of 21.4 meters and a slope of up to 5%. This area, including GPS coordinates for the SIO Pier, the center of the operating area and the four anchor locations are shown below.

Anchor#		Deg	Min	Sec	Depth	
1	N	32	52	3.162	68	ft
	W	117	15	48.054	20.73	m
2	N	32	52	4.008	72	ft
	W	117	15	47.784	21.95	m
3	N	32	52	3.78	71	ft
	W	117	15	46.782	21.64	m
4	N	32	52	2.93	67	ft
	W	117	15	47.052	20.42	m

Figure 2: Deployment Area of Interest

This area has been agreed with the site owner (SIO), all necessary permits for the deployment have been obtained and the site has been surveyed.

6.2 SHORE SIDE MONITORING AND CONTROL STATION

Shore side monitoring and control will occur at the Ellen Browning Scripps Memorial Pier, operated by Scripps Institute of Oceanography (SIO) at the University of California, San Diego (UCSD). For the duration of the test period, CalWave will be entered into a lease agreement with UCSD and have 24-hr access to the pier facilities.

Figure 3: SIO Pier

Figure 4: Instrumentation Shed – outside

Figure 5: Instrumentation Shed - inside

6.3 Transit Routes

The *vessel* will transit to the test site along the proposed transit route as determined by vessel mobilization location and operations being performed. For transit operations involving equipment under tow, contingency planning for towline failure will be included in operational planning and hazard identification, including considerations for spare towline and/or additional line handling vessel.

A list of anticipated transit routes to site is provided below.

Table 4: Anticipated Transit Routes.

Vessel	Route	Distance (nm)
Multiple	1 - SIO pier to Test Site	0.3
Multiple	2 – Driscoll Mission Bay to Test Site	8.9
R/V Beyster	3 - Pont Loma to Test Site	16.5
R/V Beyster	4 – Point Loma to Driscoll Mission Bay	10.1
DB San Diego, Jag, M/V Cooper	5 – National City to Test Site	22.2
DB San Diego, Jag, M/V Cooper	6 – National City to Driscoll Mission Bay	15.8

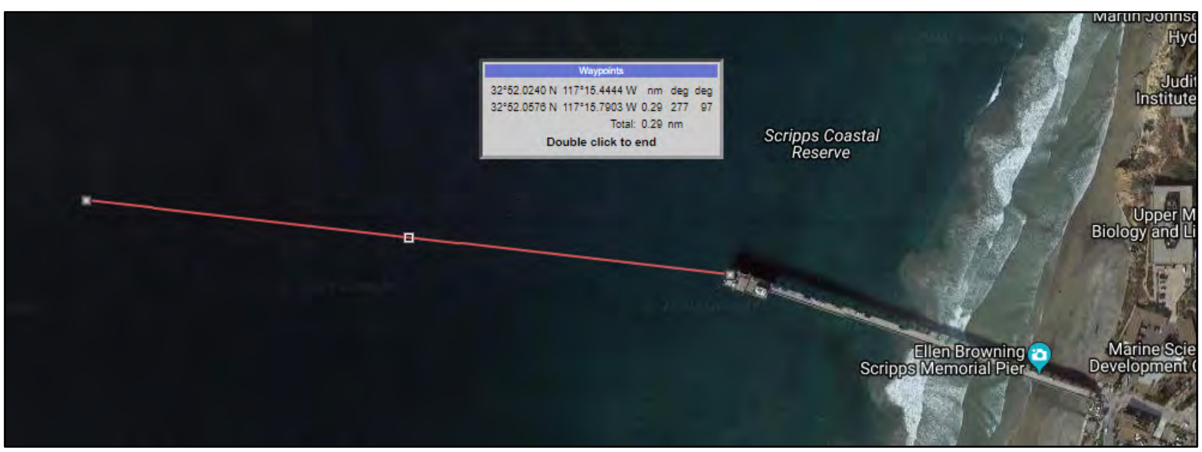


Figure 6: Transit Route 1: SIO Pier to Test Site.

Figure 7: Transit Route 4: Point Loma to Driscoll Mission Bay

Figure 8: Transit Route 5: National City to Test Site

Figure 9: Transit Route 6: National City to Driscoll Mission Bay

6.4 Site Permits

The following site permits have been approved or are in the submission process, a status is included below

Table 5: Site Permits.

Permit	Status	Comment
Landowner Permission	Received	UCSD, SIO
Army Corps of Engineers	Approved, 11/05/2019	SPL-2019-00424-RRS
California Coastal Commission (wavier)	Approved, 09/28/2018	9-18-0933-W
Fish and Wildlife	Approved, 10/04/2018	SC-013978
CA Water Board	Approved, 8/01/2019	R9-2019-0158
NOAA ITA	Not required	NOAA email response 11/13/2018
State Lands Commission	Not required	SLC phone meeting 10/19/2018
DOE Biological Assessment	Complete	NMFS concurrence letter received 5/9/2019
US Coast Guard - PATON	Approved, 02/11/2020	CG-2554 (CoastScout & PATON)

7 DETAILED RESOURCE CHARACTERIZATION

7.1 SITE DESCRIPTION

7.1.1 Existing Support Infrastructure

Scripps Institute of Oceanography is a world leading marine science and engineering institution located on the coast in La Jolla, California, just north of San Diego. Scripps operates many specialized marine science facilities, including Scripps Pier extending 300m into the bight north of Point La Jolla. Scripps Pier hosts several meteorological and oceanographic installations, the most relevant of which are detailed in the Met-Ocean Data section below and called out in Figure 10.

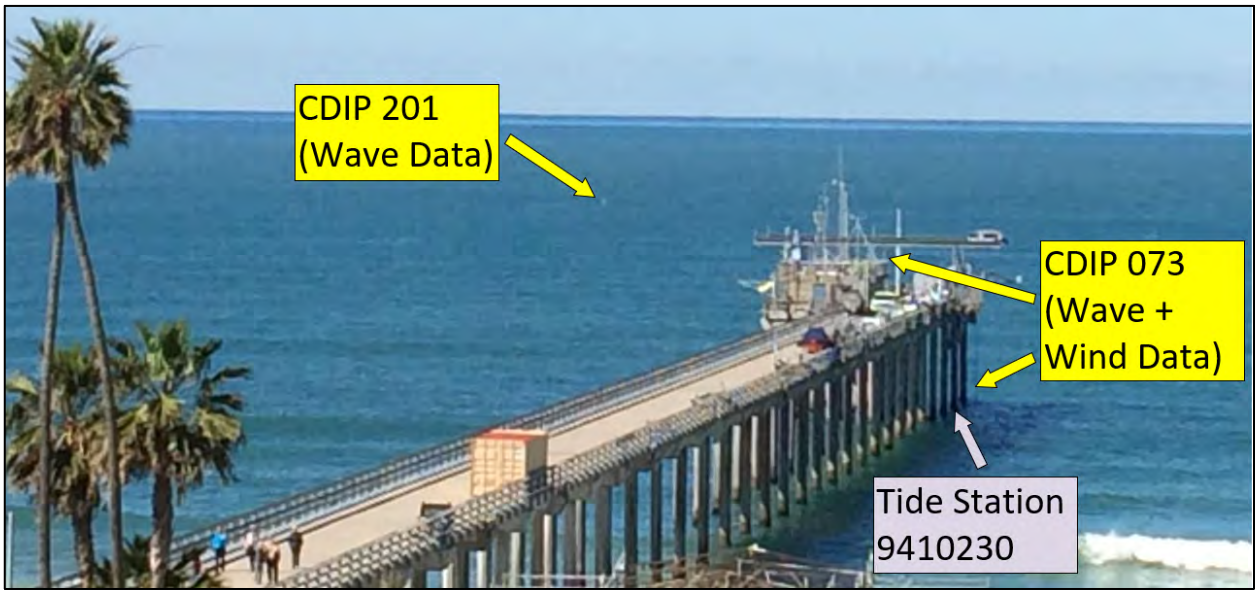


Figure 10: Scripps Pier and useful met-ocean instrumentation.

7.1.2 New Support Infrastructure

CalWave will install some new, temporary infrastructure to support the deployment. Four anchors will moor the device in place. An electrical umbilical cable will connect the device to Scripps Pier, carrying fiber optic communications and up to 5kW of electrical power. The cable will be approximately 1" and will be held to the sea floor with sandbags. The cable will terminate on the Scripps Pier deck, coming up through existing conduit.

7.2 MET-OCEAN DATA

7.2.1 Data Sources

Public meteorological and oceanographic (Met-Ocean) data sources are listed in Table 6, and a map depicting their relative positions is presented in Figure 11.

Table 6: Established met-ocean data sources near the deployment area.

ID/Name	Data Type	Important Variables	Location	Data Start	Owner
CDIP 201 "Scripps Nearshore"	Waves	H_s, T_p, DP	100m West of deployment site	2013	CDIP/SIO
CDIP 073 "Scripps Pier"	Waves, Winds	H_s, T_p, DP WDIR, WSPD	800m East (cable landing)	2005	CDIP/SIO
CDIP 100 "Torrey Pines Outer"	Waves	H_s, T_p, DP	14km Northwest	2004	CDIP/SIO
STN 9410230	Water Levels	Water Levels	800m East (cable landing)	1988	NOAA CO-OPS

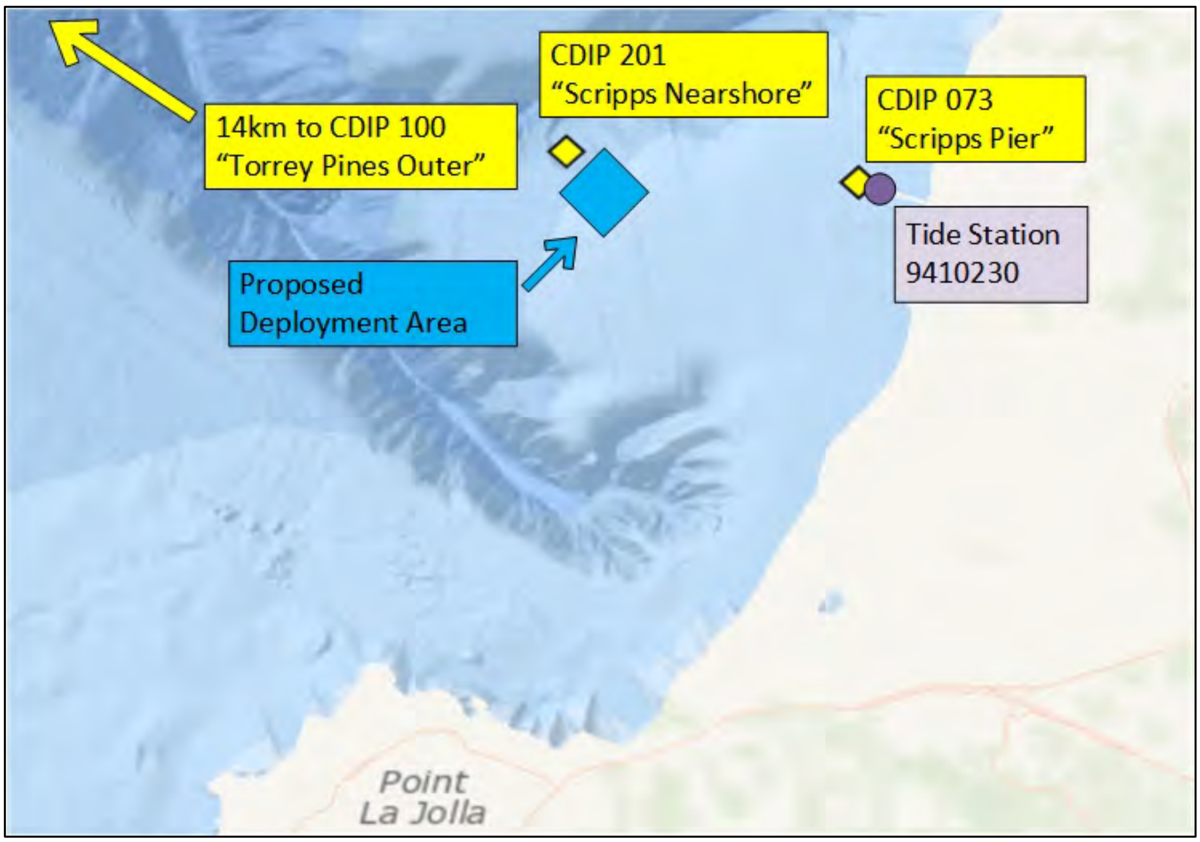


Figure 11: Established met-ocean data sources near the deployment area.

7.2.2 Wave Conditions

7.2.2.1 General Wave Climate

The wave climate around is among the most well characterized in the world, thanks to the immediate attention of leading oceanographers and engineers at Scripps Institute of Oceanography, especially the Coastal Data Information Program (CDIP). What follows below is a high-level summary to serve as a reference among CalWave and partners for deployment; much more detailed analysis of the actual conditions encountered will accompany final project reports.

CDIP Station 201, "Scripps Nearshore", is the closest data source to CalWave's planned deployment location, and thus serves as the reference for all following wave climate analysis unless otherwise noted. A combined joint probability diagram (JPD) of CDIP 201 for the planned deployment months of March-October is shown below in Figure 12Figure 13. Also noted on Figure 12 are the standard wave cases, Froude-scaled 1:5, used by CalWave for performance evaluation, survival planning, and component specification. The binned sea states show a good qualitative match for CalWave's planned demonstration, holding a high probability that the device will experience all cases relevant to performance and survival evaluation.

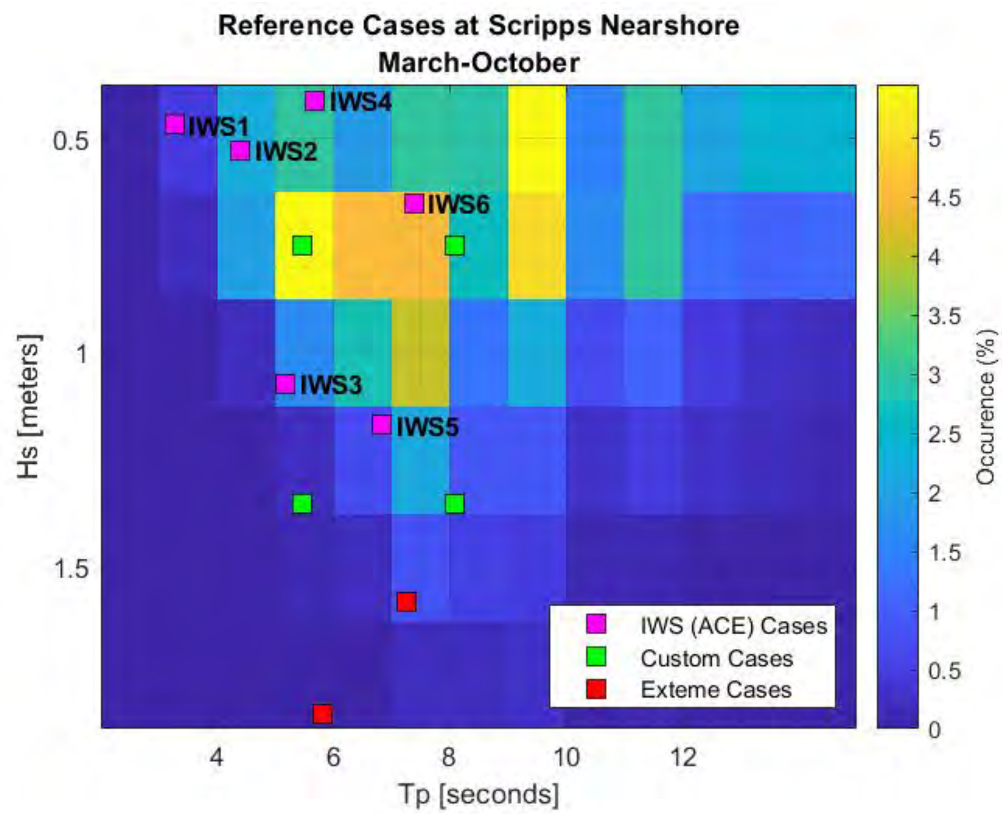


Figure 12: Joint Probability Diagram of wave data from CDIP 201 - "Scripps Nearshore", during the planned deployment months.

7.2.2.2 Monthly Wave Climate Variability

JPDs of the wave climate in each month are shown in Figure 13 demonstrating considerable seasonal variability in wave conditions at the deployment site. Winter months (January-March & November-December) experience more long-period waves, with total energy spread over a larger period and wave height range. In contrast, summer months experience much more concentrated energy including CalWave's design reference cases (including ACE relevant IWS design cases). This informs CalWave's "work-up plan" for the deployment, with installation in the spring and final recovery in the fall.

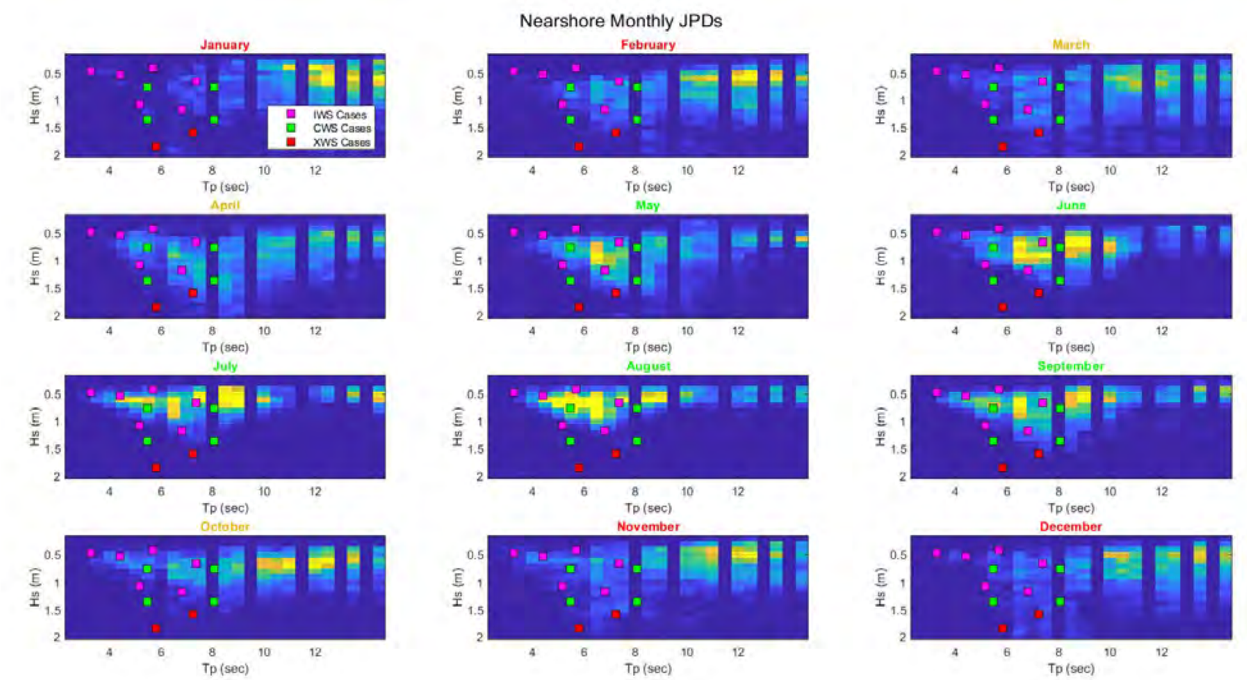


Figure 13: JPDs for CDIP 201, illustrating seasonal variation in wave height and wave period for each month of the year.

7.2.2.3 Directionality

The incident wave direction at CDIP201 is predominately from the West-Northwest (285°) during the deployment months of March-October, as shown in Figure 14.

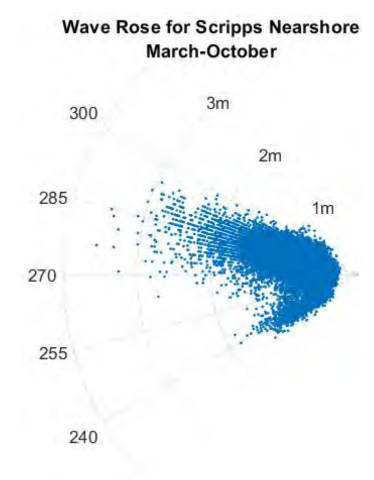


Figure 14: Aggregate wave direction during planned deployment months.

However, such a broad analysis obscures important variation in the wave directionality and accompanying wave heights and periods. In Figure 15, significant wave height is presented on the radial axis, and wave periods are grouped into distinct plots. Short period wind-waves (Tp 3-6 seconds) can come from a broad 90° cone, though still generally from 285°. The most relevant cases fall in this period range, and "performance cases" can be expected from +/- 45° off-axis. The directional tendency grows in the intermediate periods, centered around the 285° axis. At long periods (Tp > 10s), the distribution becomes bifurcated, as long waves generated by distant North Pacific and South Pacific storms approach from 290° and 240°, respectively. The device will be oriented to towards the predominant 285° axis, and so the South Pacific storms wrapping around Point La Jolla represent an energetic off-axis load that will be compensated by the device's capability to tune differently for different directions, respectively degrees of freedom of oscillation. A 1:5 scale device would be tuned to the shorter periods around 6 seconds; indeed, any waves longer than 10 seconds at 1:5 scale would correspond to periods which are exceedingly rare in full-scale device deployments. Power absorption from these long wave periods will still be an objective.

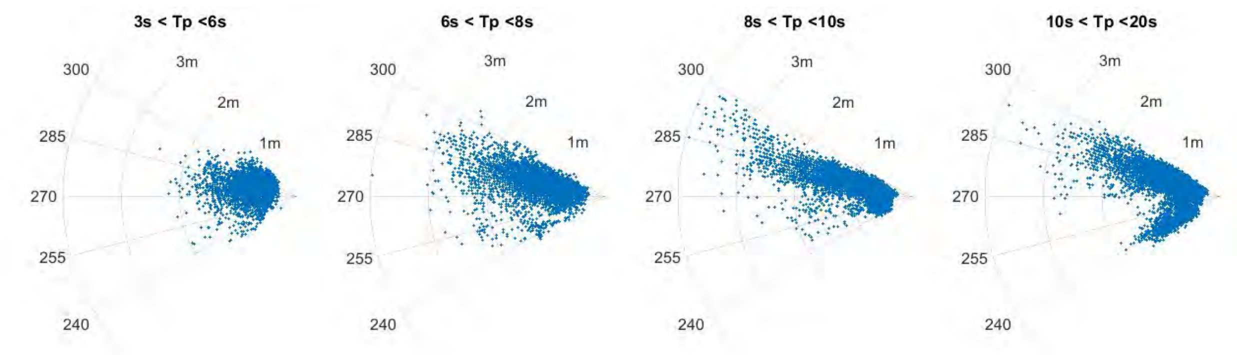


Figure 15: Dominant wave direction is more precisely examined by binning into discrete peak period ranges. The left plot, showing short-period wind-waves, is the most relevant for performance evaluation.

Another useful perspective on wave direction and peak period is by monthly variation, as shown in Figure 16. The off-axis 240° waves can come in any month, but in the most important testing months of June-September, these waves are mostly below 1.5m Hs. The largest waves, above 2m Hs, come from the West-Northwest axis, and only in the "shoulder" testing months of April/May and October/November.

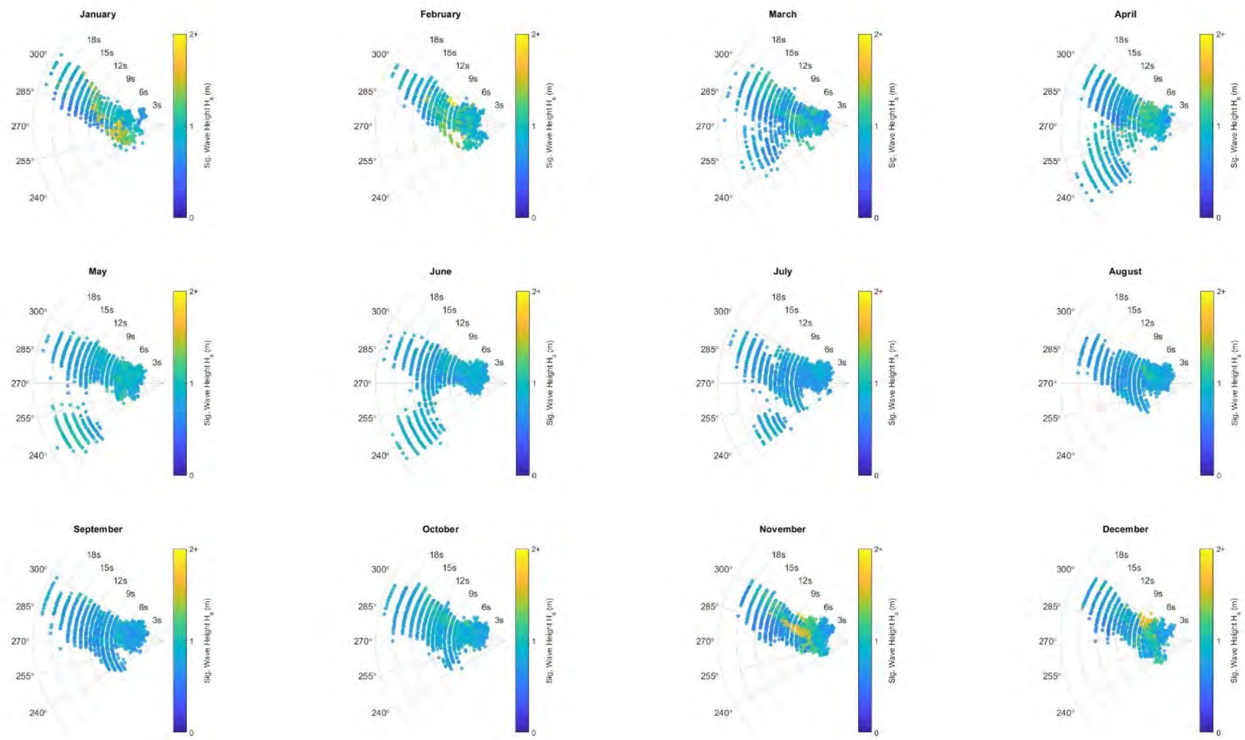


Figure 16: Dominant wave direction for each month of the year.

7.2.2.4 Summary

All the above observations are summarized in Figure 17, using 5 lines important wave climate parameters for each month at the minimum (thin green line), 5th percentile, mean, 95th percentile, and maximum (thin red line).

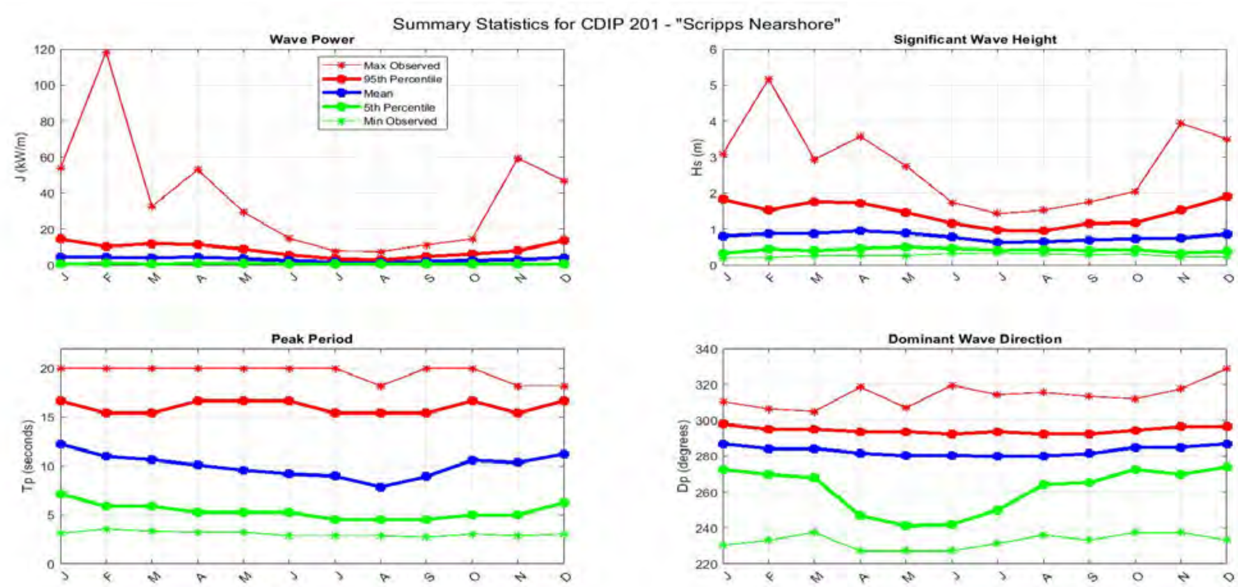


Figure 17: Summary statistics for CDIP 201 - "Scripps Nearshore", the most relevant data source for the planned deployment area.

7.2.3 Water Levels

The National Ocean Service has maintained a water level station (#9410230) directly on Scripps Pier, 800m east of the deployment location, since 1924. This station is an excellent reference for water levels during CalWave's demonstration. The datums at station 9410230 report a Mean Tide Range of 1.126 meters, with a typical daily water level variation of 1.624 meters (the "Great Diurnal Range"). (Note, "water levels" include tides as well as storm surge and other localized phenomena).

In addition to historic and real-time water level observations, NOAA publishes tide predictions up to a year in advance.

7.2.4 Surface Currents

Surface current measurements are not directly available at the deployment site. However, near real-time estimates are derived from a network of shore-based high-frequency radar installations (HFRNet) maintained by the Coastal Observing Research and Development Center (CORDC) at UCSD. These surface current predictions are available at several time and spatial resolutions; a representative screen shot from the HFRNet webpage is shown in Figure 18.

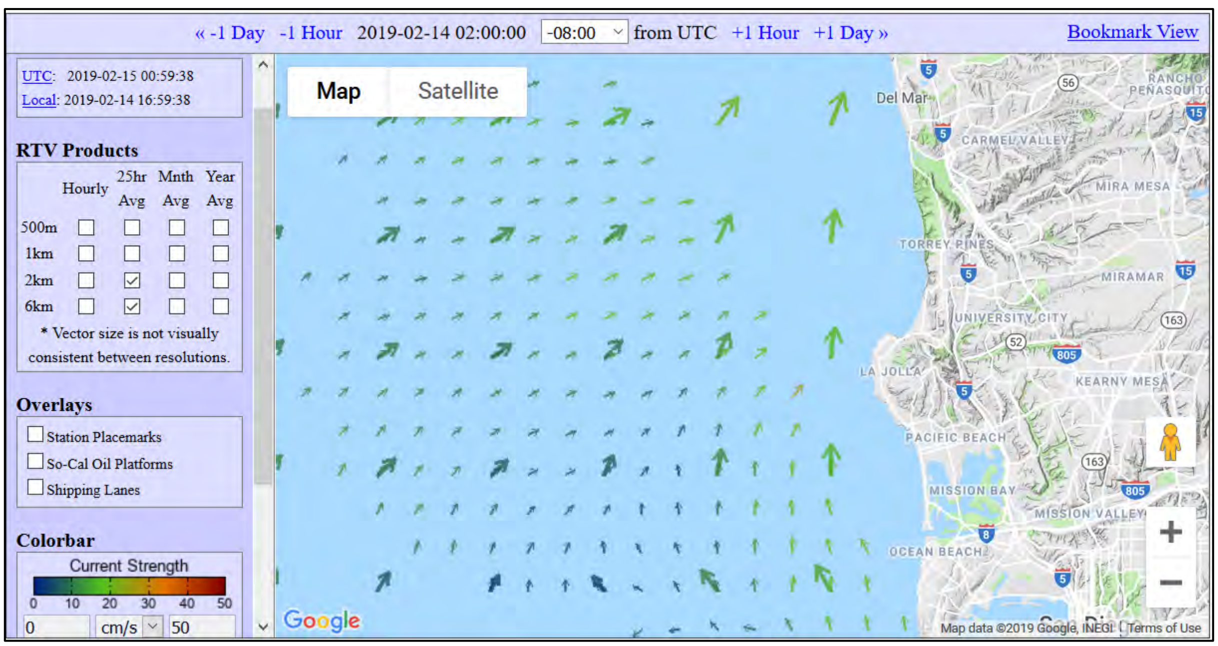


Figure 18: Screen shot of the HFRNet surface current model forecasts from CORDC.

NOAA's Center for Operational Ocean Products and Services (CO-OPS) publish current predictions for many "virtual stations" around active ports and harbors, including San Diego Bay. The closest station is PCT0026, ~ 1km west of Point Loma Light and 22 km south of the CalWave's deployment area. Nevertheless, the currents at Point Loma are rather mild, with a peak of ~50 cm/s; a representative plot of the surface currents is shown in Figure 10. CO-OPS publish annual predictions of surface currents.

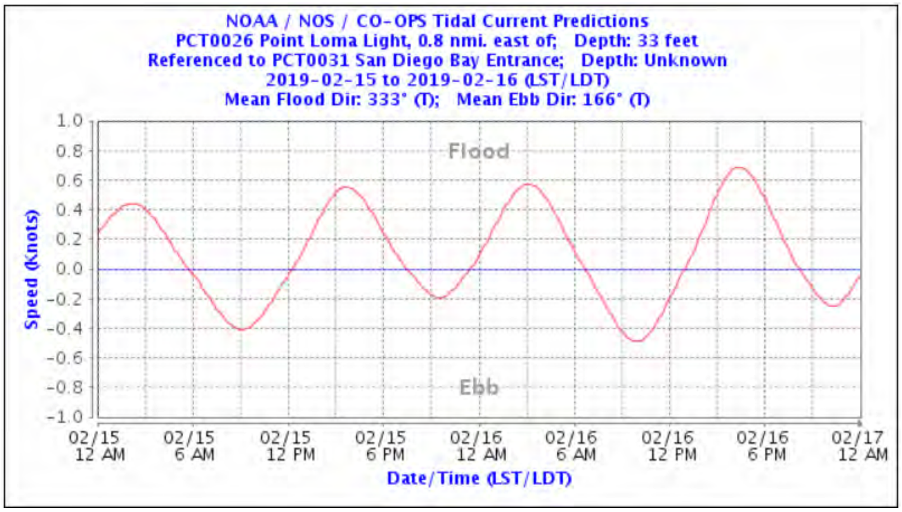
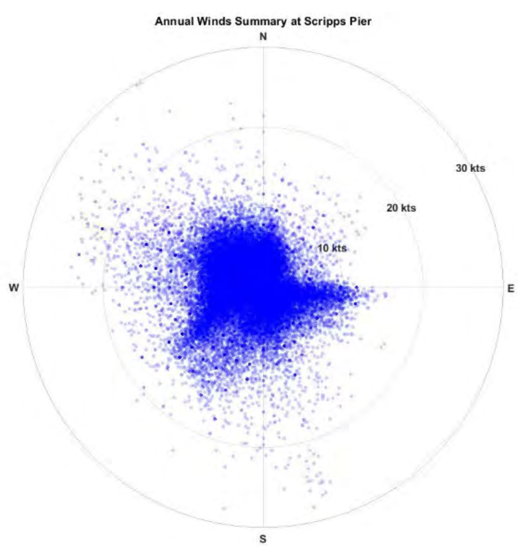


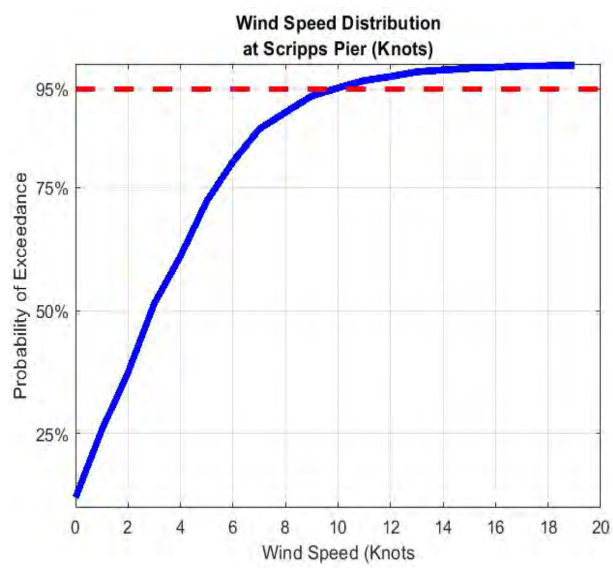
Figure 19: Surface current projects at "virtual station" PCT0026, 22km south of the deployment area.

7.2.5 Winds

Winds approach Scripps from every direction, though predominantly from the Northwest; see Figure 20. Sustained winds are below 10 knots 95% of the year, and below 10 knots for 97.5% of the planned deployment months. Most storms with winds above 20 knots tend to come from the Northwest, likely bringing localized short-period waves which will be important scaled performance evaluation cases for the WEC but will likely preclude marine operations. The other notable strong wind direction is from the Southeast, likely driven by distant Southern Pacific hurricanes in the late summer months. These winds are less likely to produce steep wind-waves, thanks to the relatively small fetch area North of Point La Jolla.



(a)



(b)

Figure 20: (a) Wind speeds recorded at Scripps Pier. (b) Cumulative Distribution Function (CDF) of wind speeds at Scripps Pier during the deployment months.

7.3 Wave Forecast tools

CDIP provides 2 wave forecast products relevant to this deployment. The “NowCast” product uses real-time buoy measurement to seed CDIP’s California Wave Model, which in turn propagates wave heights to forecast locations along the 10m contour with appropriate accounting for bathymetry and wave propagation delays. **The NowCast provides a 4-hour look-ahead** and is preferred for planning the device’s operational states because it has better accuracy in short-period waves.

CDIP’s “Forecast” product gives a 5-day look-ahead, but with much lower precision. In this case, the California Wave Model is seeded with the Pacific-scale Wave Watch III (WW3) grid at the CWM’s boundaries around the Channel Islands. The forecast product suffers from lower precision because it makes no attempt to account for local wind-seas in the nearshore areas in the lee of the Channel Islands. This product is more suitable for planning marine operations because it has a longer forecast horizon.

7.4 Extreme Sea States

Extreme seas are probabilistic events, and thus recorded sea states may not represent the most severe storms that may occur in a deployment period. The Kernel Density Estimation (KDE) method for extrapolating extreme sea states was applied to 6 years of data from CDIP 201, and the resulting 50-year return extreme sea state contour is shown in Figure 21.

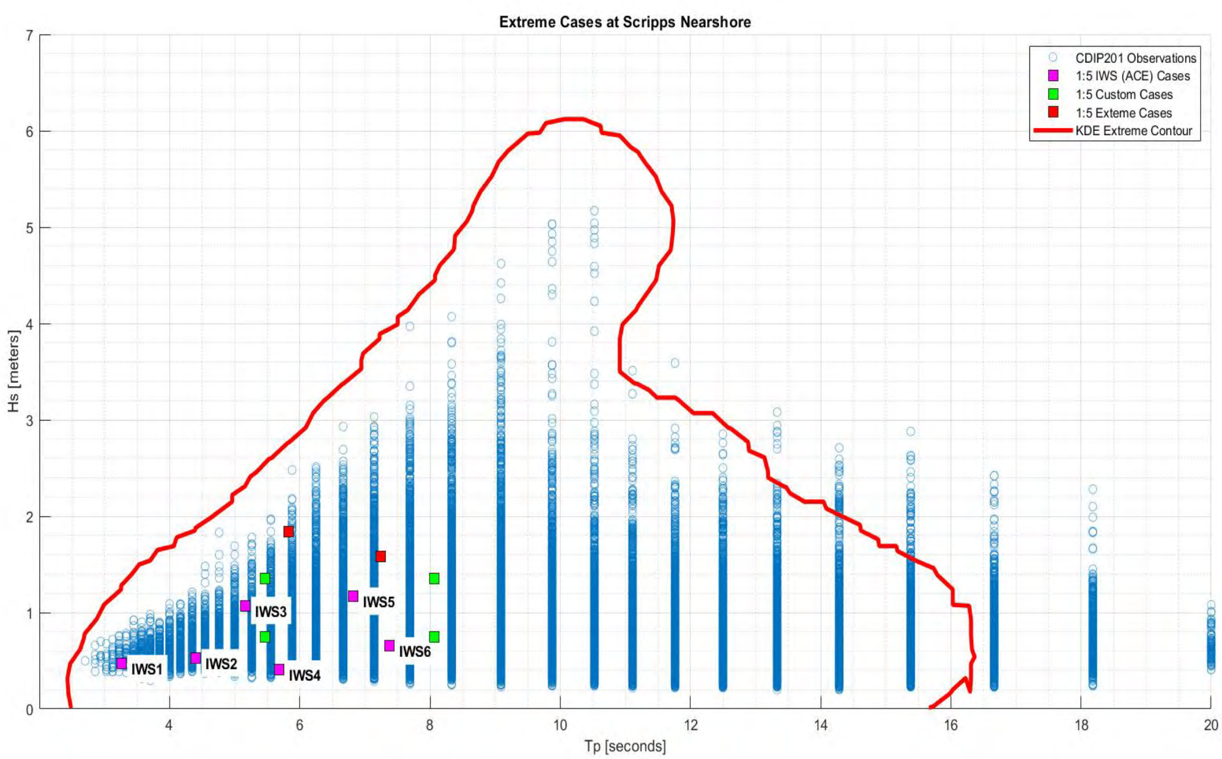


Figure 21: 50-Year Return extreme sea state contour (red), representing the probabilistic worst-case scenario at the Scripps Nearshore buoy.

7.5 Weather Windows

“Weather Windows” are to suitable times for marine operations, defined here by:

- Daylight Hours – simplified to 0700-1700 local time
- Wave Height Threshold – upper limit of allowable Hs
- Duration – number of consecutive hours meeting the first two criteria

Historic wave data can provide estimates of weather windows for each month of the planned deployment at various threshold levels. For example, if a particular marine operation requires 6 hours of daylight with waves less than 1m Hs, this would be possible 28 days in July, but only 19 days in April. Expected weather windows for each month at various significant wave height thresholds are presented in Table 2. There is a dearth of working days with significant wave height below 50cm, but considerably more available days if the wave height restriction is relaxed to 1m.

Table 7: Weather windows at the deployment site. If a marine operation can be conducted up to 1m of significant wave height, one could expect 19 days in April for such work, and 28 days in July.

Expected Operational Days at Scripps Nearshore **"Operational" = 6 continuous hours of daylight below Hs Threshold**												
Threshold Hs (m)	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug,**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
2.5	28	26	28	28	28	28	28	28	28	28	27	28
2.0	28	26	28	28	29	28	28	28	28	28	27	28
1.5	27	25	26	26	27	28	28	29	28	28	26	26
1.0	23	21	20	19	22	25	28	28	25	26	23	22
0.5	8	4	7	2	2	4	9	8	7	4	10	7

8 VESSELS & OPERATORS

8.1 SUPPORT VESSEL (19' BOSTON WHALER)

A small line handling vessel for operations either independently, or alongside a larger vessel. UCSD owns and operates several 19-ft Boston Whalers located on SIO pier and provisional contracting terms for the use of these vessels have been agreed with UCSD. The USCD small vessels are deployed with the pier crane and skippered by UCSD staff. At 0.3 nm from the pier, this provides the most immediate access to the test site for observations or operations appropriate for a small vessel.

Figure 22: Support Vessel (19' Boston Whaler).

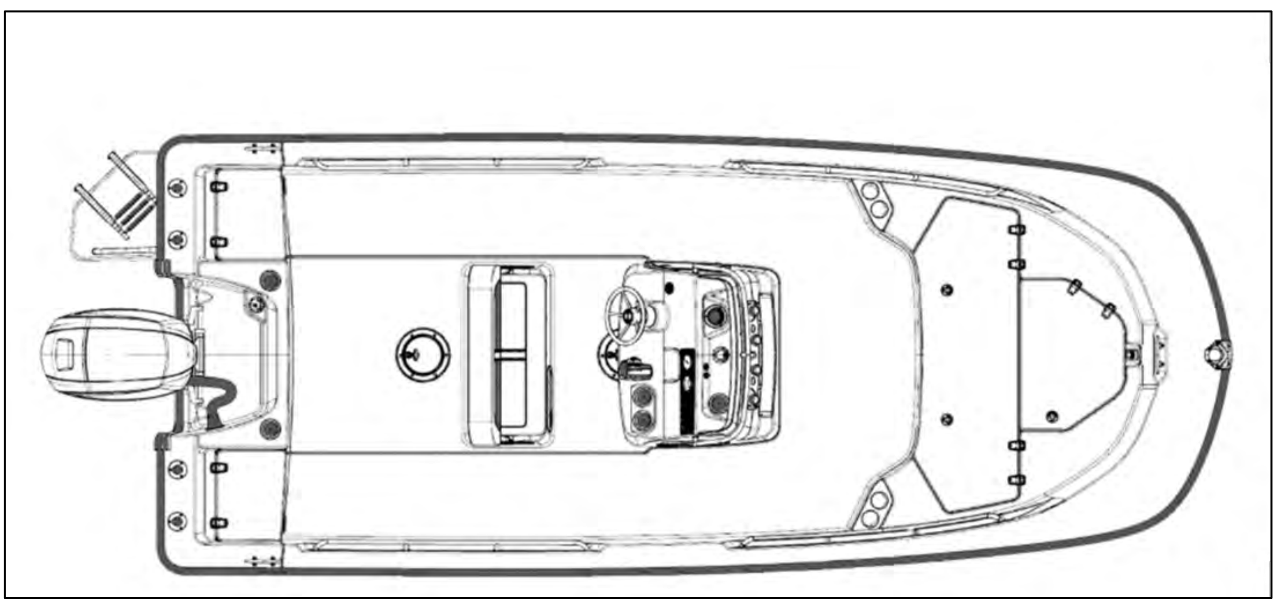


Figure 23: Boston Whaler Specifications.

<u>Vessel Specifications</u>:

- Length: 19.4 ft
- Beam: 8 ft
- Draft: 13 ft
- Weight (w/engine, fuel & water): 2769 lbs
- Maximum weight capacity: 2500 lbs
- Swamped capacity: 4000 lbs
- Persons capacity: 8
- Maximum Horsepower: 150 HP
- Minimum Horsepower: 115 HP

8.2 R/V Beyster

The research vessel Bob and Betty Beyster is a purpose-built coastal research vessel designed for efficient operations offshore in Southern California. The Beyster is owned and operated by Scripps Institute of Oceanography (SIO).

Figure 24: R/V Beyster.

This is the primary vessel intended for use during the test period. Provisional contract terms on the use of this vessel has been agreed with UCSD and will be finalized during Budget Period 2.

<u>Vessel Specifications</u>:

- Length: 42 ft
- Beam: 16 ft
- Freeboard: 3 ft
- Stern A frame capacity: 2.5 tons

- Starboard knuckle crane capacity: 660 lbs, 17 ft reach
- Dynamic Positioning System (DPS)
- Deck space: 192 ft^2
- Maximum speed: 38 kts
- Cruising speed: 25 kts
- Hand-deployable Sebotix LBV-300 Mini-ROV
- Acoustic communications transducer

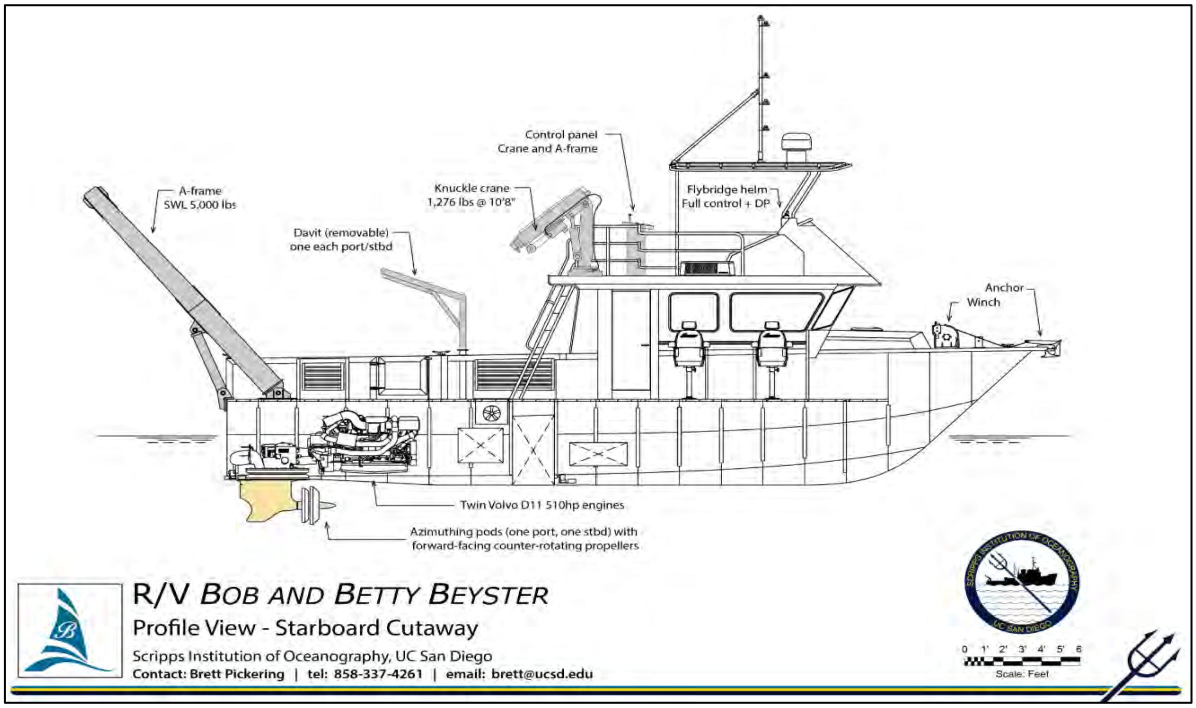


Figure 25 R/V Beyster -Starboard Cutaway

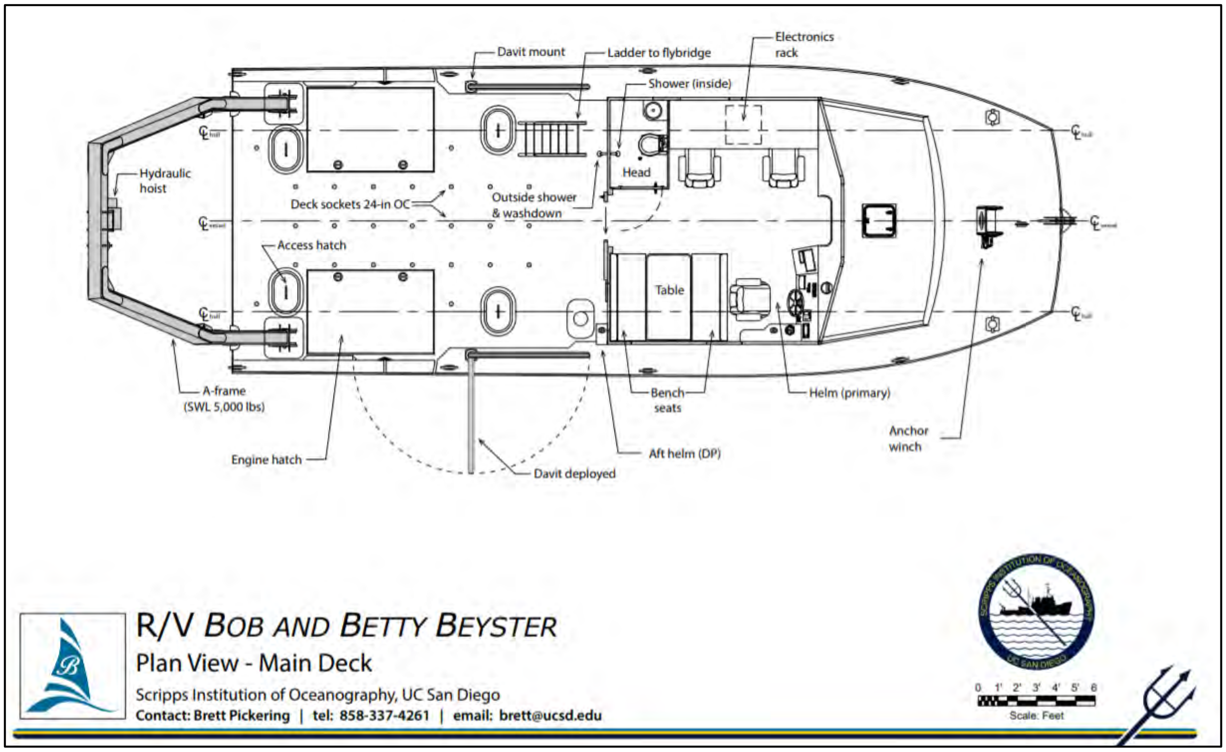


Figure 26: R/V Beyster – Main Deck Plan View

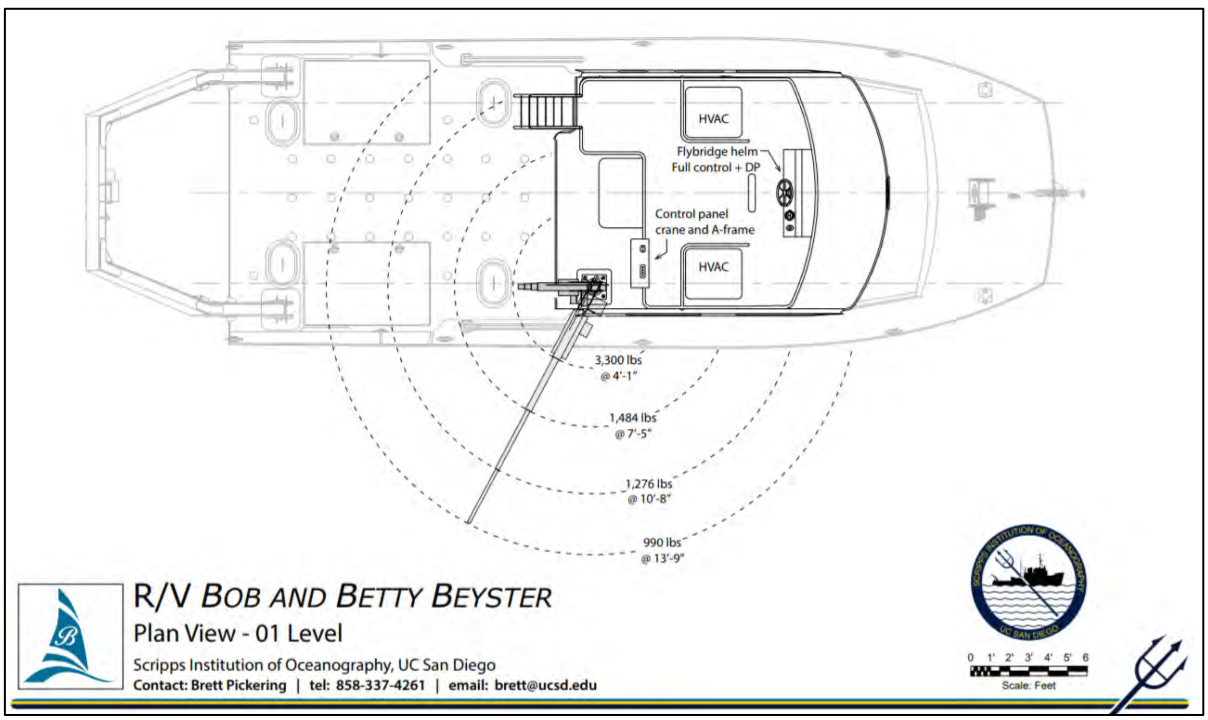


Figure 27: R/V Beyster Boom Crane Capacity

8.3 DB San Diego

The heavy lift crane barge DB San Diego, owned and operated by Pacific Maritime Group, is the intended vessel for anchor handling. This vessel is significantly oversized for the weight of anchors being deployed which will provide operational flexibility and capacity. This is particularly important for the anchor recovery operation, which could encounter suction forces from the seafloor.

Figure 28 DB San Diego

Barge Specs	
Type	Offshore Derrick Barge
Year Built	1954/2003
Length	134.9 FT
Width	58 FT
Depth	12 FT
Official Number	1231114
Capacity	150 ton revolving
Boom Length	150 feet (more available)
Generator	25 KW
Tonnage	92 G / 92 N

Figure 29 DB San Diego Specifications

8.4 Vessel Operators

The primary vessels anticipated for use in this project are owned and operated by UCSD Scripps Institute of Oceanography (SIO). For anchor handling, the primary vessel operator is anticipated to be Pacific Maritime Group. Backup vessel operators are C&W Dive Services, whose respective vessels are described in Appendix A. Contact details for primary and backup vessel operators is provided in the personnel contact list.

8.5 Dive Services Providers

For non-commercial diving UCSD research divers are available. However, use of the UCSD research divers is limited to inspections, seafloor surveys and similar low-risk, non-complex diving. For commercial diving services initial contract discussions and operational reviews have been conducted with three San Diego based dive services companies: C&W Dive Services, Phoenix International, and VMS. All three are fully certified commercial dive services companies.

Dive services are not anticipated to be a significant aspect of operations during this demonstration project, and ideally limited to anchor installation and anchor recovery operations. However, it is critical to have established relationships with local dive services suppliers should the unanticipated need arise. Contact information for dive service providers is included in the personnel contact list.

9 Project Operations

The following project operations are detailed in separate individual operations plans which are intended to be used in collaboration with this overarching Comprehensive IO&M Plan.

9.1 Dive Survey of Anchor Locations_V2.1

9.2 CoastScout Wave Measurement Buoy Installation, Operation, and Maintenance Plan_V1.1

9.3 Anchor Installation Plan_V2.5

9.4 Umbilical Lay Plan_V2.4

9.5 WEC Tow Plan_V2.5

9.6 WEC Deployment Plan (including Operation & Test Planning)_V2.6

Additionally, after-action reports will be added to this document library as those operations occur. For operations with multiple occurrences, such as WEC towing and deployment, an after-action report will be generated for each occurrence, and the operations plan updated as necessary to incorporate the learnings from each operation.

10 Appendix A: Backup Vessels & Operators

10.1 M/V Cooper

The M/V Cooper is owned and operated as a dive support vessel by C&W dive services. It is currently in the San Francisco bay area being retrofitted with deck crane and anticipated to be available summer/fall 2019.

Vessel Specifications:

LCM-8 Dive Support Vessel with an 8-ton pedestal mount hydraulic crane, independent hydraulic power system (3,000psi, 30gpm). Dry docked in 2010 for steel hull replacement on bottom.
Engines: (4x) Detroit Diesel 6-71 with 500 HP.

•Length: 74.3'
•Width: 20'
•Full Capacity: 1,150 gallons
•Gear Ratio: 2:1
•Generator: 14kw MQ Power Corp
•Gross Tons: 73
•Draft: 3'
•Cooling: Freshwater through keel coolers.
•Exhaust: Wet, outside

A Small Serviced-Disabled Veteran Owned Business ~ 1706 Hoover Avenue, National City, CA. 91950
(619) 474-2700 (Ph) (619) 477-2700 (Fax) www.cwdiving.com

Figure 30: M/V Cooper Vessel Specifications

Figure 31: M/V Cooper

10.2 Jag

The coastal tug Jag is owned and operated by Pacific Maritime Group. This vessel is more expensive and less suited to the proposed operations than either the R/V Beyster or the M/V Cooper but is included as a backup for potential anchoring and WEC handling operations.

Vessel Specifications:

Specifications:

VESSEL NAME: Jag
BUILT: 1960
REBUILT: 2007
BUILDER:
CLASS: Model Bow Ocean tug w/ push knees
HORSEPOWER: 650
DIMENSIONS: 47′ x 16′ x 8′

BOLLARD PULL:
MAINE ENGINES: (2) MTU 60 Series Tier 2
GENERATOR: 25 KW Tier 2
TOW WINCH: Single Drum, 900 ft. soft line
FUEL CAPACITY: 2,000 gal
FRESH WATER:

Figure 32: Jag Vessel Specifications

Figure 33 Coastal Tug, Jag

10.3 R/V SPROUL

UCSD research vessel (https://scripps.ucsd.edu/ships). R/V Sproul is a backup vessel for general operations and anchor handling operations. Due to relative size and cost of the vessel it is not anticipated to be used during the CalWave 1:5 scale deployment at the SIO test site.

Vessel Specifications:

- **Built:** 1981
- **Length:** 125'LOA, 116' LWL
- **Beam:** 32'
- **Draft (max):** 9'6'
- **Bow Thruster:** White-Gill trainable Hydraulically operated 155 hp
- **Open deck space:** 1,854 sq. ft
- **Transit Speed for Cruise Planning:** 8.5 knots (*variable with conditions -- contact us prior to making speed/time estimates*)
- **Speed, Minimum:** 2 knots
- **Range:** 4,300nm at 9 knots (fuel)
- **Fuel Capacity:** 25,000 gal
- **Fuel Consumption:** 1,350 gal/day full speed - 850 gal/day average

Figure 34: R/V Sproul - 1

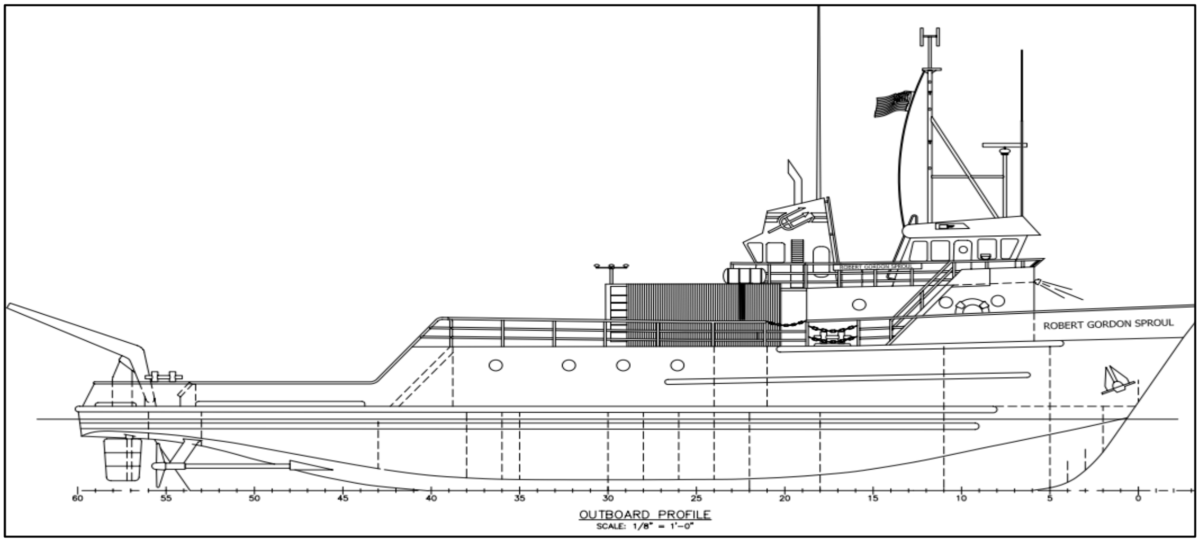


Figure 35: R/V Sproul - 2

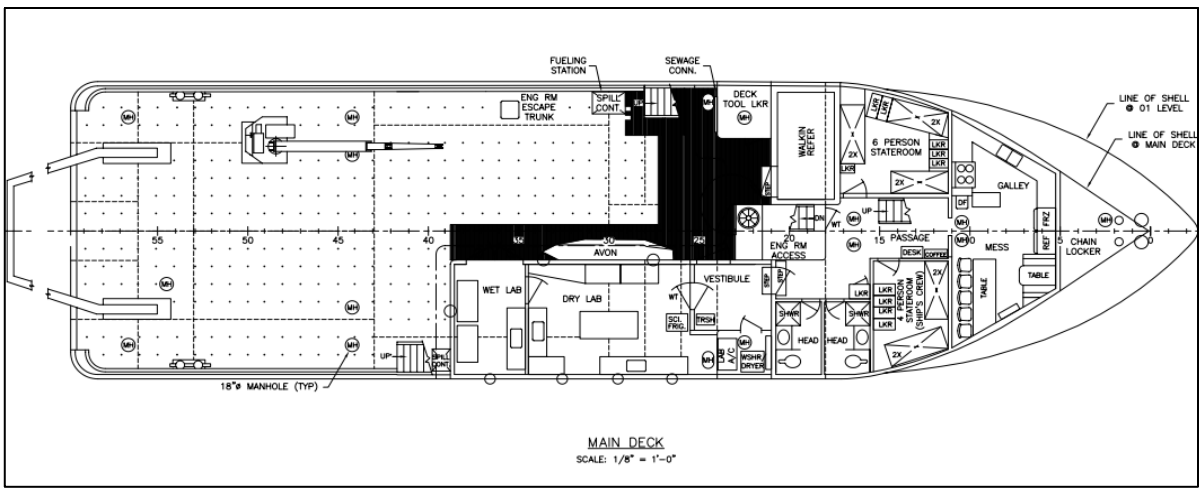


Figure 36: R/V Sproul - 3

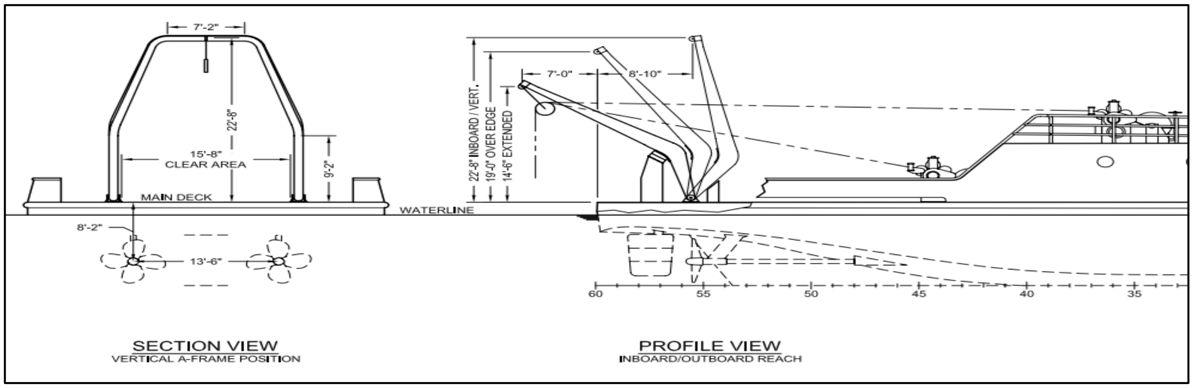


Figure 37: R/V Sproul – 4

Table 8: R/V Sproul Equipment List

CRANE TYPE	**LOCATION**	**SWL (At Sea)**
Stern A-frame	Stern Center	10,000 lbs.
Hiab Crane	Hiab Crane	2,400 lbs.
WINCH TYPE	**CABLE**	**NOTES**
Markey DESH-3 Trawl	4,500 m 3/8" 3x19 Wire	Hi speed lift: 1250 lbs. Low speed lift: 5000 lbs.
Western Gear CTD/Hydro	4,500 m .322" EM or 7,500 m " Hydro wire	Portable winch not normally installed
Northern Line CTD/Hydro	4,500 m .322 EM	
Western Gear portable	3,000 m .680" EM or 10,000 m ." 3x19	

The crane capacity chart is pending check out testing and derating after completion of retrofit but is anticipated to have a capacity of 8-tons. The M/V Cooper is considered as an appropriate backup vessel for general and anchor handling operations. The larger crane capacity, significant deck space and wider beam make the M/V Cooper able to support complex diving operations requiring surface supplied air and other dive support equipment, if required. Additionally, the bow lift gate and wide beam would allow for the WEC to be recovered to the deck of the M/V Cooper should unanticipated events cause for this need.

CWPT Open Water Demonstration

DE-EE0008097.0005

Budget Period 2

Task 5.4 Comprehensive IO&M and Testing Plan

9.1 Dive Survey of Anchor Locations

Version 2.1 - October 2019

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CONTENTS

FIGURES

TABLES

1 Introduction

This report focuses on the Installation and Operations Planning for the open water demonstration to be conducted in collaboration with University of California, San Diego (UCSD) near the Scripps Institute of Oceanography (SIO) pier, in a water depth of approximately 70 ft (21.3 m).

SIO Pier Location (terminus)

Lat.	Long.
32°52'01.36"N	117°15'26.81"W

WEC Deployment (center of mooring grid)

Lat.	Long.
32°52'03.47"N	117°15'47.42"W

All operations are being coordinated with University of California, San Diego (UCSD) Scripps Institute of Oceanography (SIO) staff as well as local vessel operators and marine operations contractors.

The details outlined in these procedures are contingent upon several factors, such as operation conditions, vessel ability, safety, efficiency, etc. Due to these factors, this plan is subject to change. The respective management personnel must be contacted and contribute to determining a safe and effective method of performing operations. The current and weather conditions must be deemed favorable before starting operations.

Before the start of any operations, all vessels and individuals involved will hold operational procedure review and safety meetings to prepare for upcoming operations. All equipment will be checked at this time and the equipment will be verified for availability for upcoming operations.

The vessel captain and CalWave representatives will approve deviations that become unavoidable in the field during the installation process. VHF working channels will be identified at this time.

This document comprises of the overall methodologies of safe operations offshore, includes vessel specifics, and operations planning for the following planned evolutions:

Table 1: Planned Offshore Operations

Activity	Days
Dive Survey of Anchor Location	1
Total Planned Operational Days Offshore	1

2 Equipment, Vessels, and Personnel

2.1 Vessels

Table 2: Vessel List

Vessel	Operator	Website	Notes
19' Boston Whaler	UCSD	https://scripps.ucsd.edu/ships	Primary work vessel

2.2 Equipment

All necessary equipment for this operation will be provided by UCSD.

2.3 Personnel

To ensure safe, effective, and efficient operations, the following contact numbers are included for use by personnel connected to the deployment operations.

Table 3: Contact List

University of California, San Diego				
Name	**Position**	**Phone**	**Mobile**	**Email**
Christian McDonald	Scientific Diving & Small Boating Safety Officer	***Private information not included in submitted documents***		
Brett Pickering	Assistant Boating Safety Officer			

CalWave Power Technologies				
Name	**Position**	**Phone**	**Mobile**	**Email**
Dan Petcovic	COO	***Private information not included in submitted documents***		

3 Project Location

3.1 Area of Operations

The area being investigated for this operation is the vicinity of the proposed anchor locations for the CalWave WEC. GPS coordinates for these locations are provided below;

Table 4: Proposed Anchor Locations

Anchor#		Deg	Min	Sec	Depth		dd	Deg	Min
A1	N	32	52	4.068	71.85	ft	32.867797	32	52.0678
	W	117	15	47.832	21.90	m	117.263287	117	15.7972
A2	N	32	52	3.144	68.85	ft	32.867540	32	52.0524
	W	117	15	48.090	20.99	m	117.263358	117	15.8015
A3	N	32	52	2.922	67.85	ft	32.867478	32	52.0487
	W	117	15	47.046	20.68	m	117.263068	117	15.7841
A4	N	32	52	3.810	71.85	ft	32.867725	32	52.0635
	W	117	15	46.710	21.90	m	117.262975	117	15.7785

3.2 Transit Routes

The *vessel* will transit to the test site along the proposed transit route as determined by vessel mobilization location and operations being performed. A list of anticipated transit routes to site is provided below;

Table 5: Anticipated Transit Routes.

Vessel	Route	Distance (nm)
Multiple	1 - SIO pier to Test Site	0.3

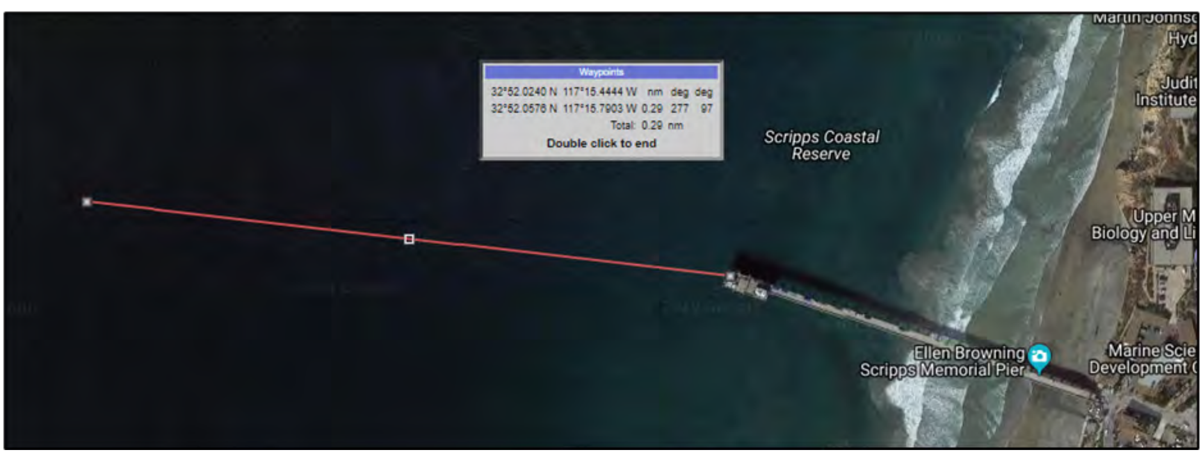

Figure 1: Transit Route 1: SIO Pier to Test Site.

4 VESSELS & OPERATORS

4.1 SUPPORT VESSEL (19' BOSTON WHALER)

The USCD small vessel is deployed with the pier crane and skippered by UCSD staff. At 0.3 nm from the pier, this provides the most immediate access to the test site for observations or operations appropriate for a small vessel.

Figure 2: Support Vessel (19' Boston Whaler).

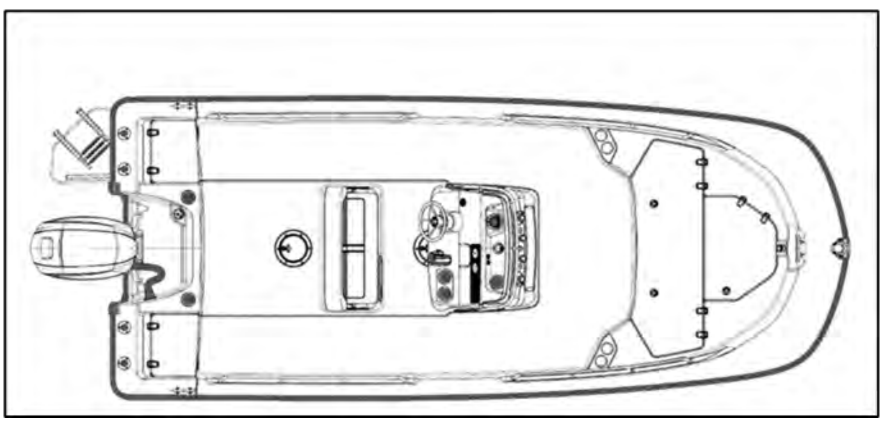

Figure 3: Boston Whaler Specifications.

5 PROJECT OPERATIONS

5.1 ANCHOR DEPLOYMENT SITE SURVEY

The survey will consist of identifying the specific anchor locations, including verifying and obtaining evidence (photograph or video) of seafloor conditions between and around anchor locations. It is important to orient the anchors such that the prevailing wave direction is in between anchors and ensure the anchors are equally spaced into a square grid for optimal conversion efficiency. Additionally, seafloor surface samples are required in order to perform geotechnical lab analysis to validate against previous geotechnical analysis performed near the proposed site and support detailed design of the anchor blocks.

The anchor grid has been defined from review of available seafloor data reports and GIS tools. This location was chosen because of the sandy benthic profile with no apparent obstructions and the shallow slope. The available seafloor data indicates an anchor spread with approximately 1 m of depth variation resulting in a slope of less than 5 degrees from any anchor point to the center of the grid.

At 70 ft (21 m) depth, each diver is allocated a maximum of 40 min bottom time without the need for decompression (a safety stop is required). Multiple dives at this depth are allowed with adequate surface interval time. It is anticipated that a team of two divers can accomplish the survey by performing multiple dives.

5.1.1 Mobilization: Anchor Survey & Marking

These procedures were written in anticipation of using a small dive support vessel. The vessel will be mobilized with all the necessary equipment to complete the scope of work and is anticipated to mobilize from SIO pier.

Table 6: Equipment List: Anchor Survey & Marking

OWNER	DESCRIPTION	SIZE	QTY
19’ Boston Whaler (BW-1)			
UCSD	Dive Support Equipment		1
UCSD	Weighted downline		1
UCSD	Underwater camera/video system	Sony a6500	1
UCSD	Backup underwater video system	GoPro	1
CalWave	Sealable bags for collecting seafloor sand	Minimum 1.56L (95in^3)	1
CalWave	Sealable bags for collecting seafloor sand	Minimum 0.42L (25in^3)	3
SIO Pier			
UCSD	Lift rigging to support vessel deployment & recovery		1

5.1.2 Operations Sequence: Anchor Survey & Marking

The following sequence details the scope of work for the anchor survey operation. The sequence may be altered in collaboration with CalWave support staff.

If any of the below conditions are encountered, the dive team shall adjust the survey location as necessary to identify alternate proposed anchor locations.

- Seafloor obstructions (e.g. large rocks, corals, marine habitats)
- Seafloor depth at proposed anchor location deviating from expected by more than +/- 1 meter

Planned downtime per dive is 10 to 15 minutes. Brief surface intervals are required between dives adhering to no-decompression constraints as determined by dive computers.

If unanticipated seafloor conditions are present, UCSD shall contact CalWave staff to coordinate the decision to investigate alternate locations. The primary focus is to find anchor coordinates corresponding to the required anchor grid layout and depth in order to provide to the anchor installation contractor.

The required anchor spacing is dependent on seafloor depth, with the below spacing assuming ~21 meter depth;

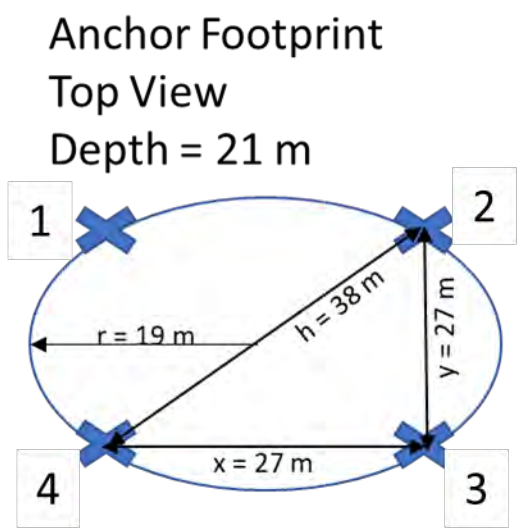

Figure 4: Anchor Point Spacing

Estimated anchor points calculated using the Great Circle Calculator, written by Ed Williams, with Earth Model WGS84/NAD83/GRS80. Conversions between datum sets have been calculated using the Earth Point calculator. Datum sets are provided with an accuracy of approximately 0.182 meters. Current assumptions for mooring geometry accounts for up to 1 meter of offset per anchor. Discussions are on-going as to anticipated possible accuracy of anchor placement during installation operations.

Table 7: Sequence: Anchor Location Dive Survey

Step	Asset	Task
1	Anchor Location Dive Survey	
1.a	*BW1*	• Deploy from SIO pier • Transit 0.3nm to anchor point 2 (32° 52’ 4.008” N, 117° 15’ 47.784” W)
1.b	*Dive Team*	• Deploy from *BW1* with underwater GPS • Validate depth at location (anticipated to be 72’ (21.95 m)) • Verify seafloor conditions including photographic or video evidence, annotating any potential hazards or obstructions • Obtain 1500-gram surface sample of seafloor sand (seafloor sand collected into ziplock bag) • Recover to BW1
1.c	*BW1*	• Transit to anchor point 1 (32° 52’ 3.162” N, 117° 15’ 48.054” W) • Validate depth at location (anticipated to be 68’ (20.73 m)) • Verify seafloor conditions including photographic or video evidence, annotating any potential hazards or obstructions • Obtain 400-gram surface sample of seafloor sand (seafloor sand collected into ziplock bag) • Recover to BW1
1.d	*BW1*	• Transit to anchor point 4 (32° 52’ 2.930” N, 117° 15’ 47.052” W)
1.e	*Dive Team*	• Deploy from BW1 • Validate depth at location (anticipated to be 67’ (20.42 m)) • Verify seafloor conditions including photographic or video evidence, annotating any potential hazards or obstructions • Obtain 400-gram surface sample of seafloor sand (seafloor sand collected into ziplock bag) • Recover to BW1
1.f	*BW1*	• Transit to anchor point 3 (32° 52’ 3.780” N, 117° 15’ 46.782” W)
1.g	*Dive Team*	• Deploy from BW1 • Validate depth at location (anticipated to be 71’ (21.64 m)) • Verify seafloor conditions including photographic or video evidence, annotating any potential hazards or obstructions • Obtain 400-gram surface sample of seafloor sand (seafloor sand collected into ziplock bag) • Recover to BW1
1.h	*BW1*	• Transit to SIO pier • Recover to pier

It is anticipated for the Anchor Survey operation to take 3-4 hours to complete. Information obtained during the survey, including photographs and video will be collected and maintained on a shared google drive, located at:
https://drive.google.com/open?id=1Rv_1IOmep9RYWKLp1TAdvVbitLL3oIg3&authuser=dan@calwave.energy&usp=drive_fs

6 AFTER ACTION REPORT

6.1 SETUP & METHODOLOGY

While mobilizing equipment, Christian provided a safety briefing and the operations plan was reviewed by all parties. The vessel was mobilized on the pier and deployed using the pier crane. All parties boarded the vessel by way of chain ladder from pier.

At each anchor location, the GPS coordinates and depths were validated by shipboard GPS and annotated. A downline was deployed at each site to provide visual reference on seafloor. Divers were then deployed. Divers obtained video evidence of seafloor conditions and sediment samples at each site, with Ruth operating the camera and Brett collecting samples.

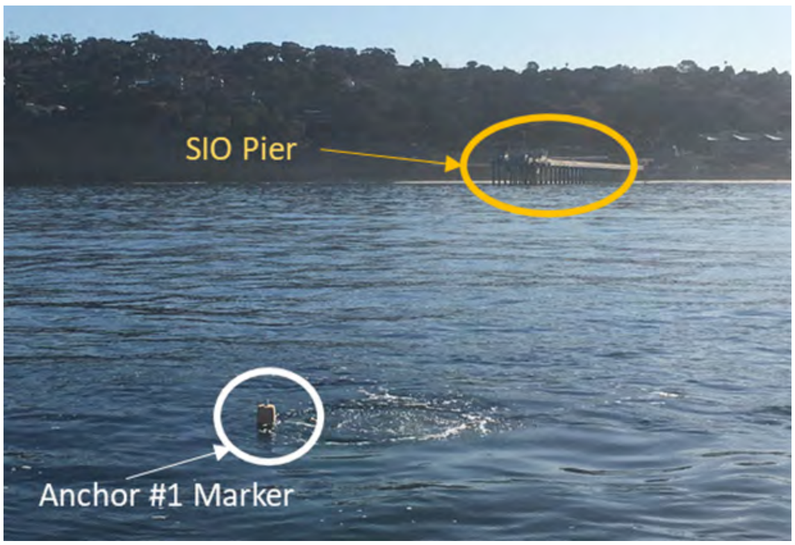

Figure 5 Visual Reference of Anchor Point #1 Distance to SIO Pier

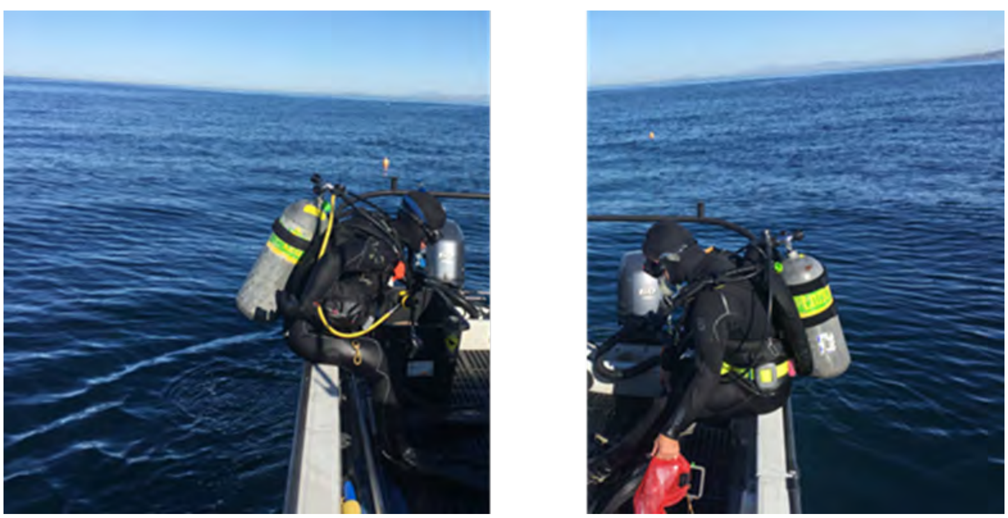

Figure 6 SIO Divers Deploying at Anchor #2

6.2 Timings

Mobilization and pre-briefing commenced at dive shed at approximately 07:00. Vessel arrived on-site at 08:40am and departed site approximately 10:45.

Table 8 Estimated vs Actual Timings

Step #	BW-1	Est. Hrs	Act. Hrs	Diff.
1	Anchor site survey			
M	Mobilize vessel at home port (SIO pier)	1.0	1.0	0
1.a	Deploy vessel and transit to anchor position 2	0.5	0.5	0
1.b	Deploy dive team & survey anchor position 2	0.5	0.4	-0.1
1.c	Recover dive team and transit to anchor position 1	0.25	0.2	-0.05
1.d	Deploy dive team & survey anchor position 1	0.5	0.4	-0.1
1.e	Recover dive team and transit to anchor position 4	0.25	0.1	-0.15
1.f	Deploy dive team & survey anchor position 4	0.5	0.35	-0.15
1.g	Recover dive team and transit to anchor position 3	0.25	0.1	-0.15
1.h	Deploy dive team & survey anchor position 3	0.5	0.4	-0.1
1.i	Transit to home port & recover vessel to pier	0.5	0.5	0
DM	Demobilize vessel	1.0	1.0	0
	Total Time Estimate (hours)	**5.75**	**4.95**	**-0.8**
	Total Time on Site (excluding mob/demob & transit to/from site)	**2.75**	**1.95**	**-0.8**

6.3 RESULTS

Seafloor samples were delivered to SCST labs in San Diego. Results from the sediment analysis will be included in the detailed design of the anchor.

Below are photographs of the vessel GPS at each anchor point, indicating time of arrival at site, GPS coordinates and depth.

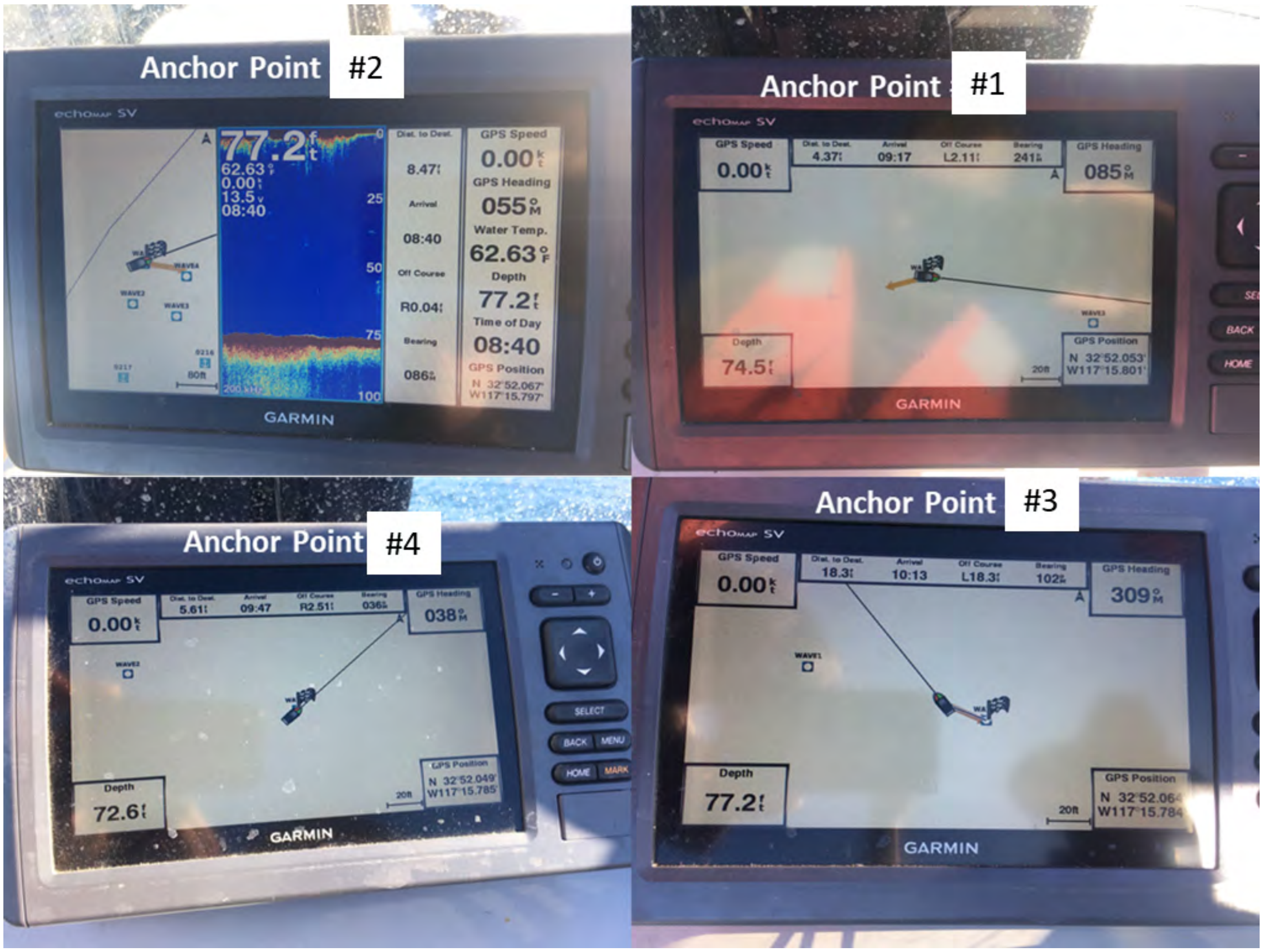

Figure 7 Vessel GPS at each Anchor Point

The below table includes the ‘Target GPS’ from the Anchor Survey operations plan (with coordinate system updated to match the vessel GPS), the ‘Survey GPS’ indicating the GPS where the survey downline was deployed, and depth readouts taken. The margin of error in the vessel GPS is approximately 8 ft (2.4 m).

Table 9 Anchor Survey locations (Target vs Actual)

Anchor#	Target GPS	Survey GPS	Error*	
2	32°52.067’	32°52.067’	5.1	ft
	117°15.796’	117°15.797’	1.6	m
1	32°52.053’	32°52.053’	0	ft
	117°15.801’	117°15.801’	0	m
4	32°52.049’	32°52.049’	5.1	ft
	117°15.784’	117°15.785’	1.6	m
3	32°52.063’	32°52.064’	21.3	ft
	117°15.780’	117°15.784’	6.5	m

**distances calculated using Great Circle Calculator (https://edwilliams.org/gccalc.htm).*

Anchor points 1-3 were surveyed at locations accurate to within the margin of error in the vessel GPS. Anchor point 4 is believed to have also been surveyed accurately, however due to a glare on the vessel GPS the photograph had to be retaken after deploying the downline and it is believed that the difference between Target and Survey is due to the drift of the vessel in the time between deploying the downline and retaking the photograph.

As the survey was completed on a rising tide, the target depth for the anchor points needs to be corrected for the tide at time of survey. The below figure shows the approximate tide at the Scripps Pier tide station at time of survey for each anchor.

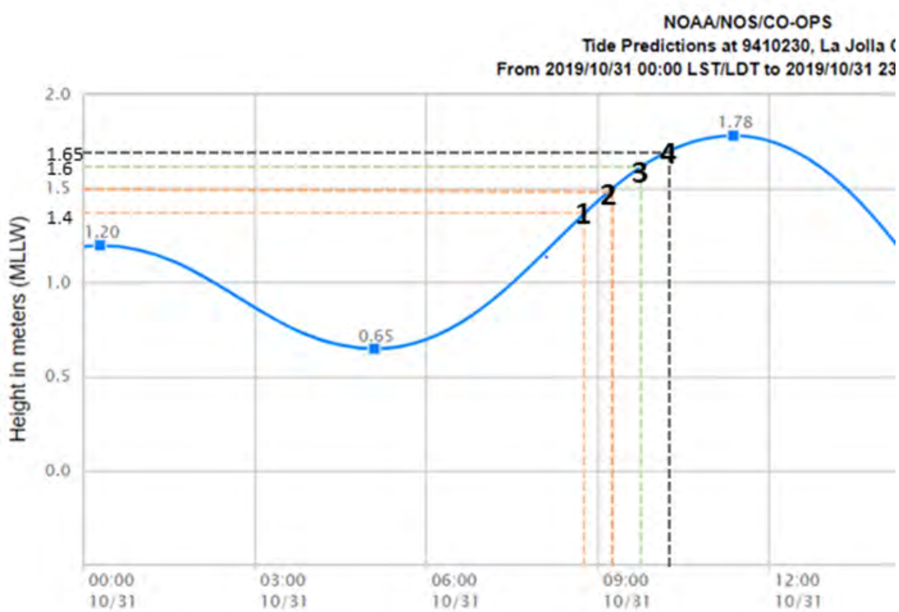

Figure 8 Tides at time of survey

Based on the above offsets, the below Target versus Actual depths were obtained for each anchor point;

Table 10 Anchor Point Depths (Target vs Actual)

Anchor#	Target Depth (MLLW)		Tide Offset	Target Depth (time of survey)		Actual Depth	Error	
2	72	ft	4.6	76.6	ft	77.2	0.6	ft
	21.95	m	1.40	23.35	m	23.53	0.18	m
1	68	ft	4.9	72.9	ft	74.5	1.6	ft
	20.73	m	1.50	22.23	m	22.71	0.48	m
4	67	ft	5.2	72.2	ft	72.6	0.4	ft
	20.42	m	1.60	22.02	m	22.13	0.11	m
3	71	ft	5.4	76.4	ft	77.2	0.8	ft
	21.64	m	1.65	23.29	m	23.53	0.24	m

As can be seen, on average the surveyed depth was ~1 ft deeper than anticipated, which is well within an acceptable limit. Equally as important as actual depth at anchor is the differential in depth between anchor points. A target was set to find a suitable anchor location with a slope of less than 5%. However, as presented below, the actual depths surveyed slightly exceed this target (5.3%). This has been reviewed and determined to be an acceptable deviation.

Table 11 Anchor Footprint Slope (Target vs Actual)

Track	Target Slope	Actual Slope	Error
2->1	-4.5%	-3.0%	1.5%
1->4	-3.7%	-2.1%	1.6%
4->3	4.5%	5.3%	1.2%
3->2	1.1%	0	1.1%
2->4	-4.0%	-3.7%	1.3%
1->3	2.4%	2.2%	0.2%

Video footage of the dive survey is located on the project server at:
https://drive.google.com/open?id=1Rv_1IOmep9RYWKLp1TAdvVbitLL3oIg3&authuser=dan@calwave.energy&usp=drive_fs

As can be seen in the video footage, all four anchor sites are free of debris, obstructions or macrobenthos.

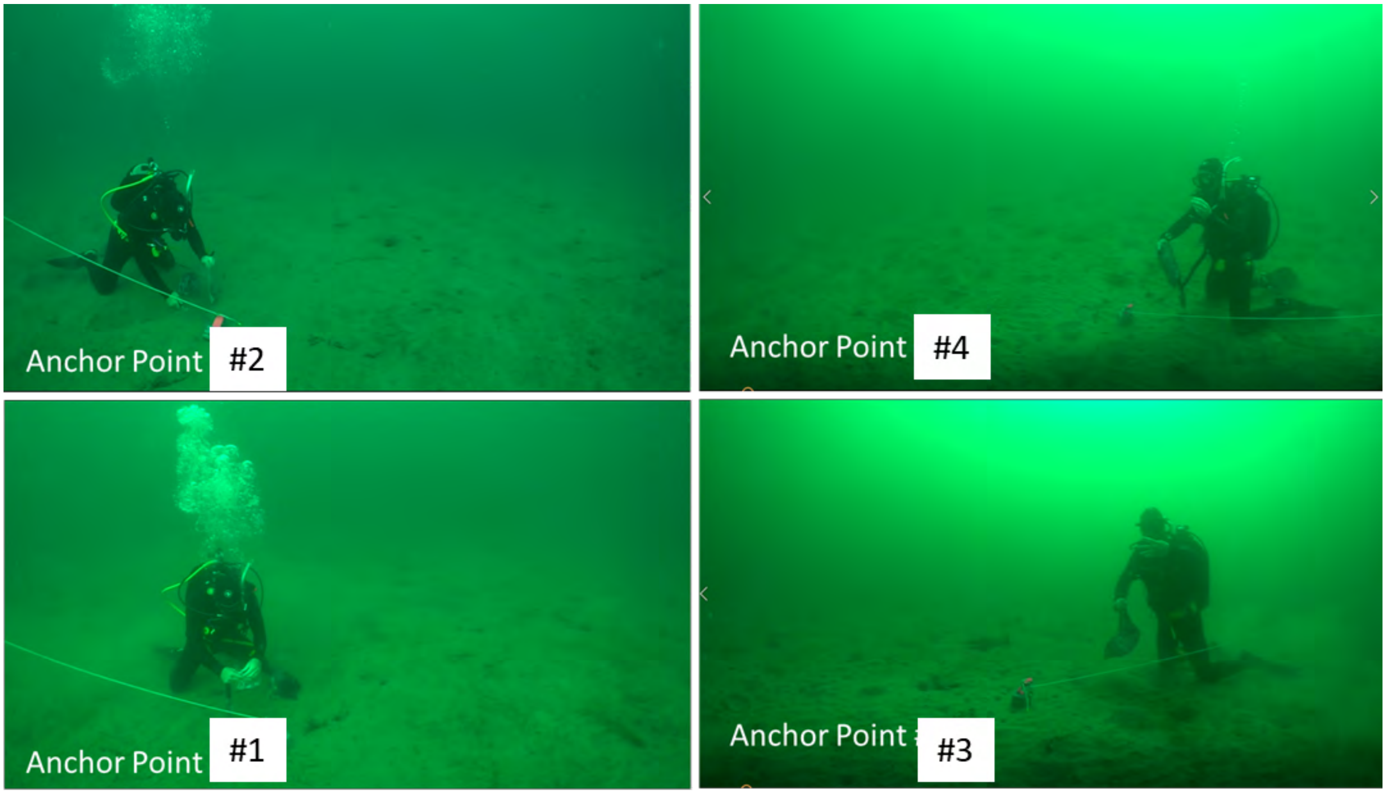

Figure 9 Screen Captures of Dive Survey

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Budget Period 2

Task 5.4 Comprehensive IO&M and Testing Plan

9.2 CoastScout Wave Measurement Buoy Installation, Operation, and Maintenance Plan

Version 1.1 - December 2019

1387 Scenic Ave, Berkeley, California, 94708 +1 510-508-9897 team@CalWave.energy

CONTENTS

1 INTRODUCTION

CalWave Power Technologies is commercializing the X-Wave™ Wave Energy Converter (WEC) buoy with several novel features which enable consistent, predictable power output while managing structural loads, ultimately providing competitive energy for coastal communities.

MarineLabs develops, produces and deploys oceanographic measurement tools to improve domain awareness in the marine environment. The MarineLab's CoastScout is a sensor buoy with a small footprint which uses inertial measurements to derive wave elevation time series and sea state parameters.

CalWave is planning an 8-month demonstration deployment of the X16, a variant of the XWave buoy, near Scripps Institute of Oceanography in La Jolla, California for the summer and fall of 2020. MarineLabs will provide two wave measurement devices to be deployed near the WEC:

1. **CoastScout Buoy** – a self-contained wave measurement and telemetry unit
2. **CoastScout Canister** – a smaller sensor package meant to "piggyback" on other buoys

This report focuses on the deployment, operation, maintenance, and recovery of the two CoastScout units. All operations are being coordinated with University of California, San Diego (UCSD) Scripps Institute of Oceanography (SIO) staff as well as local vessel operators and marine operations contractors. The details outlined in these procedures are contingent upon several factors, such as operation conditions, vessel ability, safety, efficiency, etc. Due to these factors, this plan is subject to change. Adjustments to sequences for the preset installation and connection can be made in the field with the use of Management of Change (MOC) process. The respective management personnel must be contacted and contribute to determining a safe and effective method of performing operations. The current and weather conditions must be deemed favorable before starting operations.

Before the start of any operations, all vessels and individuals involved will hold operational procedure review and safety meetings to prepare for upcoming operations. All equipment will be checked at this time and the equipment will be verified for availability for upcoming operations.

The vessel captain and CalWave representatives will approve deviations that become unavoidable in the field during the installation process. VHF working channels will be identified at this time.

This document comprises of the overall methodologies of safe operations offshore, includes vessel specifics, and operations planning for the following planned evolutions:

Table 1: Planned Offshore Operations

Activity	Days
Shore-based buoy preparation, telemetry checks, and equipment staging	1
Deployment	1
Recovery	1
Total Planned Operational Days Offshore	3

2 EQUIPMENT, VESSELS, AND PERSONNEL

2.1 VESSELS

The CoastScout is designed to be easily deployable from any small craft. Scripps' BW1, a 19' Boston Whaler, will be sufficient. The R/V Beyster could be used as a vessel of opportunity if preferred by the Scripps marine operations staff.

Table 2: Vessel List

Vessel	Operator	Website	Notes
BW1	UCSD	https://www.bostonwhaler.com/family-overview/outrage-boat-models/190-outrage/	Primary vessel
R/V Beyster	UCSD	https://scripps.ucsd.edu/ships	Alternative vessel

2.2 EQUIPMENT

2.2.1 Coast Scout Buoy

The CoastScout buoy is a small IMU-based wave measurement platform with telemetry and other auxiliary sensors. The buoy weighs ~15kg, and principle dimensions are shown in Figure 1a. Figure 1b shows MarineLabs' Scott Beatty and a CoastScout buoy en-route to a deployment. The mooring is ~100 lbs of steel chain, 1:3 scope of synthetic line, and a small leader chain at the buoy to provide righting moment. A CoastScout datasheet is in Appendix A.

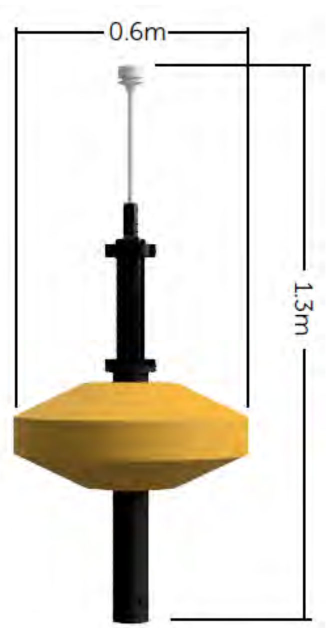


Figure 1a: CoastScout buoy principle dimensions

Figure 1b: CoastScout buoy en-route to a deployment

2.2.2 CoastScout Canister

The CoastScout Canister is a small electronics package containing just the sensors, telemetry, and batteries needed for wave measurement. It is intended to "piggyback" onto existing buoys and thus provide a rapidly-deployable and economical wave measurement platform.

Figure 2a: Proposed corner marker buoy

Figure 2b: CoastScout Canister

In this deployment, the CoastScout Canister will be attached to a corner marker buoy used to designate the project area. A proposed marker buoy is shown in Figure 2a; this document will be updated with final marker buoy and mooring plan in January 2020. A rendering of the CoastScout Canister is shown in Figure 2b.

2.3 Personnel

There groups of personnel will contribute to the CoastScout deployment.

Scripps Institute of Oceanography will operate the small boat, most likely the 19' Boston Whaler "BW1".

University of California, San Diego				
Name	**Position**	**Phone**	**Mobile**	**Email**
Christian McDonald	Scientific Diving & Small Boating Safety Officer	***Private information not included in submitted documents***		
Brett Pickering	Assistant Boating Safety Officer			

MarineLabs will provide the CoastScout buoy and CoastScout canister, assist with mooring procurement, and check the equipment assemblies prior to deployment. MarineLabs will also provide secondary/on-call support for the buoys while deployed.

MarineLabs				
Name	**Position**	**Phone**	**Mobile**	**Email**
Dr. Scott Beatty	CEO	***Private information not included in submitted documents***		

CalWave Power Technologies will choose the deployment locations best for the WEC demonstration project, procure the mooring equipment, and monitor the buoys' health and performance while deployed.

CalWave Power Technologies				
Name	**Position**	**Phone**	**Mobile**	**Email**
Dan Petcovic	COO	***Private information not included in submitted documents***		
Bryan Murray	Technical Lead			

3 Project Location

3.1 Area of Operations

The WEC will be deployed approximately 500m offshore from Scripps' Pier in La Jolla, California. SIO's CDIP 201 wave measurement buoy is approximately 400m west of the WEC's location. The CoastScout Buoy will be placed between CDIP201 and the WEC. The CoastScout Canister will be placed on the west-most corner marker buoy. The relative position of the buoys is shown in Figure 3: Project Area with relative position of the wave measurement assets..

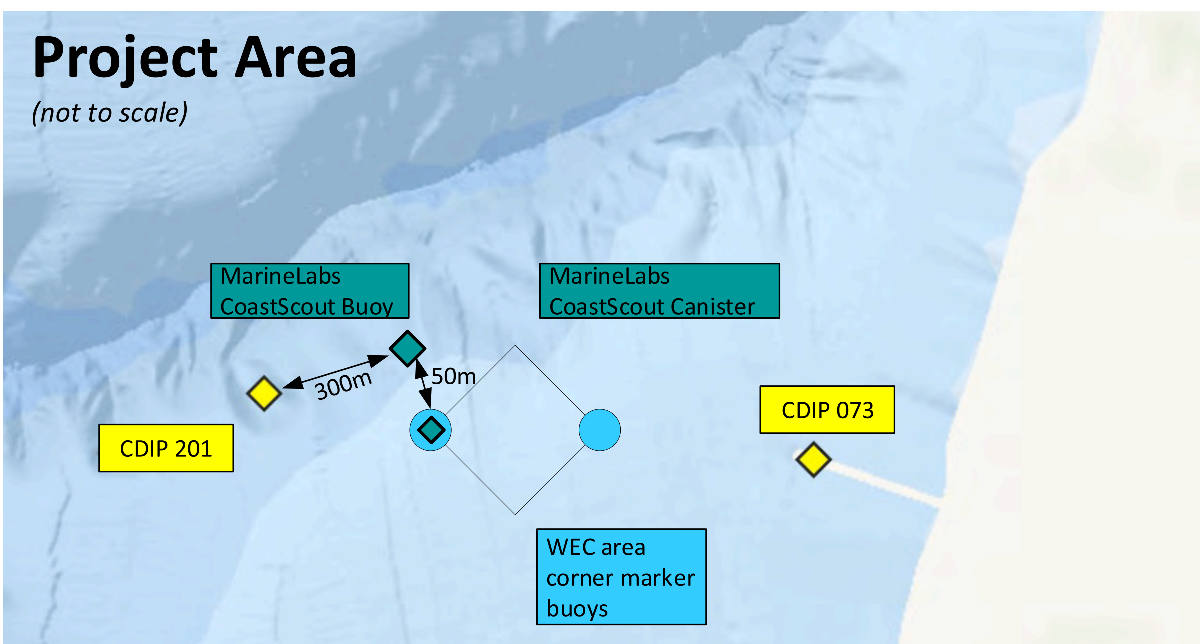


Figure 3: Project Area with relative position of the wave measurement assets.

4 Deployment Operations

4.1 Day 1: Equipment Preparation

Anticipated Timeframe: January 27 – February 7, 2020
Duration: 4 hours (1 Day)

The day before deployment MarineLabs and CalWave personnel will meet at Scripps Pier to ready the two buoys.

4.2 Day 2: Deployment

Anticipated Timeframe: January 27 – February 7, 2020
Duration: 1 Day

Scripps personnel will lead the deployment on Day 2, most likely from the BW1.

4.3 Day 3: Recovery

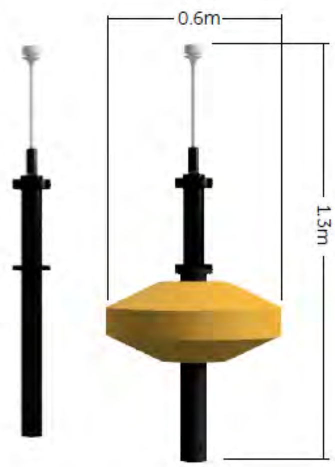
Anticipated Timeframe: December 2020
Duration: 4 hours (1 day)

The buoys will be recovered after the WEC testing period. A provision will be included for extending the CoastScout's deployment if agreed by all parties.

APPENDIX A: COASTSCOUT BUOY DATA SHEET

A compact, rugged, marine data solution

The CoastScout is an end-to-end marine data solution enhancing marine domain awareness, optimizing operational decisions, and validating coastal models. It measures high resolution directional wind, wave, and air temperature in the standard oceanographic formats that you can rely on. The data is securely transmitted, stored and processed on our cloud systems enabling your team to download and analyze the data through our interactive desktop. Ask our sales team about our additional custom analytics and data processing services.



Advantages

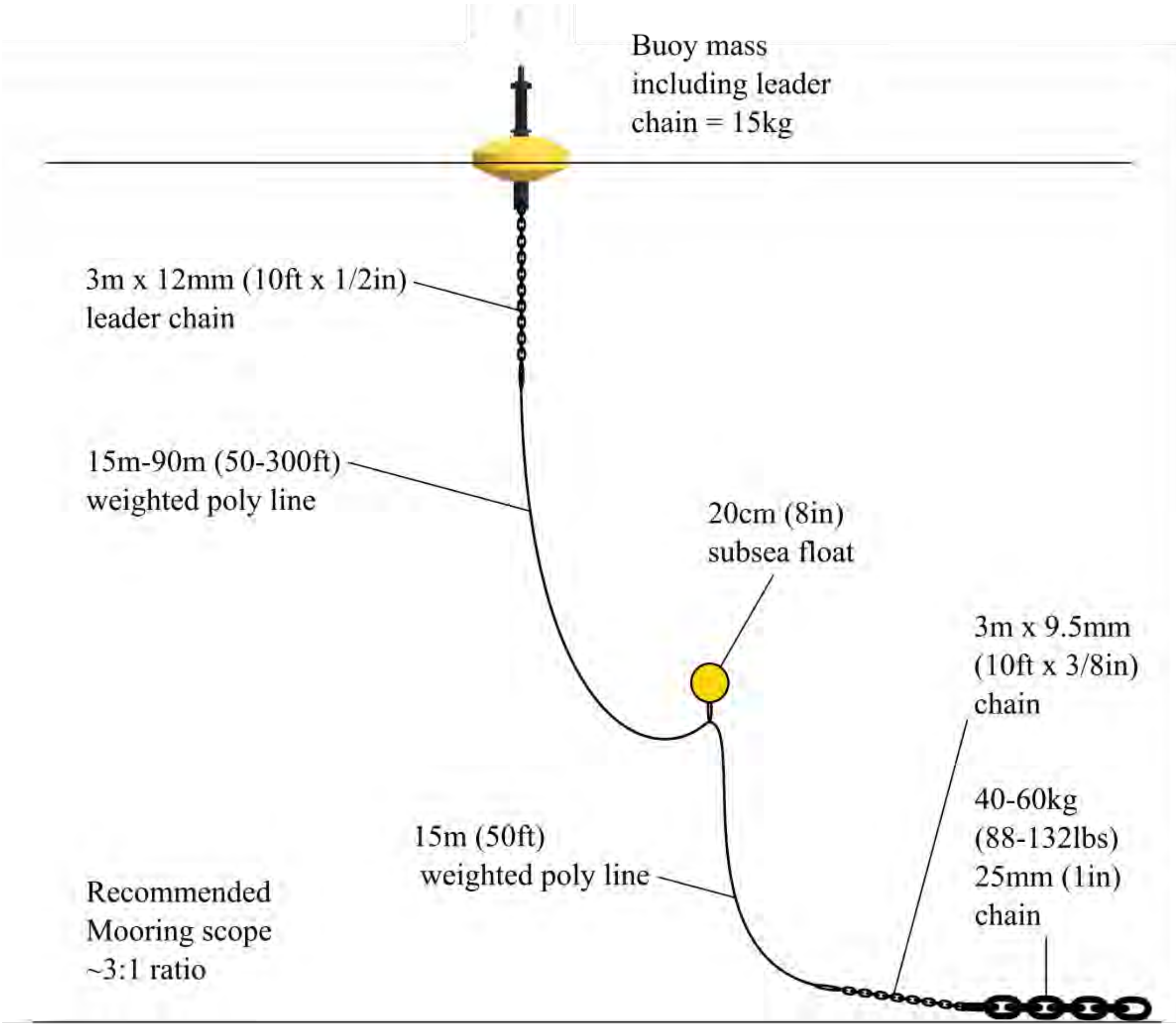
Cuts operations time and hassle compared to legacy systems.
Enables 5 minute servicing without exposing electronics at sea.
Updates you every 15min or faster with adjustable configuration.
Makes costs predictable with our Data as a Service (DaaS).
Provides new data insights from extremely high resolution data.

Specifications

Mass	Buoy 15kg, Anchor 30-60kg
Size	0.6m diameter, 1.2m height
Water depth	5-200m
Telemetry (optional)	Cellular / 3G
Default logging (configurable)	15min logging, 15min save+send
Directional resolution	5 degrees
Wind speed accuracy	Error < 2kt
Wind speed range	0.25-80kt
Wave height accuracy	Error < 2%
Wave height range	0-15 m
Wave period range	0.5-25sec
Air temperature resolution	1 degree C

MarineLabs
2A-4476 Markham St., Victoria, BC, Canada
+1 778 817 1198 | info@marinelabs.io

APPENDIX B: COASTSCOUT MOORING ARRANGEMENT



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Budget Period 2

Task 5.4 Comprehensive IO&M and Testing Plan

9.5 Anchor Installation Plan

Version 2.5 - April 2020

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FIGURES

TABLES

1 INTRODUCTION

This report focuses on the anchor installation planning for the open water demonstration to be conducted in collaboration with University of California, San Diego (UCSD) near the Scripps Institute of Oceanography (SIO) pier, in a water depth of approximately 70 ft (21.3 m).

WEC Deployment (center of mooring grid)

Lat.	Long.
32°52'03.47"N	117°15'47.42"W

Figure 1: Test Site Location

All operations are being conducted in coordination with CalWave Power Technologies (CalWave), the University of California, San Diego (UCSD) Scripps Institute of Oceanography (SIO) staff and Pacific Tugboat Services (PacTug).

The details outlined in these procedures are contingent upon several factors, such as operation conditions, vessel ability, safety, efficiency, etc. Due to these factors, this plan is subject to change. Adjustments to sequences for the preset installation and connection can be made in the field with the use of Management of Change (MOC) process. The current and weather conditions must be deemed favorable before starting operations.

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The vessel captain and CalWave representatives will approve deviations that become unavoidable in the field during the installation process. VHF working channels will be identified at this time.

This document comprises of the overall methodologies of safe operations offshore, includes vessel specifics, and operations planning for the following planned evolutions:

Table 1: Planned Offshore Operations

Activity	Days
Anchor Location Marking Pre-Dive	1
Anchor Installation	1
Anchor Recovery	1
Total Planned Operational Days Offshore	3

2. VESSELS, AND EQUIPMENT

2.1 VESSELS

Table 2: Vessel List

Vessel	Operator	Website	Notes
DB San Diego	Pacific Maritime Group	https://www.pacificmaritimegroup.com/fleet_categories/crane-barges/	Primary work vessel
Coastal Tug 1	Pacific Maritime Group	https://www.pacificmaritimegroup.com/fleet_categories/ocean-and-coastal-towing/	DB San Diego support
Coastal Tug 2	Pacific Maritime Group	https://www.pacificmaritimegroup.com/fleet_categories/ocean-and-coastal-towing/	DB San Diego support
R/V Beyster	UCSD	https://scripps.ucsd.edu/ships	Support vessel
19' Boston Whaler	UCSD	https://scripps.ucsd.edu/ships	Auxiliary support vessel (optional)

2.2 EQUIPMENT

Reinforced Concrete Anchor Blocks

The reinforced concrete anchor blocks used for the wave energy converter four-point anchoring system have been designed to provide the lowest risk solution for station keeping and ensuring a stiff reaction point for the mooring connection point. The anchor specifications and weight requirements are based on the U.S. Navy Facilities Command (NAVFAC) Geotechnical Manual and utilized input from historical seafloor sediment transport and core sample data, complimented with dive survey and surface sediment sample lab analysis conducted in 2019. The full engineering calculations report and lab analysis are available as appendices to this document.

GIS reviews of the local area were performed to find an anchor location at optimal depth and with minimal slope between anchor points; however, there is a gradual slope along the seafloor at the anchor location. Due to this slope and the nature of the seafloor sediment each anchor has a different weight corresponding to the specific slope and load direction for that anchor (e.g. load pulling an anchor towards a downhill slope requires a larger anchor than load pulling in an uphill direction).

The submerged and dry weight for each anchor is shown below.

ANCHOR	SLOPE	DIMENSION			SUBMERGED WEIGHT		DRY WEIGHT		TYPE
	(DEG)	L (IN)	W (IN)	H (IN)	(TONNE)	(KIPS)	(TONNE)	(KIPS)	
1	-2.81	144	120	43	16.8	36.9	29.3	64.5	B
2	2.01	144	120	53	20.7	45.5	36.1	79.5	A
3	5.53	144	120	64	25	54.9	43.6	96	A
4	-1.52	144	120	45	17.6	38.6	30.7	67.5	B

Figure 2: Anchor submerged and dry weights

Due to the differences in weight, the anchors are separated into 'Type A' and 'Type B'. In order to allow for a common form to be used in fabrication, all anchors have the same linear dimensions (10-ft by 12-ft) and vary in height to achieve their specific weight.

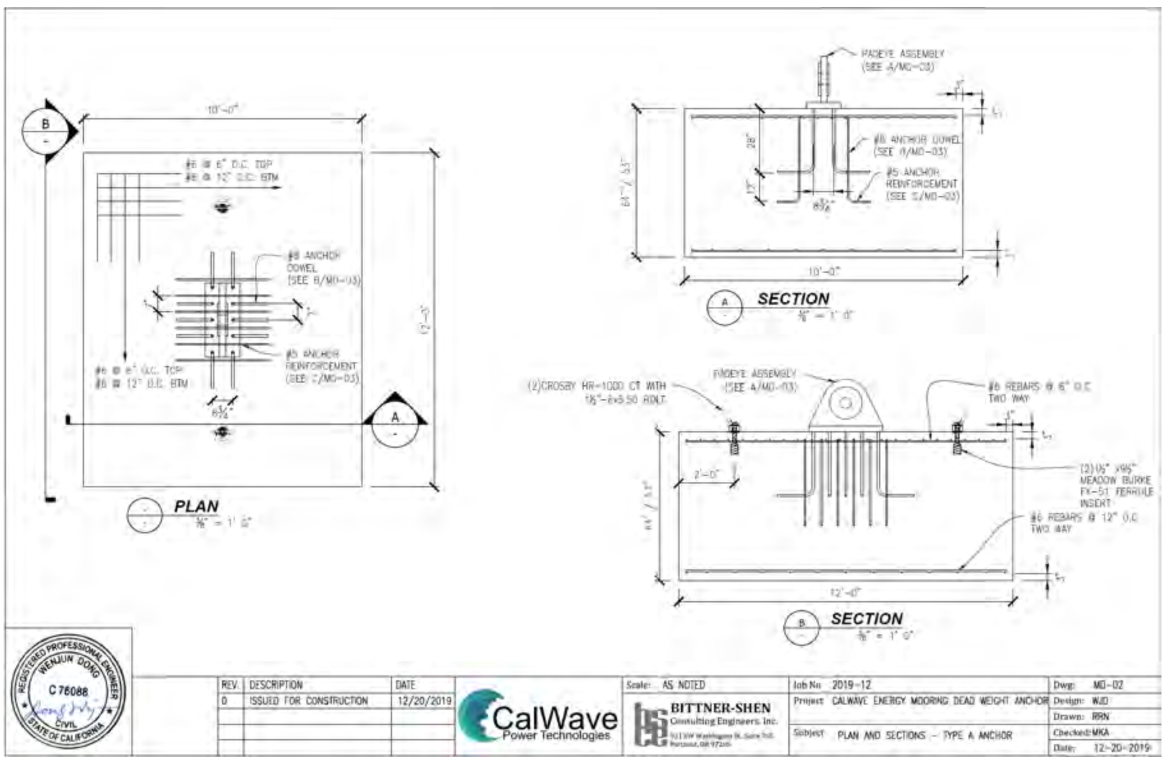


Figure 3: Type A Concrete Block Anchor Drawing

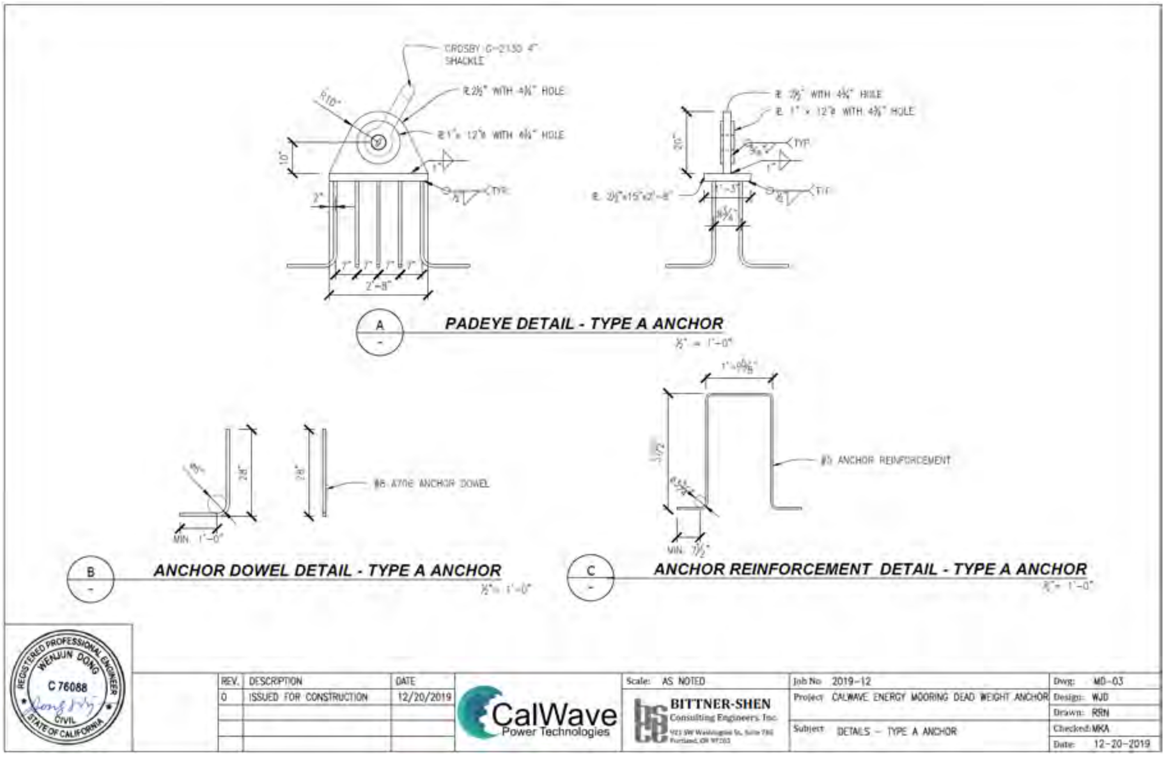


Figure 4: Type A Anchor Lifting Padeye

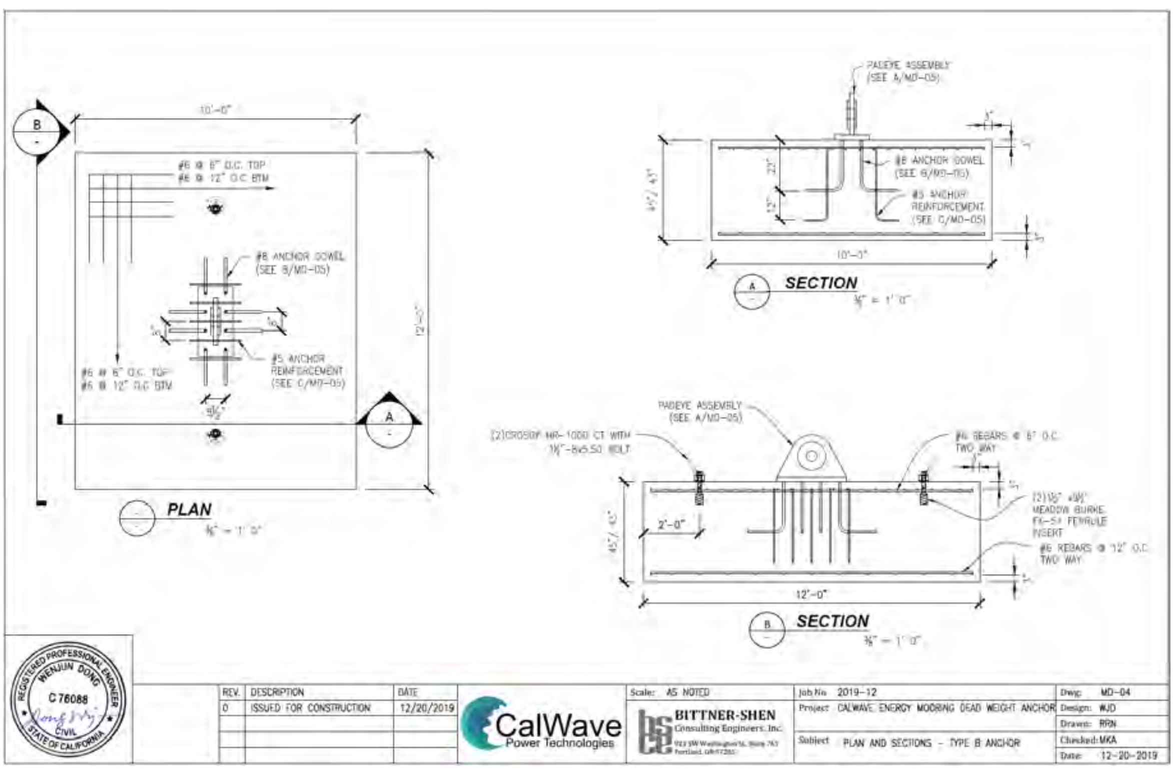


Figure 5: Type B Concrete Block Anchor Drawing

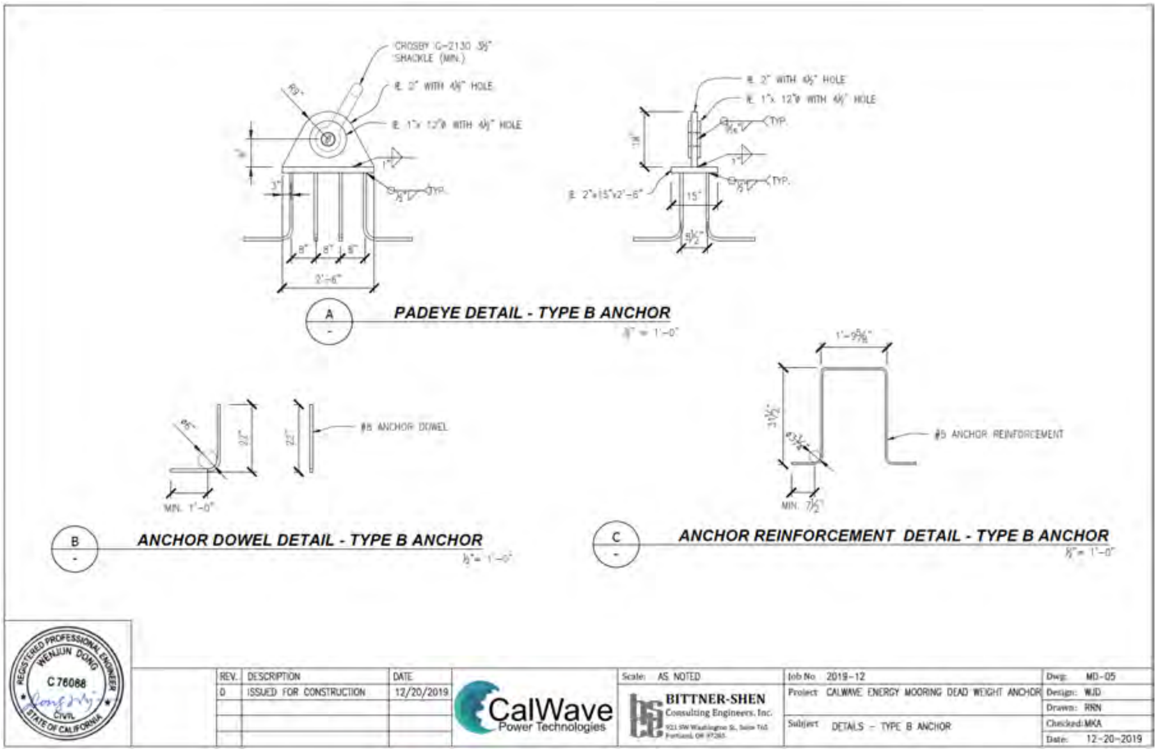


Figure 6: Type B Anchor Lifting Padeye Detail

The steel lifting padeye is designed to support lifting the dry weight of the anchor and is additionally oversized to accommodate estimated suction forces that will need to be overcome when recovering the anchor from the seafloor after the test period. The anticipated suction force is calculated based on seafloor sediment lab analysis and sand/silt content.

As the lifting padeye is sized for loads significantly in excess of the design mooring loads of the CalWave WEC, additional lift rings are cast into the anchor blocks to be used as mooring connection points. This will allow for handling of this mooring line from a second vessel (R/V Beyster) to ensure control of the blocks during lifting operations and to accurately orient the blocks towards the center of the mooring grid.

The DB San Diego will use 1-1/8" wire rope in an endless line configuration for the lifting operation. The wire rope will be in excess of 150 ft long in order to complete the operation. The wire rope is routed through the center shackle attached to the anchor lifting padeye. The mouth of the shackle is sufficiently sized to allow for the swaged end (including thimble) to be pulled through from the surface.

Figure 7: 1-1/8" Wire Rope

In order to accommodate the thimble (based on below dimensions), the allowed clearance in the lifter will need to be in excess of 6”.

Size (IN) (nominal wire rope diameter)	Apx. Weight in Pounds	A	B	C	D	E	F
1-1/8-1-1/4	4.000	7.00	5.88	5.12	2.88	1.88	1.31

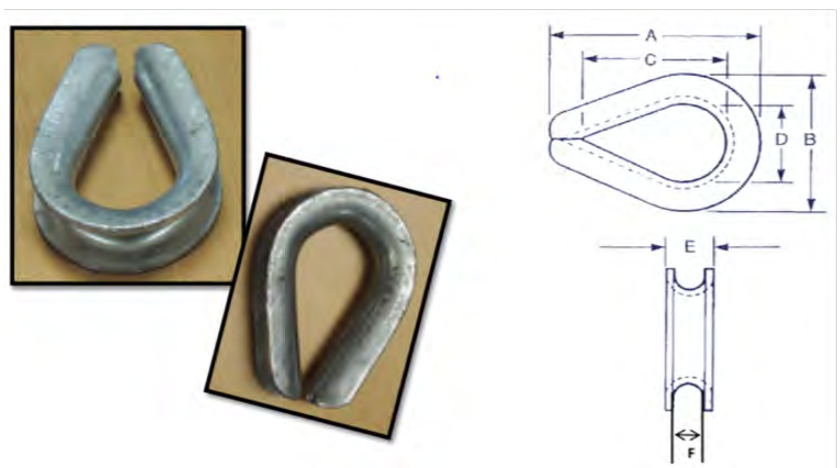
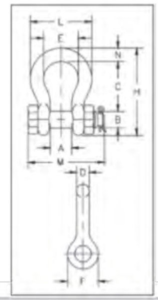


Figure 8: Wire Rope Thimble Dimensions



G-2130 / S-2130 Bolt Type Anchor Shackles

Nominal Size (in)	Working Load Limit (t)*	Stock No.			Weight Each (lb)	Dimensions (in)										Tolerance +/-	
		G-2130	S-2130	G-2130OC		A	B	C	D	E	F	H	L	M	N	C	A
3-1/2	† 120 ‡	1019739	–	–	265.00	5.25	3.76	14.63	3.62	9.00	8.00	24.88	17.02	17.00	4.38	.25	.25
4	† 150 ‡	1019757	–	–	338.00	5.50	4.26	14.50	4.00	10.00	9.00	25.68	18.00	17.75	4.56	.25	.25

Type A Anchor

Type B Anchor

Figure 9: Anchor Padeye Shackle Dimensions

3 Project Location

3.1 Area of Operations

The area being investigated for this operation is the vicinity of the proposed anchor locations for the CalWave WEC. GPS coordinates for these locations are provided in DMS, DMM, and DD format below.

Table 3: Anchor Placement Locations

Anchor#		Deg	Min	Sec	Depth		dd	Deg	Min
A1	N	32	52	4.068	71.85	ft	32.867797	32	52.0678
	W	117	15	47.832	21.90	m	117.263287	117	15.7972
A2	N	32	52	3.144	68.85	ft	32.867540	32	52.0524
	W	117	15	48.090	20.99	m	117.263358	117	15.8015
A3	N	32	52	2.922	67.85	ft	32.867478	32	52.0487
	W	117	15	47.046	20.68	m	117.263068	117	15.7841
A4	N	32	52	3.810	71.85	ft	32.867725	32	52.0635
	W	117	15	46.710	21.90	m	117.262975	117	15.7785

It is important to differentiate the anchor positions above with the WEC mooring connection point locations. The anchors to be installed will be lifted by the crane barge from a center lift point, whereas the WEC moorings will connect to a separate hoist ring 4-ft away from the centered lift point (in the direction of the load).

The tolerance required for accuracy of anchor placement is +/- 1.5 meters. It is unlikely that this level of accuracy can be attained with the crane barge GPS alone. Therefore, it is intended that the crane barge placement of lowering the crane into the water be +/- 0.001 minutes.

The table below contains the anchor placement coordinates with tolerances, including a min and max GPS reading. This tolerance is for crane barge boom positioning only and once each anchor is in the water column, the R/V Beyster will assist with more accurate placement.

Table 4: Crane Barge Boom Location Tolerance

#	Deg	Min	Tolerance (+/-)	max	min
A1	32	52.0678	0.001	52.069	52.067
	117	15.7972	0.001	15.798	15.796
A2	32	52.0524	0.001	52.053	52.051
	117	15.8015	0.001	15.803	15.801
A3	32	52.0487	0.001	52.050	52.048
	117	15.7841	0.001	15.785	15.783
A4	32	52.0635	0.001	52.065	52.063
	117	15.7785	0.001	15.78	15.778

This tolerance sets up a bounding box of 5.4 meters by 4.5 meters, as shown below by the yellow dashed line for Anchor Point #1. The red dashed circle is the allowable tolerance of +/- 1.5 meters.

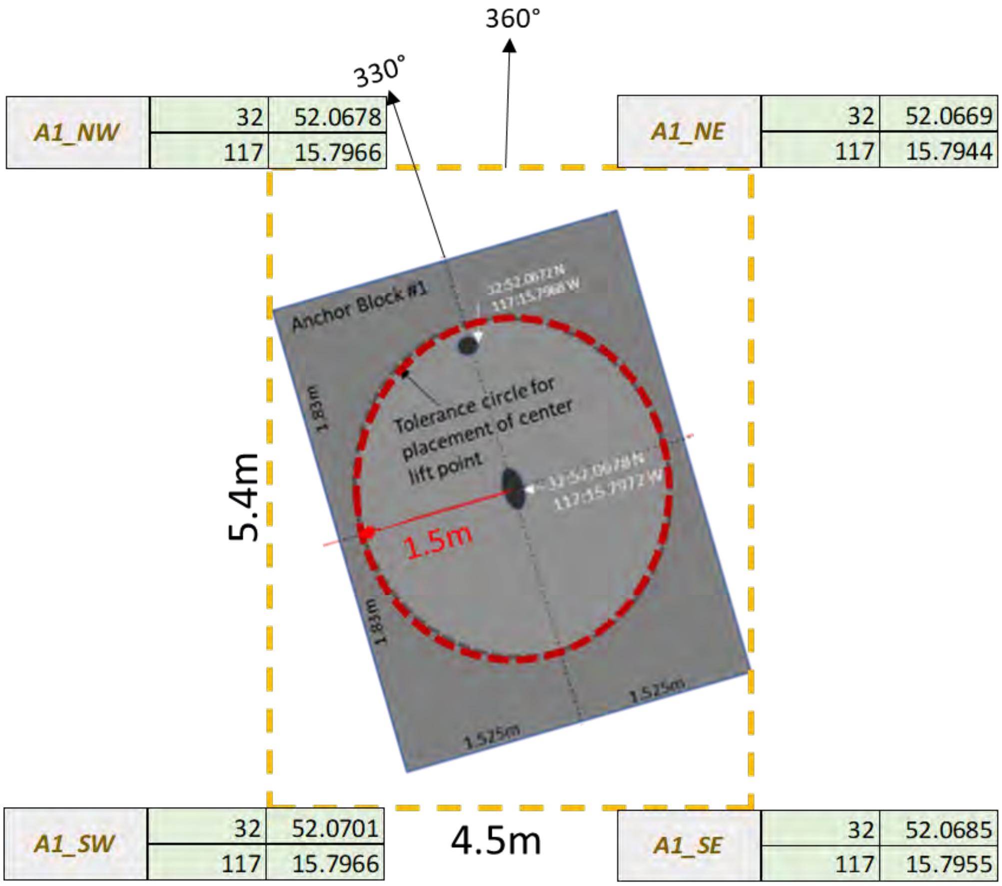


Figure 10: Anchor Tolerance Deviation

This tolerance is intended to get the crane barge as close as possible to the target location, allowing the R/V Beyster to correctly align the anchor block and use its ROV to verify anchor placement with the assistance of seafloor markings.

The figure below shows the anchor placement orientations relative to the CalWave prototype device. The black dots in the center of the anchor blocks (A1, A2, A3, A4) are the padeyes that will be used by the crane barge and the red dots (M1, M2, M3, M4) are the offset lift hoist rings that will be connected to the mooring lines.

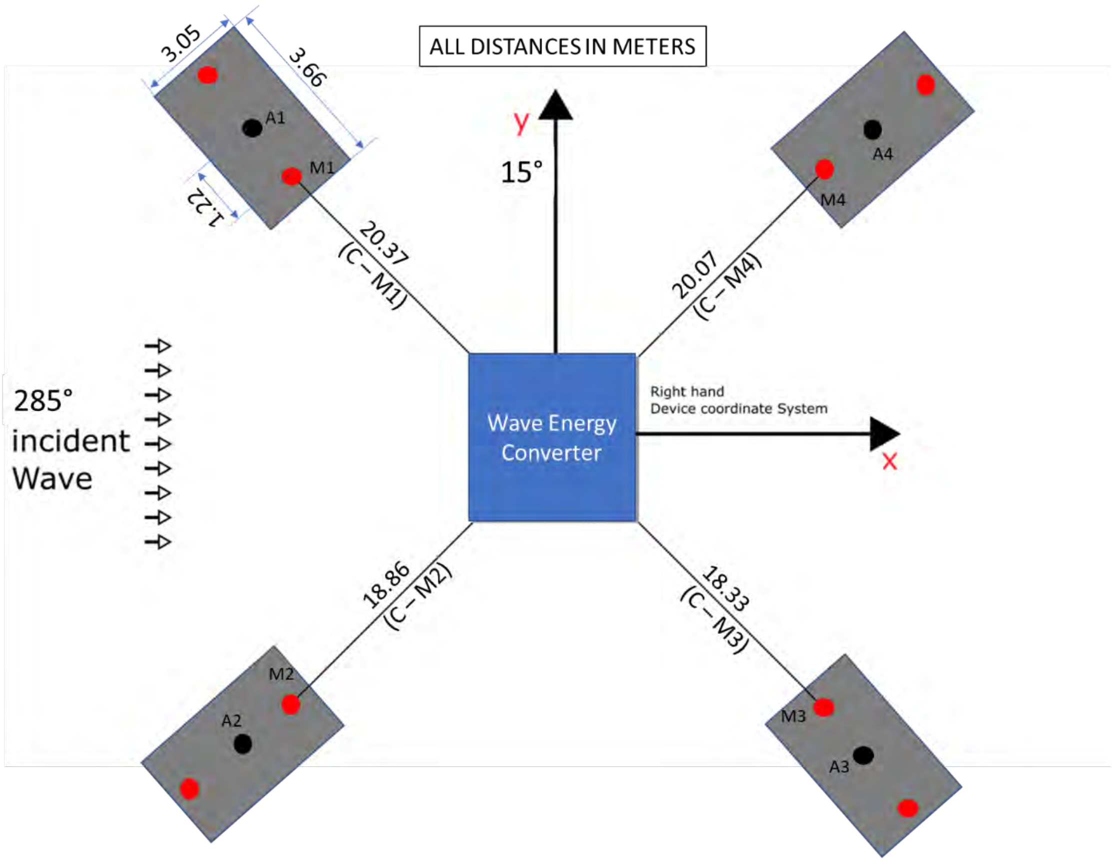


Figure 11: Mooring Placement Orientation

There are also five buoys deployed or planned to be deployed in the general operational area. Two of these buoys are owned and operated by UCSD staff (CDIP201 & LANCE1). The other three buoys are related to the prototype deployment and operated by CalWave (CoastScout, ATON2 & ATON4). The GPS coordinates for these buoys are located in the table below and the relative distances and watch circles for each are included the figure below the table.

Table 5: Buoy Locations Near Site

#		Deg	Min	Sec	Depth		dd	Deg	Min
ATON2	N	32	52	2.268	69.85	ft	32.867297	32	52.0378
	W	117	15	49.878	21.29	m	117.263855	117	15.8313
Coast Scout	N	32	52	4.284	80.85	ft	32.867857	32	52.0714
	W	117	15	51.024	24.64	m	117.264173	117	15.8504
ATON4	N	32	52	4.686	74.85	ft	32.867968	32	52.0781
	W	117	15	44.922	22.81	m	117.262478	117	15.7487
LANCE1	N	32	52	7.320	95.00	ft	32.868700	32	52.1220
	W	117	15	48.960	28.96	m	117.263600	117	15.8160
CDIP201	N	32	52	4.264	149.00	ft	32.867851	32	52.0711
	W	117	16	0.012	45.42	m	117.266670	117	16.0002

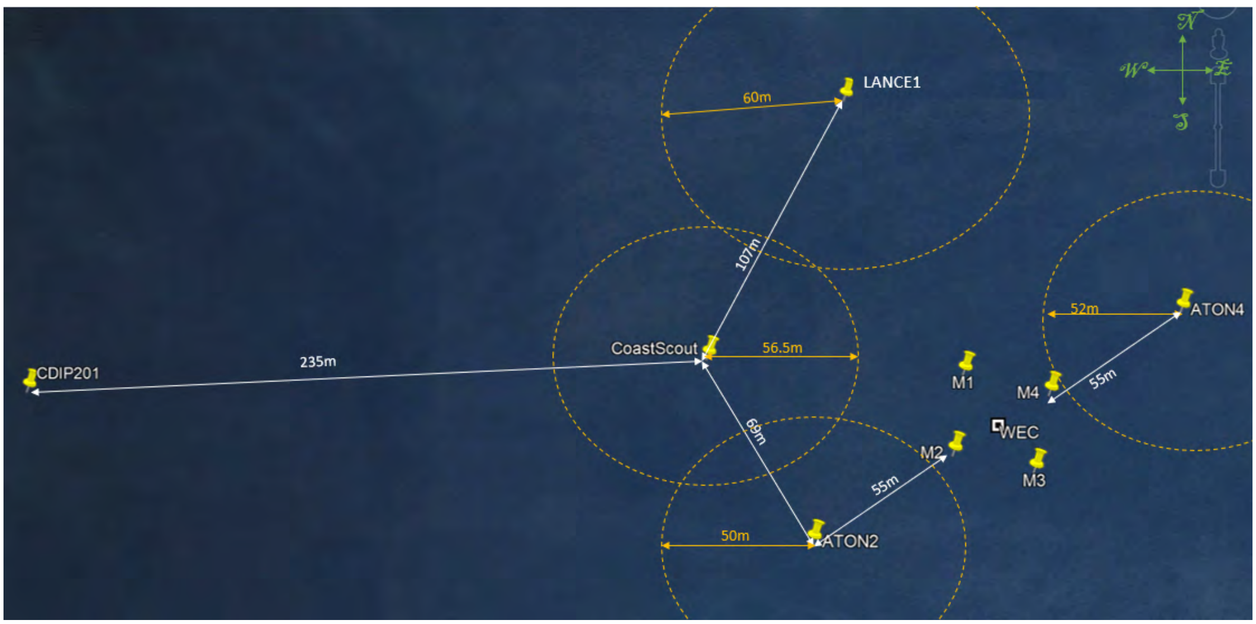


Figure 12: Locations of Buoys Near Site

3.2 Transit Routes

The *vessel* will transit to the test site along the proposed transit route as determined by vessel mobilization location and operations being performed. A list of anticipated transit routes to site is provided below inclusive of the PacTug primary work vessel, UCSD support vessel and UCSD backup safety and line handling vessel.

Table 6: Anticipated Transit Routes.

Vessel	Route	Distance (nm)
DB San Diego	1 – National City to Test Site	22.2
R/V Beyster	2 – Point Loma to Test Site	16.5
19' BW	3 – SIO Pier to Test Site	0.3

Figure 13: Transit Route 1 - National City to Test Site

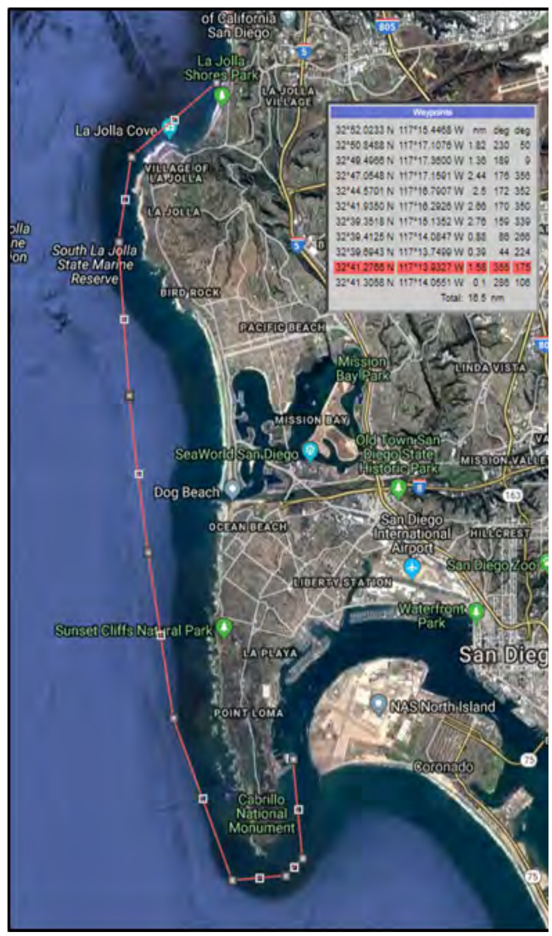


Figure 14: Transit Route 2 - Point Loma to Test Site

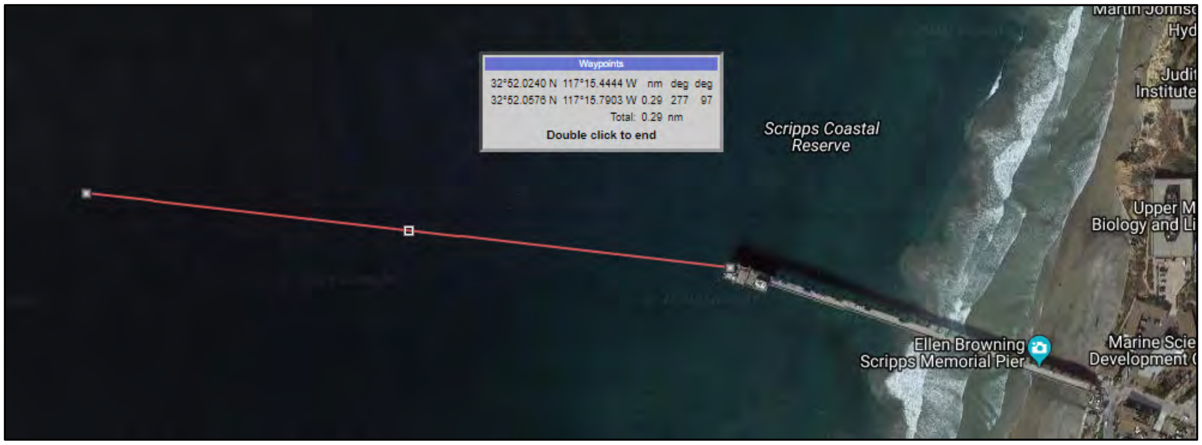


Figure 15: Transit Route 3: SIO Pier to Test Site

3.3 Site Permits

The following site permits have been approved or are in the submission process.

Table 7: Site Permits.

Permit	Status	Comment
Landowner Permission	Received	UCSD, SIO
Army Corps of Engineers	Approved, 11/05/19	SPL-2019-00424-RRS
California Coastal Commission (wavier)	Approved, 09/28/2018	9-18-0933-W
Fish and Wildlife	Approved, 10/04/2018	SC-013978
CA Water Board	Approved, 8/1/2019	R9-2019-0158
NOAA ITA	Not required	NOAA email response 11/13/2018
State Lands Commission	Not required	SLC phone meeting 10/19/2018
DOE Biological Assessment	Complete	NMFS concurrence letter received 5/9/2019
US Coast Guard PATON (CoastScout & ATON2)	Approved, 02/12/2020	CG2554

4 VESSELS & OPERATORS

4.1 CRANE BARGE - DB SAN DIEGO

The heavy lift crane barge DB San Diego, owned and operated by Pacific Maritime Group, is the intended vessel for anchor handling. This vessel is significantly oversized for the weight of anchors being deployed which will provide operational flexibility and capacity. This is particularly important for the anchor recovery operation, which could encounter suction forces from the seafloor.

Figure 16: DB San Diego

Barge Specs	
Type	Offshore Derrick Barge
Year Built	1954/2003
Length	134.9 FT
Width	58 FT
Depth	12 FT
Official Number	1231114
Capacity	150 ton revolving
Boom Length	150 feet (more available)
Generator	25 KW
Tonnage	92 G / 92 N

Figure 17: DB San Diego Specifications

4.2 Support Vessel – R/V Beyster

The research vessel Bob and Betty Beyster is a purpose-built coastal research vessel designed for efficient operations offshore in Southern California. The Beyster is owned and operated by Scripps Institute of Oceanography (SIO).

Figure 18: R/V Beyster.

This is the primary vessel intended for use during the test period. Provisional contract terms on the use of this vessel has been agreed with UCSD and will be finalized during Budget Period 2.

Vessel Specifications:

- Length: 42 ft
- Beam: 16 ft
- Freeboard: 3 ft
- Stern A frame capacity: 2.5 tons
- Starboard knuckle crane capacity: 660 lbs, 17 ft reach
- Dynamic Positioning System (DPS)
- Deck space: 192 ft^2
- Maximum speed: 38 kts
- Cruising speed: 25 kts
- Hand-deployable Sebotix LBV-300 Mini-ROV
- Acoustic communications transducer

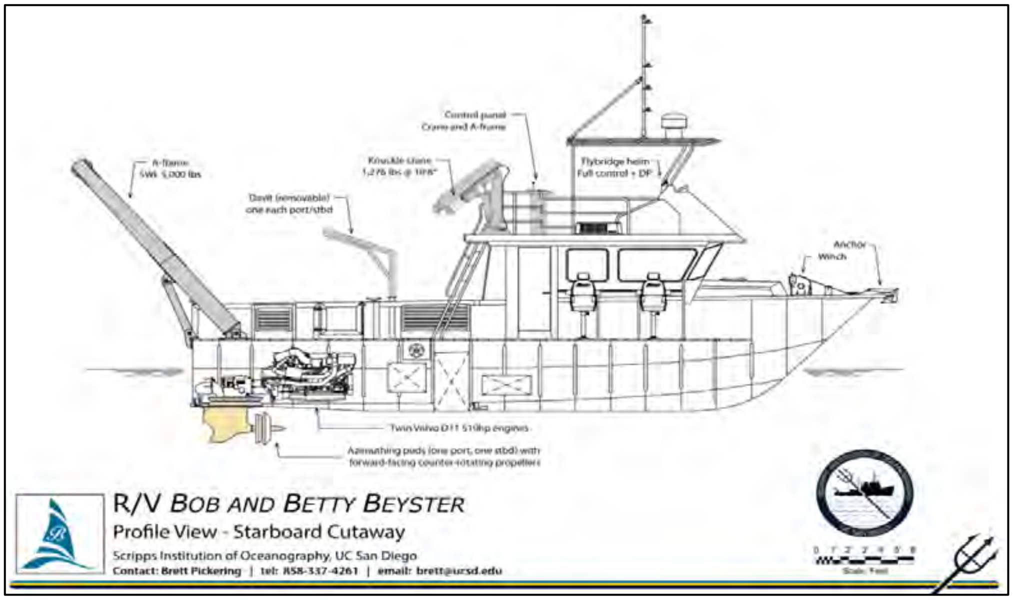


Figure 19: R/V Beyster -Starboard Cutaway

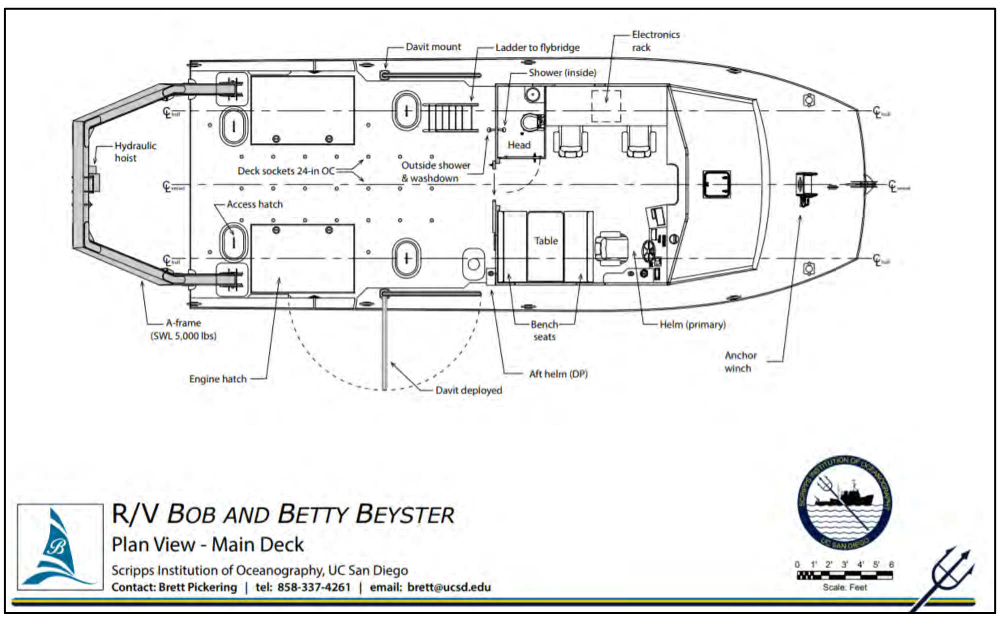


Figure 20: R/V Beyster – Main Deck Plan View

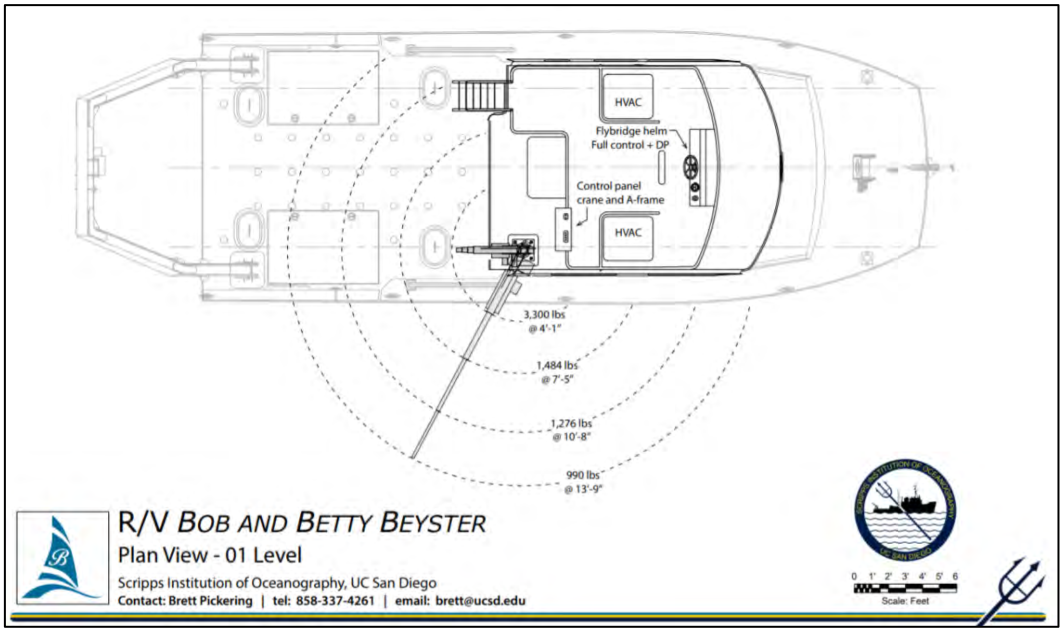


Figure 21: R/V Beyster Boom Crane Capacity

Vessel Specifications:

- Length: 19.4 ft
- Beam: 8 ft
- Draft: 13 ft
- Weight (w/engine, fuel & water): 2769 lbs
- Maximum weight capacity: 2500 lbs
- Swamped capacity: 4000 lbs
- Persons capacity: 8
- Maximum Horsepower: 150 HP
- Minimum Horsepower: 115 HP

4.3 Support Vessel – Backup Option (19' Boston Whaler)

A small line handling vessel for operations either independently, or alongside a larger vessel. UCSD owns and operates several 19-ft Boston Whalers located on SIO pier and provisional contracting terms for the use of these vessels have been agreed with UCSD. The USCD small vessels are deployed with the pier crane and skippered by UCSD staff. At 0.3 nm from the pier, this provides the most immediate access to the test site for observations or operations appropriate for a small vessel.

Figure 22: Support Vessel (19' Boston Whaler).

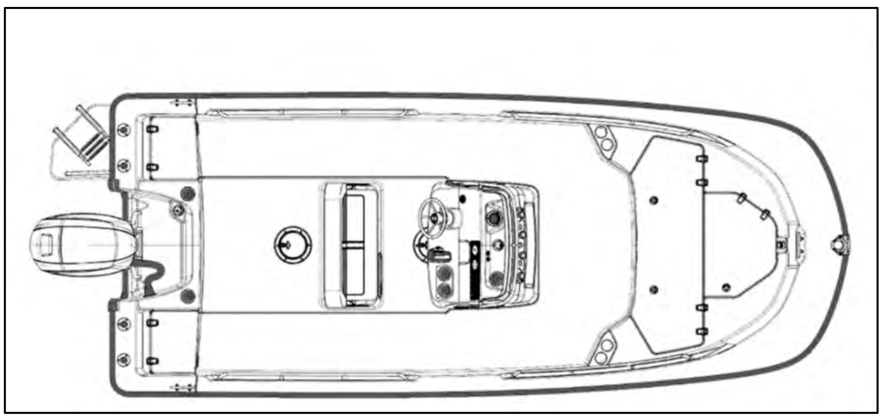


Figure 23: Boston Whaler Specifications.

5 Project Operations

5.1 Marking Pre-Dive

Shortly before deploying the concrete anchor blocks, research divers will pre-dive the site and place markers in the seafloor indicating the location of each anchor block and the allowable tolerance for placement.

The below figure illustrates anchor block #1 with a +/- 1.5m installation tolerance and the locations of six flags that would be placed to indicate these boundaries.

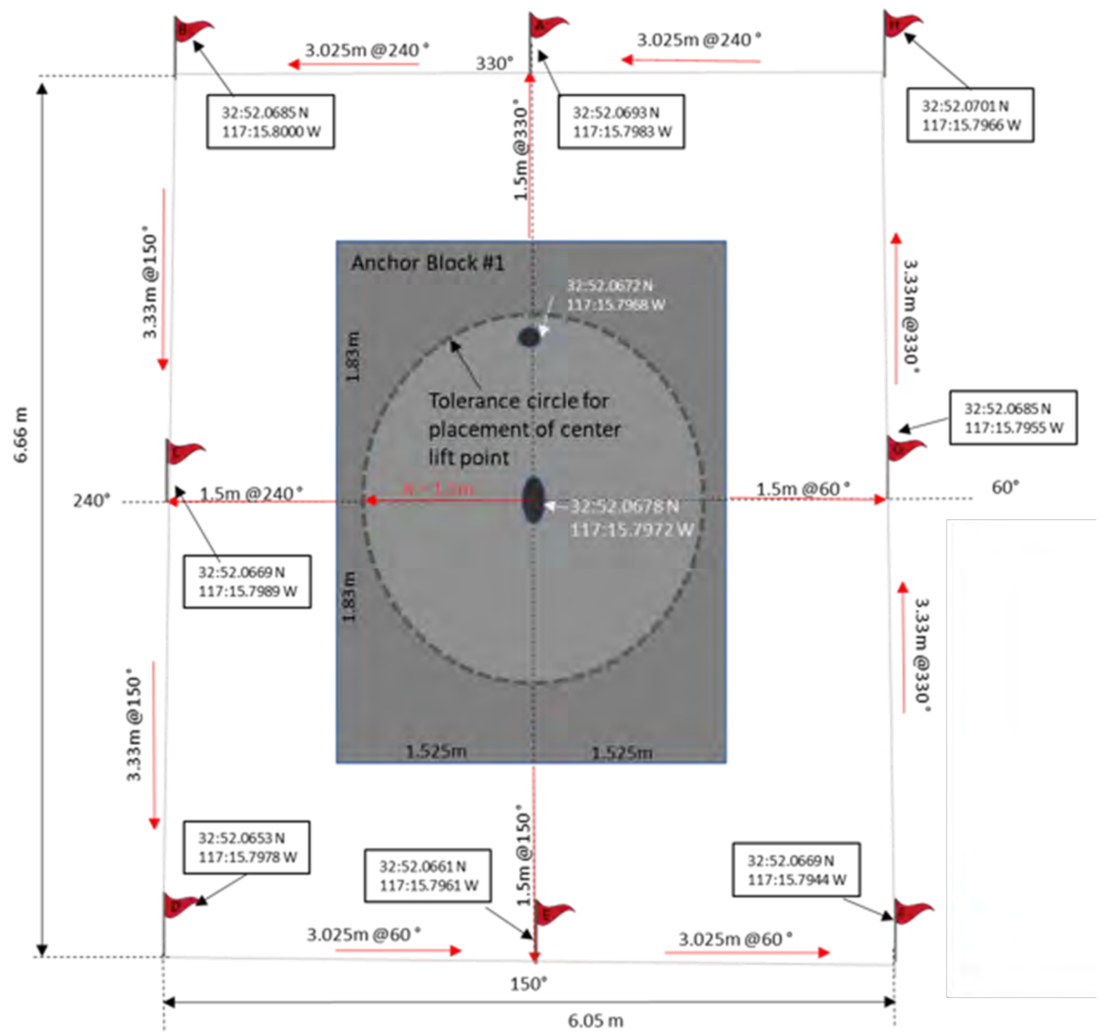


Figure 24: Anchor #1 Pre-Dive Markers

5.1.1 Mobilization: Marking Pre-Dive

The vessels will be mobilized with necessary equipment to complete the scope of work from their respective home ports. All vessels are fit out with standard safety equipment, life jackets and other personal protective equipment as required or recommended by the U.S. Coast Guard and determined by the vessel owners and vessel captain.

It is anticipated that the R/V Beyster will support dive services for this operation. This is due to the capacity of the R/V Beyster to accurately identify and verify seafloor positioning.

To mark the anchor locations, 4-ft tall (1/2-in wide) bamboo stakes with ~6-in strip of reflective tape at the top will be used. The divers will install the stakes into the soft seafloor sand approximately 7-inches deep with the help of a rubber mallet.

Figure 25: Example Marking Stakes

Table 8: Equipment List: Marking Pre-Dive

OWNER	DESCRIPTION	SIZE	QTY
R/V Beyster			
CalWave	Marking Stakes (8 per anchor)	4-ft x 0.5”	32
CalWave	Rubber Mallet	Standard	4
UCSD	Short (blue) line	3.025m	4
UCSD	Long (white) line	3.33m	4

5.1.2 Operations Sequence: Marking Pre-Dive

The dive plan consists of using the R/V Beyster to accurately identify a first marker location (Marker A), then deploy the dive time to place the marker swim the distance and heading for the remaining markers.

In order to accurately measure distance subsea, the divers will work in a pair with one diver tying too ends of a pre-measured string to two bamboo stakes and placing one stake. The other diver will swim along a specific heading until the end of the string and place the next stake and tie the next pre-measured string. The first diver will then swim to the second diver, take the next stake and swim the heading to the next location, with this process repeating around the anchor block tolerance boundary. Because the bounding box is not square, two differing length strings are used, and color coded to minimize risk of using the incorrect length string.

Table 9: Sequence: Marking Pre-Dive

<table>
<tr><th>Step #</th><th>Vessel</th><th>Assignment</th></tr>
<tr><td>1</td><td colspan="2">Transit to Anchor Point #1 and deploy dive team</td></tr>
<tr><td>1.a</td><td>R/V Beyster</td><td>
- Proceed to test site via transit route 2 (~25kts)
- Locate marker point 1. A and deploy downline
<table>
<tr><th></th><th></th><th>Deg</th><th>Min</th><th>Sec</th><th>Depth</th><th></th><th>dd</th><th>Deg</th><th>Min</th></tr>
<tr><td rowspan="2">Flag 1. A</td><td>N</td><td>32</td><td>52</td><td>4.158</td><td>71.85</td><td>ft</td><td>32.867822</td><td>32</td><td>52.0693</td></tr>
<tr><td>W</td><td>117</td><td>15</td><td>47.898</td><td>21.90</td><td>m</td><td>117.263305</td><td>117</td><td>15.7983</td></tr>
</table>
- Deploy dive team</td></tr>
<tr><td>2</td><td colspan="2">Mark Anchor Point #1</td></tr>
<tr><td>2.a</td><td>Diver #1</td><td>- Locate downline and drive Flag 1. A into the seafloor at downline
- Tie one end of short (blue) string to Flag 1. A
- Tie the other end of short (blue) string to Flag 1. B</td></tr>
<tr><td>2.b</td><td>Diver #2</td><td>- Take Flag 1. B and swim at heading 240° until end of string (3.025m)
- Drive Flag 1. B into the seafloor
- Tie one end of long (white) string to Flag 1. B
- Tie other end of long (white) string to Flag 1. C</td></tr>
<tr><td>2.c</td><td>Diver #1</td><td>- Untie short (blue) string from Flag 1. A
- Swim to Flag 1. B and take Flag 1. C from Diver #2
- Swim at heading 150° until end of string (3.33m)
- Drive Flag 1. C into the seafloor
- Tie other end of long (white) string to Flag 1. C</td></tr>
<tr><td>2.d</td><td>Diver #2</td><td>- Untie long (white) string from Flag 1. B
- Swim at heading 150° until end of string (3.33m to reach Diver #1 and continuing 3.33m farther on same heading)
- Drive Flag 1. D into the seafloor
- Tie one end of short (blue) string to Flag 1. D
- Tie other end of short (blue) string to Flag 1. E</td></tr>
<tr><td>2.e</td><td>Diver #1</td><td>- Untie long (white) string from Flag 1. C</td></tr>
</table>

<table>
<tr><td></td><td></td><td>- Swim along heading 150° to Diver #1 and take Flag 1. E
- Swim along heading 60° until end of string (3.025m)
- Drive Flag 1. E into the seafloor
- Tie other end of short (blue) string to Flag 1. E</td></tr>
<tr><td>2. f</td><td>Diver #2</td><td>- Untie short (blue) string from Flag 1. D
- Swim along heading 60° until end of string (3.025m to reach Diver #1 and continuing 3.025m farther on same heading)
- Drive Flag 1. F into the seafloor
- Tie one end of long (white) string to Flag 1. F
- Tie other end of long (white) string to Flag 1. G</td></tr>
<tr><td>2.g</td><td>Diver #1</td><td>- Untie short (blue) string from Flag 1. E
- Swim along heading 60° to meet Diver #1 and take Flag 1. G
- Swim along heading 330° until end of string (3.33m)
- Drive Flag 1. G into the seafloor
- Tie other end of long (white) string to Flag 1. G</td></tr>
<tr><td>2.h</td><td>Diver #2</td><td>- Untie long (white) string from Flag 1. F
- Swim at heading 330° until end of string (3.33m to reach Diver #1 and continuing 3.33m farther on same heading)
- Drive Flag 1. H into the seafloor
- Tie one end of short (blue) string to Flag 1. H</td></tr>
<tr><td>2.i</td><td>Diver #1</td><td>- Untie long (white) string from flag 1. G
- Swim at heading 330° to meet Diver #2 and take loose end of short (blue) string
- Swim at heading 240° until end of string (3.025m) and verify this aligns with Flag 1. A</td></tr>
<tr><td>2.j</td><td>Diver #1 & #2</td><td>- Recover to R/V Beyster</td></tr>
<tr><td>2.k</td><td>R/V Beyster</td><td>- Use vessel sonar to validate marker Flag locations</td></tr>
<tr><td>3</td><td colspan="2">Transit to Anchor Point #2 and deploy dive team</td></tr>
<tr><td>3.a</td><td>R/V Beyster</td><td>- Proceed to Anchor Point #2
- Locate marker point 2. A and deploy downline
<table>
<tr><td></td><td></td><td>Deg</td><td>Min</td><td>Sec</td><td>Depth</td><td></td><td>dd</td><td>Deg</td><td>Min</td></tr>
<tr><td rowspan="2">Flag 2. A</td><td>N</td><td>32</td><td>52</td><td></td><td></td><td>ft</td><td></td><td>32</td><td></td></tr>
<tr><td>W</td><td>117</td><td>15</td><td></td><td></td><td>m</td><td></td><td>117</td><td></td></tr>
</table>
- Deploy dive team</td></tr>
</table>

<table>
<tr><td>4</td><td colspan="2">Mark Anchor Point #2</td></tr>
<tr><td>4.a</td><td>Dive Team</td><td>- Drive Flags 2. A – 2. G using same methodology as Anchor Point #1
- Recover to R/V Beyster</td></tr>
<tr><td>4.b</td><td>R/V Beyster</td><td>- Use vessel sonar to validate marker Flag locations</td></tr>
<tr><td>5</td><td colspan="2">Transit to Anchor Point #3 and deploy dive team</td></tr>
<tr><td>5.a</td><td>R/V Beyster</td><td>- Proceed to Anchor Point #3
- Locate marker point 3. A and deploy downline
<table>
<tr><td></td><td></td><td>Deg</td><td>Min</td><td>Sec</td><td>Depth</td><td></td><td>dd</td><td>Deg</td><td>Min</td></tr>
<tr><td rowspan="2">Flag 3. A</td><td>N</td><td>32</td><td>52</td><td></td><td></td><td>ft</td><td></td><td>32</td><td></td></tr>
<tr><td>W</td><td>117</td><td>15</td><td></td><td></td><td>m</td><td></td><td>117</td><td></td></tr>
</table>
- Deploy dive team</td></tr>
<tr><td>6</td><td colspan="2">Mark Anchor Point #3</td></tr>
<tr><td>6.a</td><td>Dive Team</td><td>- Drive Flags 3. A – 3. G using same methodology as Anchor Point #1
- Recover to R/V Beyster</td></tr>
<tr><td>6.b</td><td>R/V Beyster</td><td>- Use vessel sonar to validate marker Flag locations</td></tr>
<tr><td>7</td><td colspan="2">Transit to Anchor Point #4 and deploy dive team</td></tr>
<tr><td>7.a</td><td>R/V Beyster</td><td>- Proceed to Anchor Point #4
- Locate marker point 4. A and deploy downline
<table>
<tr><td></td><td></td><td>Deg</td><td>Min</td><td>Sec</td><td>Depth</td><td></td><td>dd</td><td>Deg</td><td>Min</td></tr>
<tr><td rowspan="2">Flag 4. A</td><td>N</td><td>32</td><td>52</td><td></td><td></td><td>ft</td><td></td><td>32</td><td></td></tr>
<tr><td>W</td><td>117</td><td>15</td><td></td><td></td><td>m</td><td></td><td>117</td><td></td></tr>
</table>
- Deploy dive team</td></tr>
<tr><td>8</td><td colspan="2">Mark Anchor Point #4</td></tr>
<tr><td>8.a</td><td>Dive Team</td><td>- Drive Flags 4. A – 4. G using same methodology as Anchor Point #1
- Recover to R/V Beyster</td></tr>
<tr><td>8.b</td><td>R/V Beyster</td><td>- Use vessel sonar to validate marker Flag locations</td></tr>
<tr><td>9</td><td>R/V Beyster</td><td>- Transit to home port</td></tr>
</table>

Table 10: Anchor #1 Marker Grid Layout

Center of grid	N	32	52	3.47	70.85	ft	32.867631	32	52.058
	W	117	15	47.42	21.60	m	117.263172	117	15.790
#		Deg	Min	Sec	Depth		dd	Deg	Min
A1	N	32	52	4.068	71.85	ft	32.867797	32	52.0678
	W	117	15	47.832	21.90	m	117.263287	117	15.7972
Flag 1.A	N	32	52	4.158	71.85	ft	32.867822	32	52.0693
	W	117	15	47.898	21.90	m	117.263305	117	15.7983
Flag 1.B	N	32	52	4.110	71.85	ft	32.867808	32	52.0685
	W	117	15	48.000	21.90	m	117.263333	117	15.8000
Flag 1.C	N	32	52	4.014	71.85	ft	32.867782	32	52.0669
	W	117	15	47.934	21.90	m	117.263315	117	15.7989
Flag 1.D	N	32	52	3.918	71.85	ft	32.867755	32	52.0653
	W	117	15	47.868	21.90	m	117.263297	117	15.7978
Flag 1.E	N	32	52	3.966	71.85	ft	32.867768	32	52.0661
	W	117	15	47.766	21.90	m	117.263268	117	15.7961
Flag 1.F	N	32	52	4.014	71.85	ft	32.867782	32	52.0669
	W	117	15	47.664	21.90	m	117.263240	117	15.7944
Flag 1.G	N	32	52	4.110	71.85	ft	32.867808	32	52.0685
	W	117	15	47.730	21.90	m	117.263258	117	15.7955
Flag 1.H	N	32	52	4.206	71.85	ft	32.867835	32	52.0701
	W	117	15	47.796	21.90	m	117.263277	117	15.7966

5.1.3 Estimated Timeline: Marking Pre-Dive

Only vessel time is added to total time calculation (highlighted activities do not require vessel on-site)

For the below operation, a total of two vessels are anticipated.

Table 11: Timeline: Anchor Installation

Step #	Activity	Hours
M	*Mobilize R/V Beyster & dive team at Home Port (Point Loma)*	*1.0*
1	*R/V Beyster Transit to Test Site (16.5nm @ 25kts)*	*0.75*
2	Mark Anchor Point #1	1.0
3	Transit to Anchor Point #2	0.5
4	Mark Anchor Point #2	1.0
5	Transit to Anchor Point #3	0.5
6	Mark Anchor Point #3	1.0
7	Transit to Anchor Point #4	0.5
8	Mark Anchor Point #4	1.0
9	*R/V Beyster Transit to Home Port (16.5nm @ 25kts)*	*0.75*
DM	*Demobilize R/V Beyster & dive team*	*1.0*
	Total Time Estimate (hours) – R/V Beyster	**9.0**
	Total Time on Site (hours) – R/V Beyster	**5.5**

Anticipated as a one-day operation.

5.2 Anchor Installation

In anticipation of deploying the CalWave wave energy converter (WEC), four concrete block gravity-based anchors are to be deployed at the SIO test site. These anchors, deployed at the specific locations provided in section 4.1 will form a non-square mooring grid, as shown below.

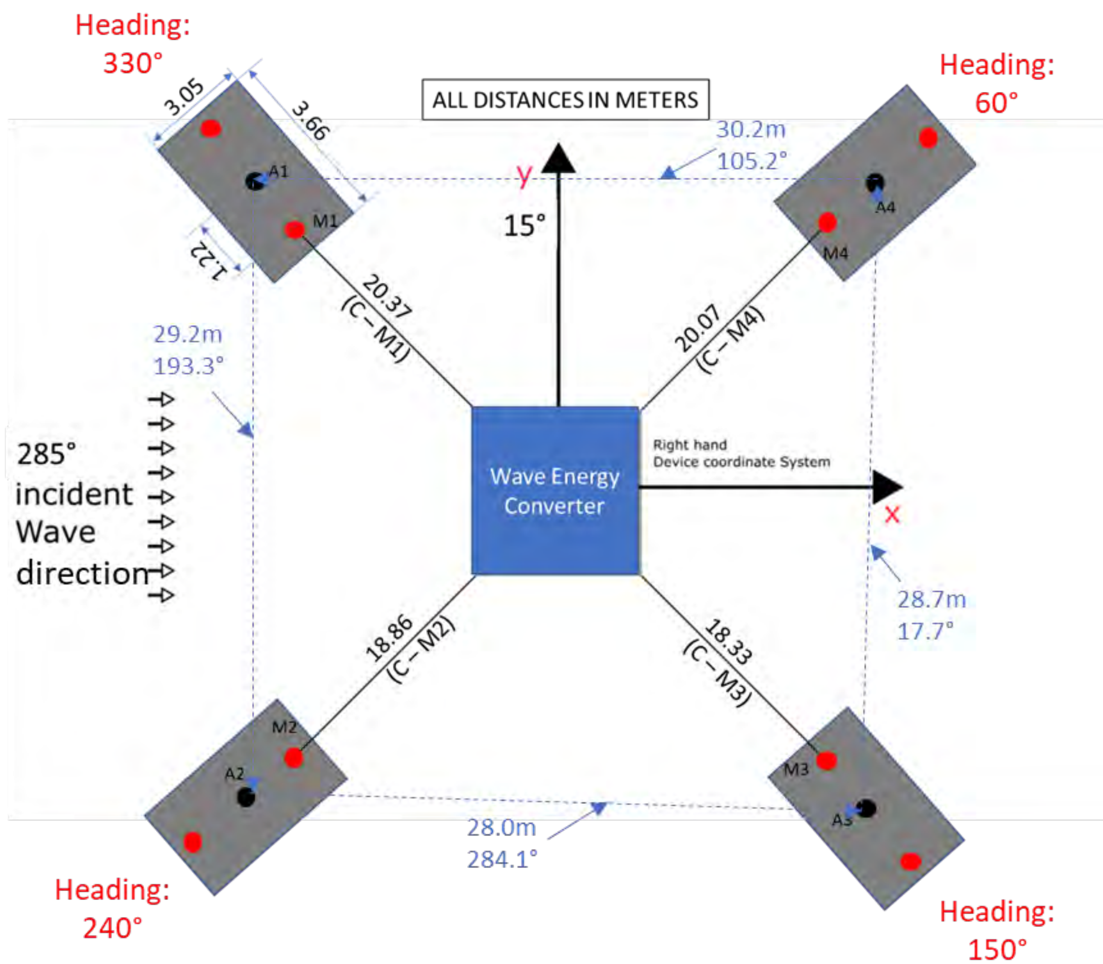


Figure 26: Anchor Footprint Dimensions

It is critical that the placements are accurate to +/- 1.5 meter. An offset beyond this tolerance will have negative consequences to the performance of the WEC technology.

The area identified for anchor installation has been dive surveyed for any obstructions, benthic features, or macrobenthos and sediment samples have been analyzed with results supporting the anchor design and load calculations. The coordinates for each anchor have updated to match the format of the GPS on the vessel and have been corrected based on the completed dive survey (readjusted for MLLW) and are provided in the table below.

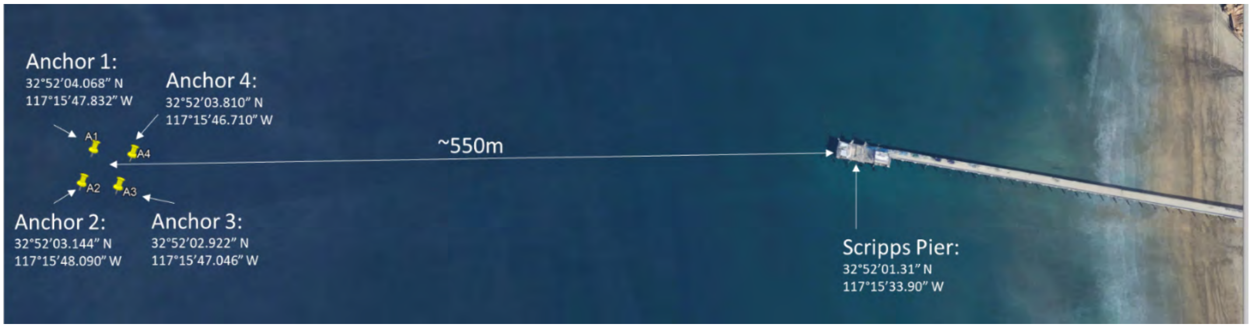


Figure 27: Anchor locations relative to Scripps Pier

<u>Overview</u>

Prior to the anchor deployment operation, SIO research divers shall plant marking stakes in the seafloor to mark the anchor location. One of the secondary attachment points will be connected to the 30mm WEC mooring line which will be passed to the R/V Beyster to be used as a tag line to ensure anchor orientation and position and upon successful anchor deployment shall be left in place connected to a marker buoy. It is important to note that the WEC mooring lines are shorter than the water depth and will therefore need to be shackled to an additional line in between the mooring line and marker buoy. The R/V Beyster will deploy a Seabotix ROV to monitor the lowering anchor and relay feedback to the crane operator ensuring the anchors land within the bounding box of the reflective bamboo stakes.

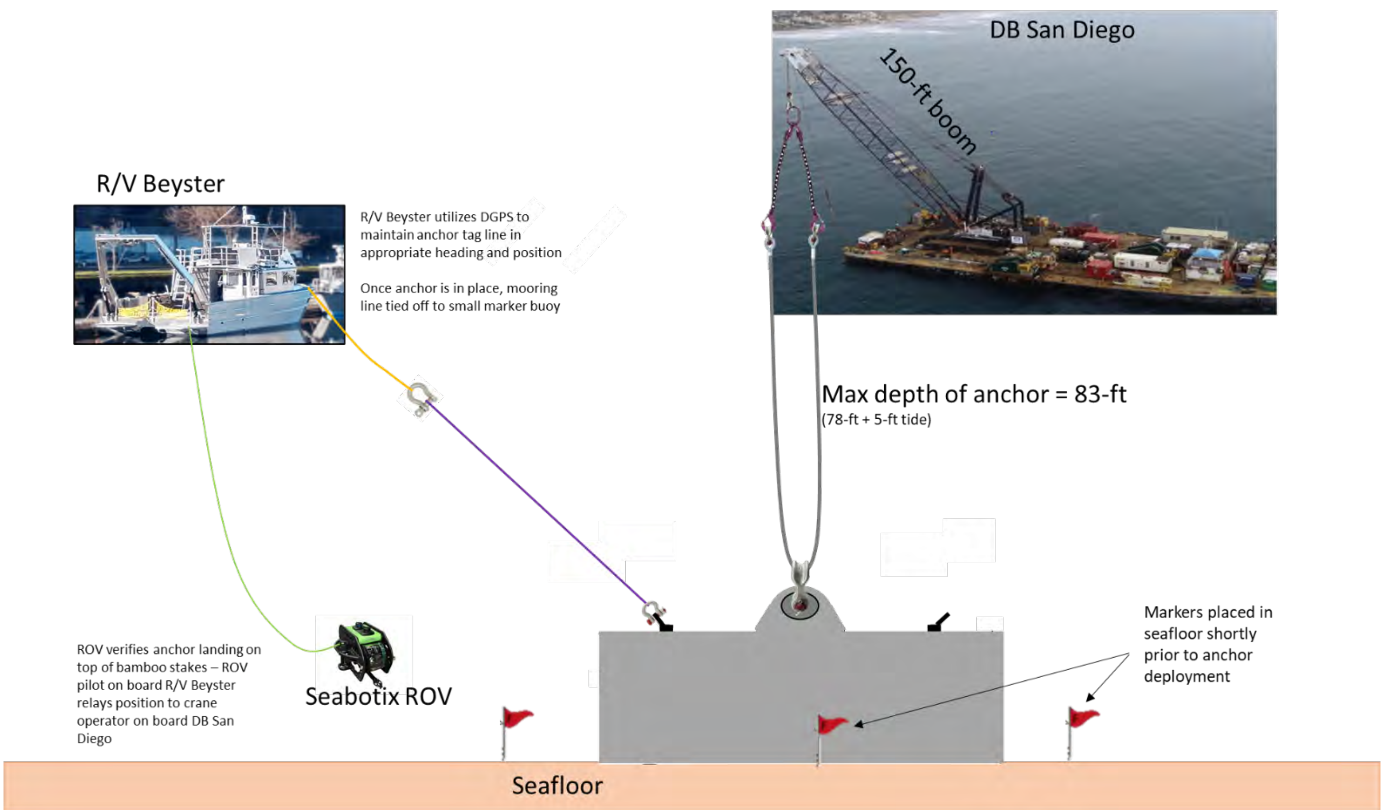


Figure 28: Anchor Deployment Overview

To assist in accurate anchor placement in the event of low subsea visibility, the R/V Beyster will position itself in the center of the mooring grid for each anchor installation, verifying the appropriate heading to ensure anchor block orientation. The marker buoy lines that are used as tag lines will be marked with brightly colored tape such that the tape will be at the water surface when the anchor is on the seafloor in the correct location. This will also provide a visual indication to the R/V Beyster crew as to the relative depth of the anchor block during deployment. The placement of the marking tape is tide dependent and will therefore need to be placed shortly prior to deploying each anchor (based on table below).

As there are no commercial divers planned to assist in anchor placement, there is a ‘point of no return’ that occurs when the wire rope is disconnected from the crane. Therefore, if silt or other subsurface conditions make it difficult for the Seabotix ROV to verify anchor position as it is being lowered, a reasonable effort must be made to wait for the silt to settle after the anchor is resting on the seafloor (as indicated by the reduced tension in the wire rope), for the ROV to verify the anchor is placed within the marked bounding box. If it is determined that sufficient visibility will not be gained by waiting (~30 min), then the R/V Beyster will verify the anchor block placement with sonar.

5.2.1 Mobilization: Anchor Installation

The vessels will be mobilized with necessary equipment to complete the scope of work from their respective home ports. All vessels are fit out with standard safety equipment, life jackets and other personal protective equipment as required or recommended by the U.S. Coast Guard and determined by the vessel owners and vessel captain.

It is anticipated that the concrete anchor blocks will be delivered to the Pacific Tugboat Services yard in National City.

Table 12: Equipment List: Anchor Installation

OWNER	DESCRIPTION	SIZE	QTY
DB San Diego			
PacTug	Wire rope lifting sling, ~200-ft long	1-1/8”	2
CalWave	Anchor Block #1 (Type B)	64.5k lbs	1
CalWave	Mooring line #1 (20.5m length)	30mm	1
CalWave	Anchor Block #2 (Type A)	79.5k lbs	1
CalWave	Mooring line #2 (18.9m length)	30mm	1
CalWave	Anchor Block #3 (Type A)	96k lbs	1
CalWave	Mooring line #3 (18.3m length)	30mm	1
CalWave	Anchor Block #4 (Type B)	67.5k lbs	1
CalWave	Mooring line #4 (20.1m length)	30mm	1
CalWave	Shackle (mooring line to marker buoy line)	1”	4
CalWave	Shackle (marker buoy line to marker buoy)	1”	4
CalWave	Marker buoy for mooring line	Standard	4
CalWave	Crosby G-2130 shackle (mooring line to anchor)	1”	4
CalWave	Crosby G-2130 shackle (Type A anchors center lift)	4”	2
CalWave	Crosby G-2130 shackle (Type B anchors center lift)	3.5”	2
R/V Beyster			
UCSD	Soft hook for item recovery		2
UCSD	Fenders (for coming alongside the crane barge)	Standard	3

The below deck layout drawing illustrates a 135-ft by 58-ft barge deck with ~42-ft square crane turret. CalWave shall deliver all above indicated equipment to the PacTug yard in National City for mobilization. Prior to mobilization PacTug shall ensure appropriate rigging and lifting hardware is on-board and appropriately inspected, including any necessary spares. During pre-deployment mobilization at the PacTug yard in National City, the mooring lines shall be connected to the anchor block secondary attachment points with marine shackles. The WEC mooring lines differ in length for each anchor and will need to be marked prior to mobilization and verified to ensure the appropriate mooring line is connected to the correct anchor. Given the size and weight of the anchor blocks and the requirement for calm weather for deployment, it is not anticipated that it will be required to fasten the anchors to the deck of the vessel. Additionally, CalWave will deliver to UCSD staff the equipment indicated above to be mobilized on the R/V Beyster

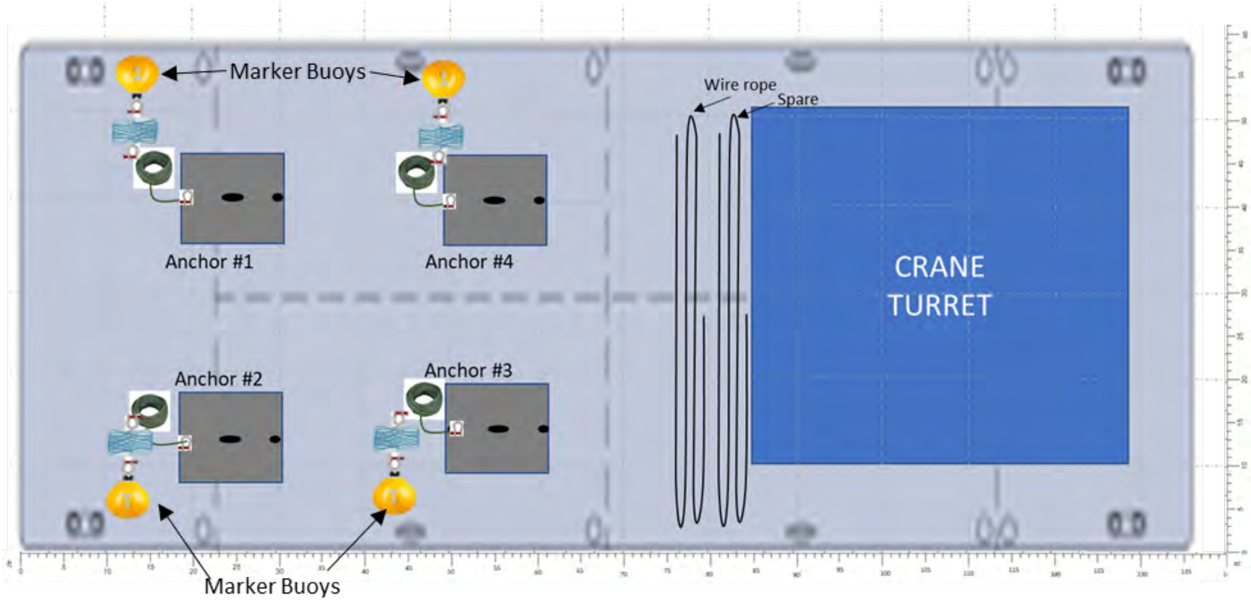


Figure 29: DB San Diego Deck Layout – Anchor Deployment

The R/V Beyster shall be mobilized in her home port in Point Loma. Mobilization shall consist of attaching the small marker buoys to additional line with marine shackles on both ends.

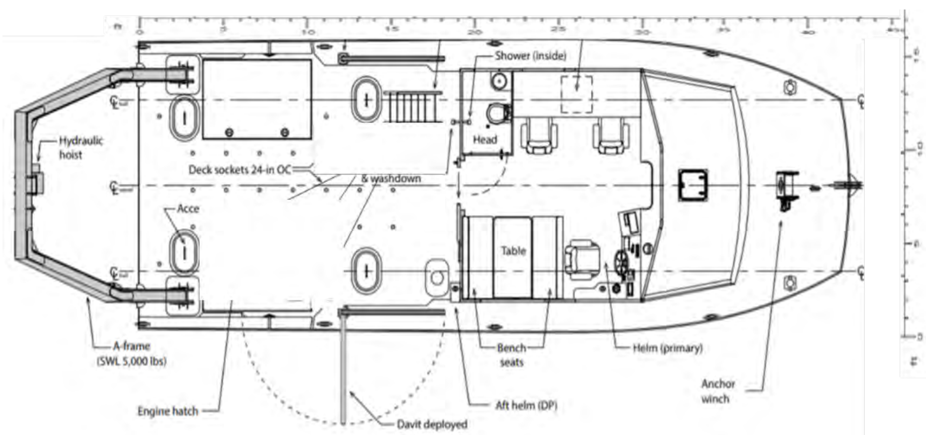


Figure 30: R/V Beyster Deck Layout - Anchor Deployment

5.2.2 Operations Sequence: Anchor Installation

The following sequence table details the scope of work for the anchor installation and commissioning evolution. The table below provides details for each vessel to deploy anchors at the SIO test site. The sequence may be altered at the direction of the vessel captains in collaboration with CalWave staff on-board.

The PacTug operated DB San Diego is anticipated to be the primary vessel for this operation, supported by the UCSD operated R/V Beyster. As shown below, the anchors will be deployed at depths ranging from 67 – 72 ft (MLLW) and along a nearly square grid with sides of ~90 to 100 feet. Accounting for tide, the maximum anticipated depth is potentially as high as 78-ft. In order to accommodate this, the wire rope used for deployment will need to be at least 156-ft to reach the surface, plus an additional 15-20-ft to allow for each of line handling on deck of the vessel.

The below operational sequence commences with reinforced concrete anchor blocks and associated hardware having been delivered to the PacTug yard and secured as per the mobilization plan.

Winds at the test site typically come from approximately 285 degrees, as shown in the below pictured mooring layout, it is proposed to deploy anchors in the order of 2 -> 1 -> 3 -> 4 such that the vessel deck is able to be leeward of the anchor position being deployed at all times. The below figure also provides relative dimensions of the two vessels and anchor placements.

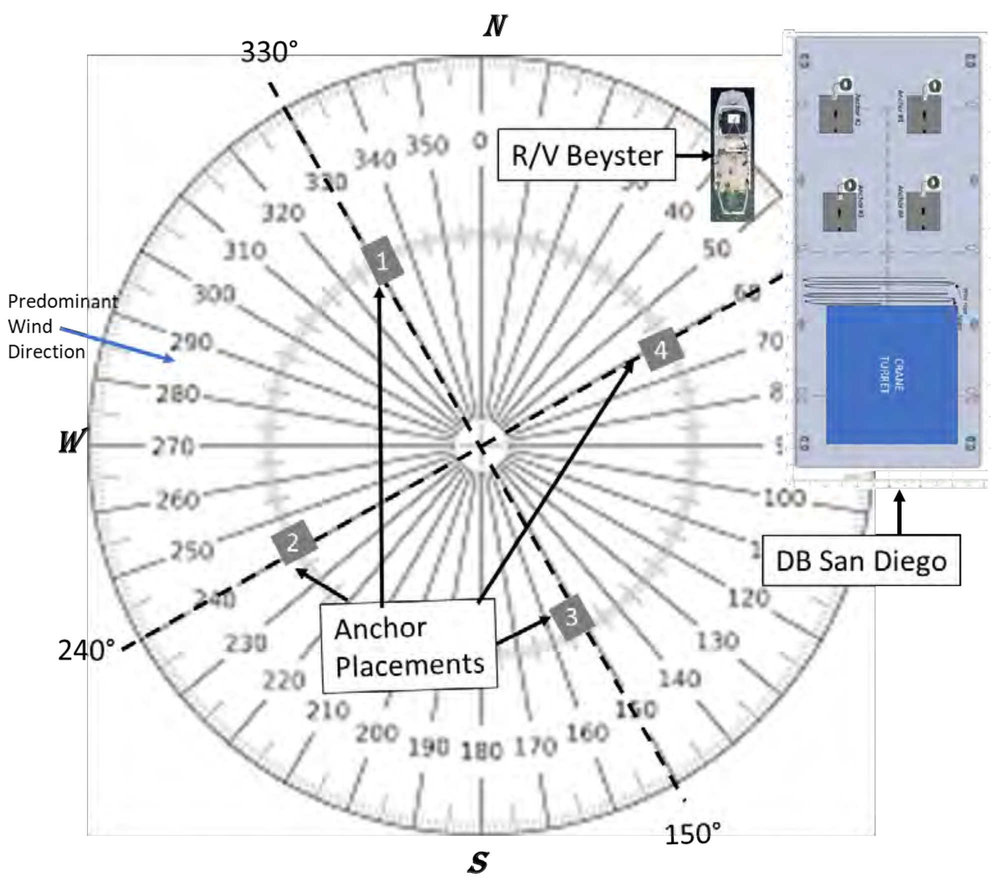


Figure 31: Anchor Grid w/ Compass & Relative Vessel Sizes

The below figure illustrates the locations and potential watch circles (orange dashed circles) for the various aids to navigation and other buoys deployed near the test site. The anchor placements (A1, A2, A3, A4), the DB San Diego, and the R/V Beyster are included at the appropriate scale for reference. The buoys operated by CalWave (ATON2, ATON4, CoastScout) can be removed prior to the anchor placement operation if required.

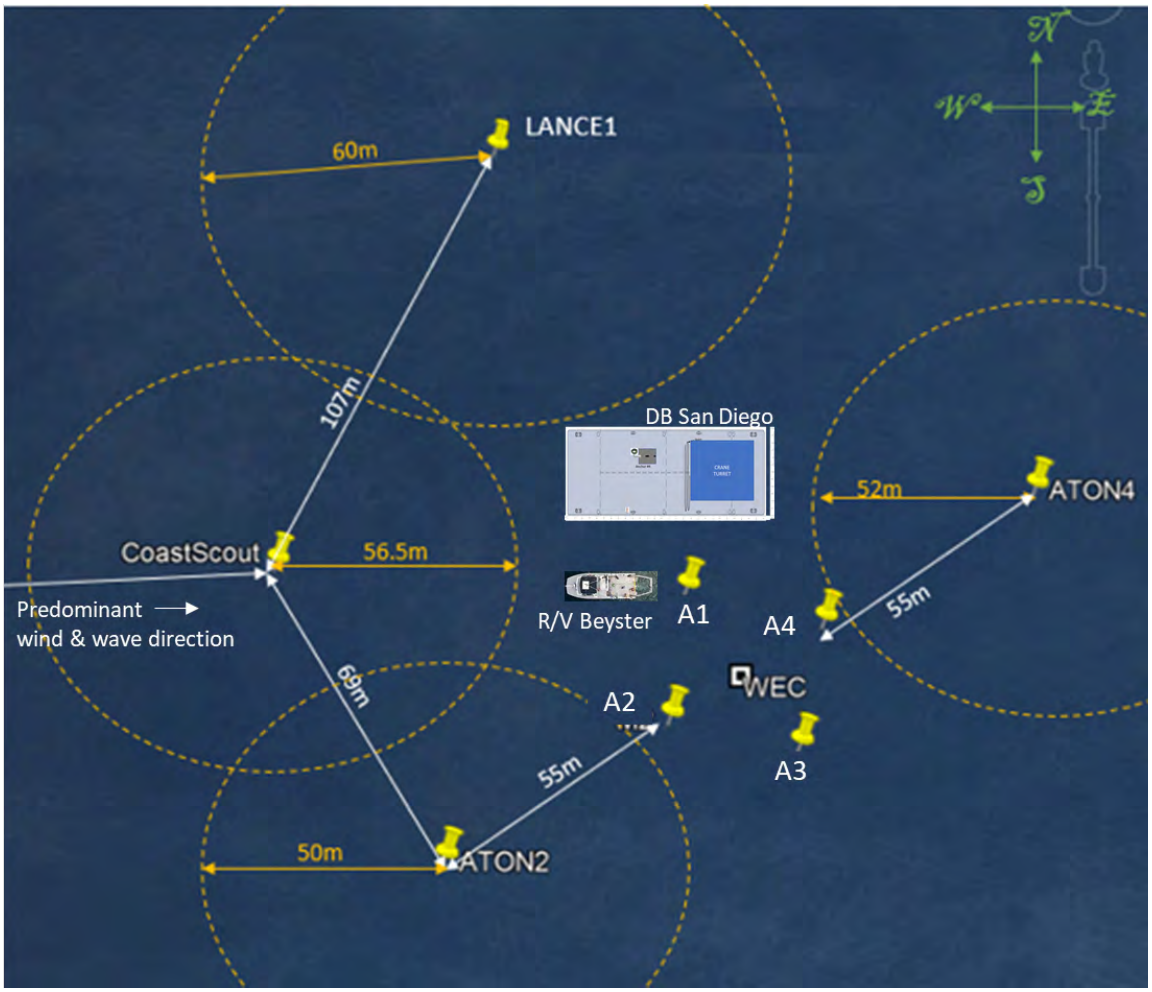
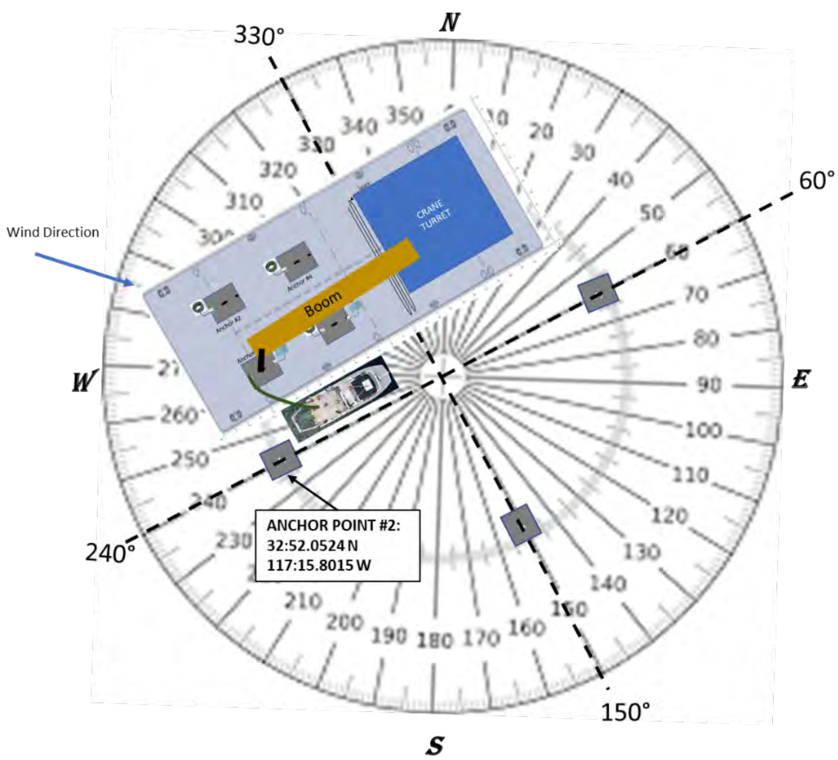
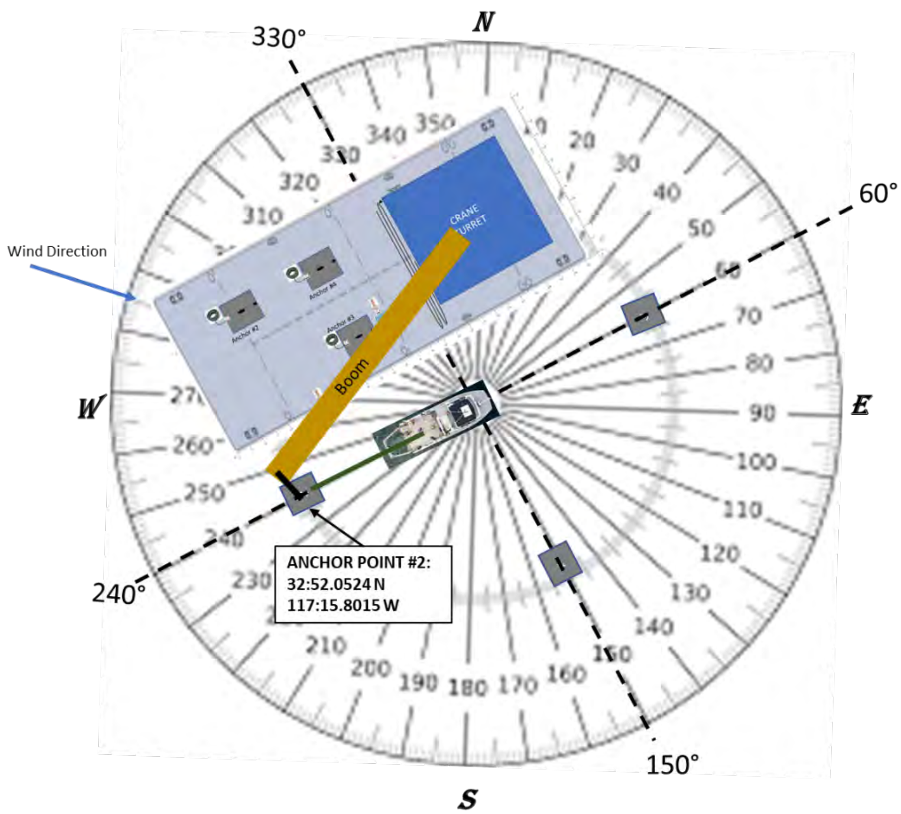


Figure 32: Relative Size & Distance of Buoys in Vicinity

Table 13: Sequence: Anchor Installation

<table>
<tr><th>Step #</th><th>Vessel</th><th>Assignment</th></tr>
<tr><td>1</td><td colspan="2">Transit to site & Maneuver to Anchor #2 Position</td></tr>
<tr><td>1.a</td><td>DB San Diego</td><td>
- PacTug Lead: Proceed to test site via transit route 1 (~5kts)
- PacTug Lead: At test site, position leeward of anchor position #2
<table>
<tr><th>#</th><th></th><th>Deg</th><th>Min</th><th>Sec</th><th>Depth</th><th></th><th>dd</th><th>Deg</th><th>Min</th></tr>
<tr><td rowspan="2">A2</td><td>N</td><td>32</td><td>52</td><td>3.144</td><td>68.85</td><td>ft</td><td>32.867540</td><td>32</td><td>52.0524</td></tr>
<tr><td>W</td><td>117</td><td>15</td><td>48.090</td><td>20.99</td><td>m</td><td>117.263358</td><td>117</td><td>15.8015</td></tr>
</table>
</td></tr>
<tr><td>1.b</td><td>R/V Beyster</td><td>
- PacTug Lead: Proceed to test site via transit route 2 (~25kts)
- PacTug Lead: Approach forward port side of DB San Diego


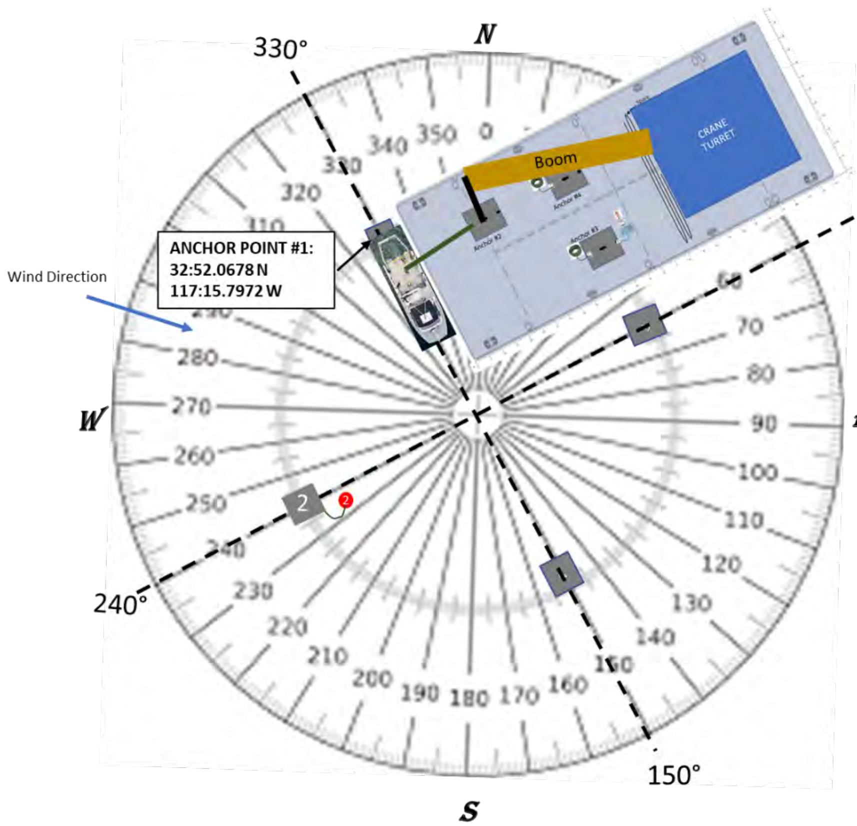
</td></tr>
<tr><td>2</td><td colspan="2">Deploy Anchor #1</td></tr>
<tr><td>2.a</td><td>DB San Diego</td><td>
- Rigger 1: Loop 1-1/8” steel wire through center lift point on anchor #2 and rig both ends of steel wire to crane
- Crane Operator: Boom up to extend line until taut
- CalWave Lead: Pass mooring line #2 and marker buoy to R/V Beyster
- Crane Operator: Communicate with R/V Beyster while transitioning weight of anchor #2 to crane
</td></tr>
</table>

2.b	*R/V Beyster*	- ***CalWave 2:*** Receive anchor #2 mooring line and marker buoy - ***CalWave 2:*** Use mooring line as tag line to ensure anchor stability and prohibit rotation during lifting operation, position such that mooring line is orientated at 60° heading from anchor block #2, in the direction of the center of the mooring grid. - ***ROV Pilot:*** Deploy ROV to locate seafloor markers for anchor point #2, confirm when markers are located - ***Beyster Captain:*** Position vessel to center of mooring grid, validate heading of 60° and location of N 32:52.058, W 117:15.790	
2.c	*Both vessels*	- ***CalWave Lead:*** Coordinate between ROV pilot, DB San Diego crane operator and R/V Beyster captain to lower anchor on to markers, maintaining mooring line orientation - ***DB_SD Crane Operator:*** Slowly lower anchor block, calling out estimated depth every 10-ft - ***ROV Pilot:*** Announce when anchor is visible and if any directional changes are required during descent - ***CalWave 2:*** Announce when marked tape is at sea surface (indicating anchor should be at correct position) 	
2.d	*R/V Beyster*	- ***ROV Pilot:*** Announce when anchor is on seafloor within marker boundaries (confirm with DB_SD Crane Operator wire rope is slack)	

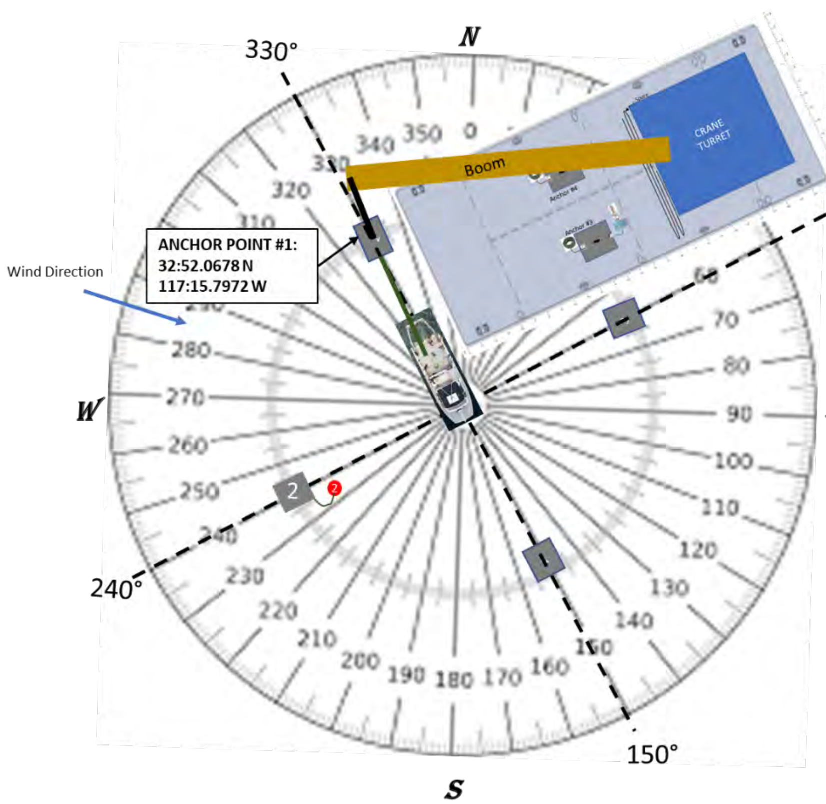
		- ***CalWave 2:*** Deploy marker buoy - ***ROV Pilot:*** Recover ROV
2.e	*DB San Diego*	- ***Rigger 1:*** Verify with CalWave Lead & Crane Operator, then disconnect one end of wire rope and pull through anchor lifting point* ****point of no return***
3	Maneuver to Anchor #1 Position	

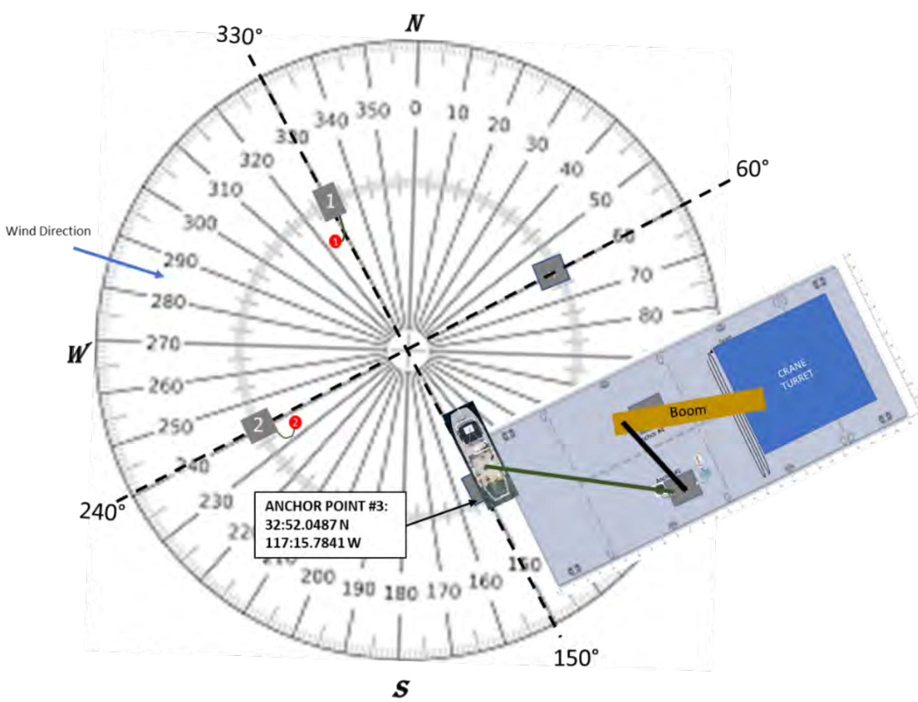
#		Deg	Min	Sec	Depth		dd	Deg	Min
A1	N	32	52	4.068	71.85	ft	32.867797	32	52.0678
	W	117	15	47.832	21.90	m	117.263287	117	15.7972

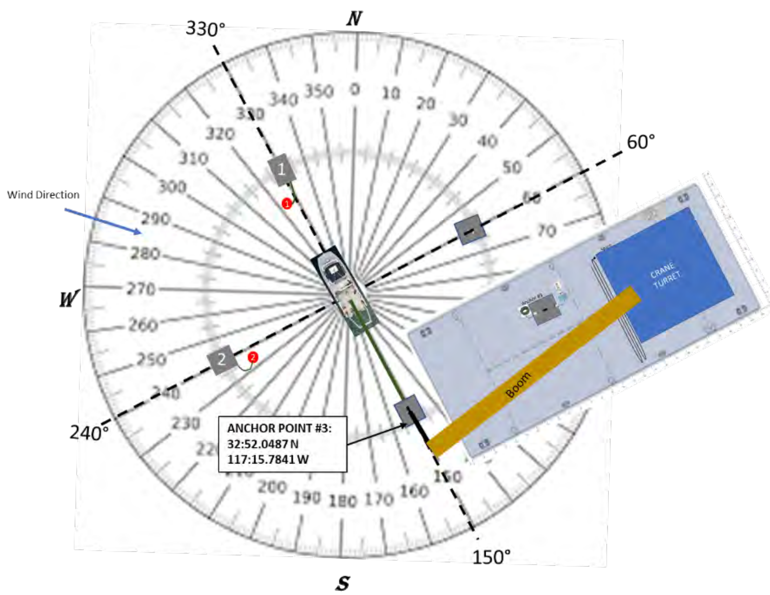
3.a	*DB San Diego*	- ***PacTug Lead:*** Maneuver ~100-ft NE such that anchor point #1 is off the bow
3.b	*R/V Beyster*	- ***Beyster Captain:*** Position along the bow of DB San Diego, with the bow heading SE

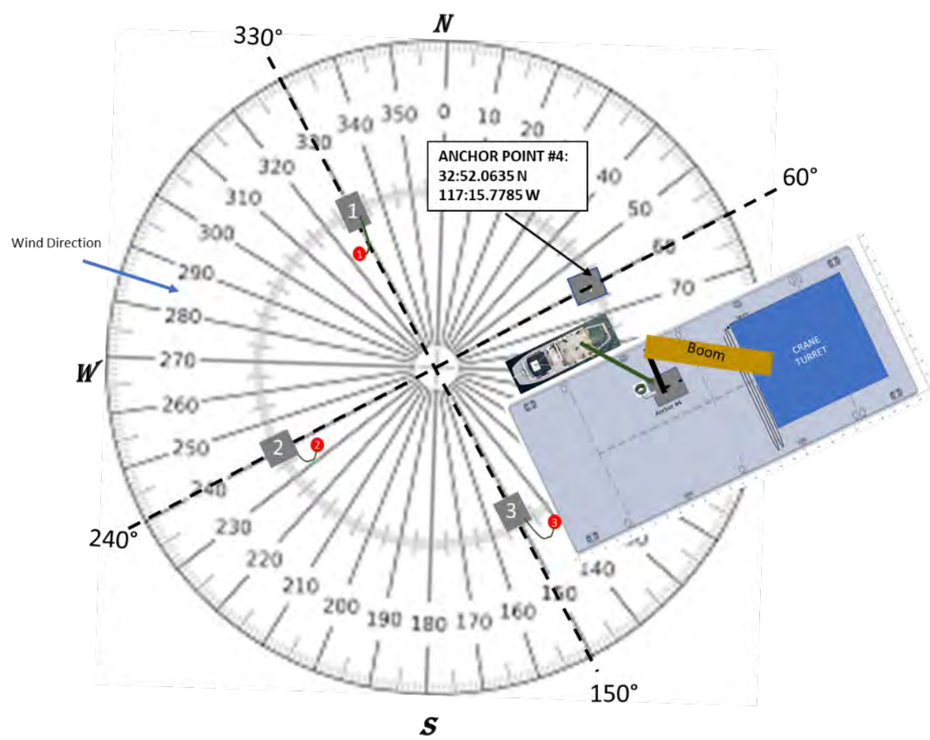


4	Deploy Anchor #1	
4.a	*DB San Diego*	- ***Rigger 1:*** Loop 1-1/8" steel wire through center lift point on anchor #1 and rig both ends of steel wire to crane - ***Crane Operator:*** Boom up to extend line until taut - ***CalWave Lead:*** Pass mooring line #1 and marker buoy to R/V Beyster

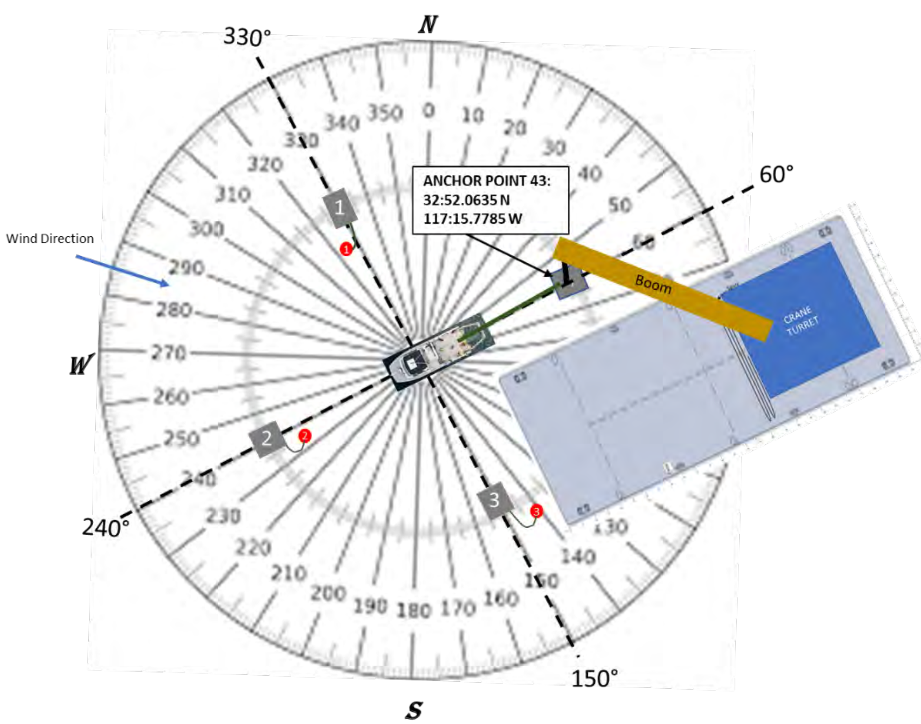
<table>
<tr><td></td><td></td><td>- Crane Operator: Communicate with R/V Beyster while transitioning weight of anchor #1 to crane</td><td></td></tr>
<tr><td>4.b</td><td>R/V Beyster</td><td>- CalWave 2: Receive anchor #1 mooring line and marker buoy
- CalWave 2: Use mooring line as tag line to ensure anchor stability and prohibit rotation during lifting operation, position such that mooring line is orientated at 150° heading from anchor block #1, in the direction of the center of the mooring grid.
- ROV Pilot: Deploy ROV to locate seafloor markers for anchor point #1, confirm when markers are located
- Beyster Captain: Position vessel to center of mooring grid, validate heading of 150° and location of N 32:52.058, W 117:15.790</td><td></td></tr>
<tr><td>4.c</td><td>Both Vessels</td><td>- CalWave Lead: Coordinate between ROV pilot, DB San Diego crane operator and R/V Beyster captain to lower anchor on to markers, maintaining mooring line orientation
- DB_SD Crane Operator: Slowly lower anchor block, calling out estimated depth every 10-ft
- ROV Pilot: Announce when anchor is visible and if any directional changes are required during descent
- CalWave 2: Announce when marked tape is at sea surface (indicating anchor should be at correct position)

</td><td></td></tr>
</table>

<table>
<tr><td>4.d</td><td>R/V Beyster</td><td>- ROV Pilot: Announce when anchor is on seafloor within marker boundaries (confirm with DB_SD Crane Operator wire rope is slack)
- CalWave 2: Deploy marker buoy
- ROV Pilot: Recover ROV</td></tr>
<tr><td>4.e</td><td>DB San Diego</td><td>- Rigger 1: Verify with CalWave Lead & Crane Operator, then disconnect one end of wire rope and pull through anchor lifting point*
*point of no return</td></tr>
<tr><td>5</td><td colspan="2">Maneuver to Anchor #3 Position
<table>
<tr><th>#</th><th></th><th>Deg</th><th>Min</th><th>Sec</th><th>Depth</th><th></th><th>dd</th><th>Deg</th><th>Min</th></tr>
<tr><td rowspan="2">A3</td><td>N</td><td>32</td><td>52</td><td>2.922</td><td>67.85</td><td>ft</td><td>32.867478</td><td>32</td><td>52.0487</td></tr>
<tr><td>W</td><td>117</td><td>15</td><td>47.046</td><td>20.68</td><td>m</td><td>117.263068</td><td>117</td><td>15.7841</td></tr>
</table></td></tr>
<tr><td>5.a</td><td>DB San Diego</td><td>- PacTug Lead: Maneuver ~130-ft SE to position with anchor point #3 off the bow</td></tr>
<tr><td>5.b</td><td>R/V Beyster</td><td>- PacTug Lead: Position along the bow of DB San Diego, with the bow heading NW

</td></tr>
<tr><td>6</td><td colspan="2">Deploy Anchor #3</td></tr>
<tr><td>6.a</td><td>DB San Diego</td><td>- Rigger 1: Loop 1-1/8” steel wire through center lift point on anchor #3 and rig both ends of steel wire to crane
- Crane Operator: Boom up to extend line until taut
- CalWave Lead: Pass mooring line #3 and marker buoy to R/V Beyster</td></tr>
</table>

		- ***Crane Operator:*** Communicate with R/V Beyster while transitioning weight of anchor #3 to crane	
6.b	*R/V Beyster*	- ***CalWave 2:*** Receive anchor #3 mooring line and marker buoy - ***CalWave 2:*** Use mooring line as tag line to ensure anchor stability and prohibit rotation during lifting operation, position such that mooring line is orientated at 330° heading from anchor block #3, in the direction of the center of the mooring grid. - ***ROV Pilot:*** Deploy ROV to locate seafloor markers for anchor point #3, confirm when markers are located - ***Beyster Captain:*** Position vessel to center of mooring grid, validate heading of 330° and location of N 32:52.058, W 117:15.790	
6.c	*Both Vessels*	- ***CalWave Lead:*** Coordinate between ROV pilot, DB San Diego crane operator and R/V Beyster captain to lower anchor on to markers, maintaining mooring line orientation - ***DB_SD Crane Operator:*** Slowly lower anchor block, calling out estimated depth every 10-ft - ***ROV Pilot:*** Announce when anchor is visible and if any directional changes are required during descent - ***CalWave 2:*** Announce when marked tape is at sea surface (indicating anchor should be at correct position) 	
6.d	*R/V Beyster*	- ***ROV Pilot:*** Announce when anchor is on seafloor within marker boundaries (confirm with DB_SD Crane Operator wire rope is slack) - ***CalWave 2:*** Deploy marker buoy - ***ROV Pilot:*** Recover ROV	

<table>
<tr><td>6.e</td><td>DB San Diego</td><td>- Rigger 1: Verify with CalWave Lead & Crane Operator, then disconnect one end of wire rope and pull through anchor lifting point*
*point of no return</td></tr>
<tr><td>7</td><td colspan="2">Maneuver to Anchor #4 Position
<table>
<tr><th>#</th><th></th><th>Deg</th><th>Min</th><th>Sec</th><th>Depth</th><th></th><th>dd</th><th>Deg</th><th>Min</th></tr>
<tr><td rowspan="2">A4</td><td>N</td><td>32</td><td>52</td><td>3.810</td><td>71.85</td><td>ft</td><td>32.867725</td><td>32</td><td>52.0635</td></tr>
<tr><td>W</td><td>117</td><td>15</td><td>46.710</td><td>21.90</td><td>m</td><td>117.262975</td><td>117</td><td>15.7785</td></tr>
</table></td></tr>
<tr><td>7.a</td><td>DB San Diego</td><td>- PacTug Lead: Maintain position</td></tr>
<tr><td>7.b</td><td>R/V Beyster</td><td>- Beyster Captain: Position along the starboard side of DB San Diego

</td></tr>
<tr><td>8</td><td colspan="2">Deploy Anchor #4</td></tr>
<tr><td>8.a</td><td>DB San Diego</td><td>- Rigger 1: Loop 1-1/8” steel wire through center lift point on anchor #4 and rig both ends of steel wire to crane
- Crane Operator: Boom up to extend line until taut
- CalWave Lead: Pass mooring line #4 and marker buoy to R/V Beyster
- Crane Operator: Communicate with R/V Beyster while transitioning weight of anchor #4 to crane</td></tr>
<tr><td>8.b</td><td>R/V Beyster</td><td>- CalWave 2: Receive anchor #4 mooring line and marker buoy
- CalWave 2: Use mooring line as tag line to ensure anchor stability and prohibit rotation during lifting operation, position such that mooring line is</td></tr>
</table>

<table>
<tr><td></td><td></td><td>orientated at 240° heading from anchor block #4, in the direction of the center of the mooring grid.
- ROV Pilot: Deploy ROV to locate seafloor markers for anchor point #4, confirm when markers are located
- Beyster Captain: Position vessel to center of mooring grid, validate heading of 240° and location of N 32:52.058, W 117:15.790</td><td></td></tr>
<tr><td>8.c</td><td>Both Vessels</td><td>- CalWave Lead: Coordinate between ROV pilot, DB San Diego crane operator and R/V Beyster captain to lower anchor on to markers, maintaining mooring line orientation
- DB_SD Crane Operator: Slowly lower anchor block, calling out estimated depth every 10-ft
- ROV Pilot: Announce when anchor is visible and if any directional changes are required during descent
- CalWave 2: Announce when marked tape is at sea surface (indicating anchor should be at correct position)



</td><td></td></tr>
<tr><td>8.d</td><td>R/V Beyster</td><td>- ROV Pilot: Announce when anchor is on seafloor within marker boundaries (confirm with DB_SD Crane Operator wire rope is slack)
- CalWave 2: Deploy marker buoy
- ROV Pilot: Recover ROV</td><td></td></tr>
<tr><td>8.e</td><td>DB San Diego</td><td>- Rigger 1: Verify with CalWave Lead & Crane Operator, then disconnect one end of wire rope and pull through anchor lifting point*
*point of no return</td><td></td></tr>
</table>

9	Transit to home port		
9.a	*DB San Diego*	- ***PacTug Lead:*** Transit to home port via transit route 1 (~5kts)	
9.b	*R/V Beyster*	- ***Beyster Captain:*** Transit to home port via transit route 2 (~25kts)	

5.2.3 Estimated Timeline: Anchor Installation

Only vessel time is added to total time calculation (highlighted activities do not require vessel on-site)

For the below operation, a total of two vessels are anticipated.

Table 14: Timeline: Anchor Installation

Step #	Activity	Hours
M.a	*Mobilize DB San Diego at Home Port (National City)*	*3.0*
M.b	*Mobilize R/V Beyster at Home Port (Point Loma)*	*1.0*
1.a	*DB San Diego Transit to Test Site (22.2nm @ 5kts)*	*4.5*
1.b	*R/V Beyster Transit to Test Site (16.5nm @ 25kts)*	*0.75*
2	Deploy Anchor #2	1.0
3	Maneuver to Anchor Position #1	0.5
4	Deploy Anchor #1	1.0
5	Maneuver to Anchor Position #3	0.5
6	Deploy Anchor #3	1.0
7	Maneuver to Anchor Position #4	0.5
8	Deploy Anchor #4	1.0
9.a	*DB San Diego Transit to Home Port (22.2nm @ 5kts)*	*4.5*
9.b	*R/V Beyster Transit to Home Port (16.5nm @ 25kts)*	*0.75*
M.a	*Demobilize DB San Diego*	*1.0*
M.b	*Demobilize R/V Beyster*	*1.0*
	Total Time Estimate (hours) – DB San Diego	**18.5**
	Total Time on Site (hours) – DB San Diego	**5.5**
	Total Time Estimate (hours) – R/V Beyster	**9.0**

	Total Time on Site (hours) – R/V Beyster	**5.5**

Anticipated as a one-day operation. Assuming the above timing estimates above it is anticipated to depart home port pre-dawn in order to arrive on site shortly before sunrise and allow longest possible daylight window for deployment, likely transiting back to home port after dark.

5.3 Anchor Recovery

The recovery of the anchor blocks after completion of the test program will utilize similar vessels and resources, but without the added complexity of accurate positioning.

Divers will be required to connect the lifting eyes to the crane barge wire rope for this operation. Further details of this operation will be provided closer to the timing of the operation. The lifting padeyes of the anchor blocks are rated for calculated estimates of overcoming suction force.

6 References

6.1 U.S. Navy Facilities Command (NAVFAC) Geotechnical Manual Navy: SP-2209-OCN, Feb 2012

6.2 Deadweight Anchor Design Calculations, Bittner-Shen Consulting Engineers, Dec 2019

Includes design calculations for anchors and summary of seafloor sediment sample analysis results. Copies of lab analysis reports are included in the design calculations document.

6.3 CalWave Geotechnical Bench Study, Sep 2019

Summary and points of specific note from historical geotechnical studies and surveys of the Scripps Canyon region. References to source documents are included in the bench study report.

7 Calculations

Detailed calculations and geotechnical lab analysis reports are included in the above referenced *Deadweight Anchor Design Calculations* document provided by Bittner-Shen Consulting Engineers.

8 HAZID

8.1 Administrative

Date of planned operation:

Date of HAZID briefing:

Attendees:

*by signing below, I attest that I have read and understand the operational plan and agree to operate safely and in accordance with this plan.

Name	Company	Signature

Planned Vessel Crew

Vessel	Name	Company	Role
DB San Diego		PacTug	PacTug Lead
DB San Diego		CalWave	CalWave Lead
DB San Diego		PacTug	Rigger 1
Tug 1		PacTug	Tug 1 Captain
Tug 2		PacTug	Tug 2 Captain
R/V Beyster		Scripps	Beyster Captain
R/V Beyster		CalWave	CalWave 2
R/V Beyster		Scripps	ROV Pilot
R/V Beyster		Scripps	Crew 1
BW 1		Scripps	Captain
BW 1		Scripps	Crew 1

Vessel Call Times (DATE)

Vessel	Port	Crew Arrival Time	Departure Time
DB San Diego	National City		
Tug 1	National City		
Tug 2	National City		
R/V Beyster	Point Loma		

8.2 Risk Categories

Severity	Consequences				Increasing Probability				
					1	2	3	4	5
	People	Assets	Environment	Reputation	Never heard of in the industry	Heard of in the industry	Has happened in the organization or more than once per year in the industry	Has happened at the location or more than once per year in the organization	Has happened more than once per year at the location
0	No injury or health effect	No damage	No effect (no or temporary impact - days)	No impact (local media, no significant concern)	L	L	L	L	L
1	Slight injury or health effect (first aid or medical treatment)	Slight damage	Slight effect (local scale, short term damage – weeks)	Slight impact (short term local concern)	L	L	L	L	L
2	Minor injury or health effect (restricted work case or LTI)	Minor damage	Minor effect (local scale, short term damage – months)	Minor impact (short term national mention)	L	L	L	M	M
3	Major injury or health effect (partial disability)	Moderate damage	Moderate effect (local scale, medium terms damage – years)	Moderate impact (medium term national concern)	L	L	M	M	H
4	< 3 fatalities, or permanent total disabilities	Major damage	Major effect (local scale, long term damage – decades)	Major impact (regional or persistent national concern)	L	M	M	H	H
5	> 3 fatalities	Massive damage / total loss	Massive effect (regional scale, permanent damage)	Massive impact (global concern and media coverage)	M	M	H	H	H

L	Low Risk
M	Medium Risk
H	High Risk

Figure 33: Risk Categories

8.3 Risk Identification and Mitigation

Table 15: Summary of Identified Risks

Anchor Installation					
	Consequence				
Prob.	1	2	3	4	5
5	0	0	0	0	0
4	0	0	1	0	0
3	0	0	2	0	0
2	0	0	2	1	4
1	0	0	0	0	1

Anchor Installation			
Total risks	High	Medium	Low
11	0	9	2
	0%	*82%*	*18%*

Table 16: HAZID

ID	Hazard Category	Scenario	Likely Threats	Top Events	Controls in Place	C	P	RP	Rank	Comments	Action Party	Closed?
X.0220	Secure for sea											
X.0220.1	Pier side work	Personnel safety	Slips, trips, falls	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0220.2	Lifting operations	Personnel safety	Crush injury	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0220.3	Lifting operations	Equipment failure	Connection equipment or line failure	Injury to personnel, loss of equipment	Equipment inspections, operator training	5	1	5	Low			
X.0220.4	Lifting operations	Inclement weather	Delays, additional cost	Schedule delays incurring additional cost	Flexible deployment window	3	2	6	Low			
X.0221	Vessel operations											
X.0221.1	Working offshore	Personnel safety	Slips, trips, falls	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0230	Lower anchor to seafloor											
X.0230.1	Anchor placement accuracy	Inaccurate anchor placement	Anchor placement not withing required footprint	Reduction in WEC performance	UCSD to pre-dive and mark locations, observe with ROV during install	3	4	12	Med			
X.0230.2	Anchor orientation accuracy	Inaccurate anchor placement	Anchor placement orientation not aligned with	Reduction in WEC performance	UCSD vessel position and heading using tag line	3	3	9	Med			

			center of mooring grid									
X.0230.3	Working with multiple vessels	Crane barge, tugs & Beyster operating in the same space	Vessel impact or near miss	Injury to personnel, damage to equipment	Pre-deployment planning, vessel coordination	4	2	8	Med			
X.0230.4	Vessel operations near existing buoys	Multiple UCSD and CalWave small data buoys deployed near operational location	Line entanglement in propellers, damage to buoys	Injury to personnel, damage to equipment	Data buoys can be moved off-station prior to operations if deemed necessary	3	3	9	Med			
X.0230.5	Lifting operations offshore	Personnel safety	Crush injury	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0240	Buoy off mooring line											
X.0240.1	Marker buoy persistence on station	Marker buoy does not adequately maintain station	Dropped equipment, connection failure, insufficient buoyance, line entanglement	Line entanglement, schedule/cost risk if dive services needed to recover	Watch circle overlap review, discuss with UCSD if center bridal is preferred	3	2	6	Low			
X.0250	Dive operations											
N/A	No planned dive operations (seafloor markers to be placed prior to operations											

	and covered by separate HAZID)												
X.0260	Reposition anchor												
X.0260.1	Anchor block repositioning	Incorrect anchor block requires repositioning	Cost, schedule risk										

CWPT Open Water Demonstration
DE-EE0008097.0005
Budget Period 2

Task 5.4 Comprehensive IO&M and Testing Plan

9.4 Umbilical Lay Plan

Version 2.4 – April 2020

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CONTENTS

FIGURES

TABLES

1 INTRODUCTION

This report focuses on the umbilical lay planning for the open water demonstration to be conducted in collaboration with University of California, San Diego (UCSD) near the Scripps Institute of Oceanography (SIO) pier, in a water depth of approximately 70 ft (21.3 m).

WEC Deployment (center of mooring grid)

Lat.	Long.
32°52'03.47"N	117°15'47.42"W

Figure 1: Test Site Location

All operations are being conducted in coordination with CalWave Power Technologies (CalWave) and the University of California, San Diego (UCSD) Scripps Institute of Oceanography (SIO) staff.

The details outlined in these procedures are contingent upon several factors, such as operation conditions, vessel ability, safety, efficiency, etc. Due to these factors, this plan is subject to change. Adjustments to sequences for the preset installation and connection can be made in the field with the use of Management of Change (MOC) process. The current and weather conditions must be deemed favorable before starting operations.

Before the start of any operations, all vessels and individuals involved will hold operational procedure review and safety meetings to prepare for upcoming operations. All equipment will be checked at this time and the equipment will be verified for availability for upcoming operations.

The vessel captain and CalWave representatives will approve deviations that become unavoidable in the field during the installation process. VHF working channels will be identified at this time.

This document comprises of the overall methodologies of safe operations offshore, includes vessel specifics, and operations planning for the following planned evolutions:

Table 1: Planned Offshore Operations

Activity	Days
Umbilical Lay Route Survey	1
Umbilical Lay	1
Umbilical Recovery	1
Total Planned Operational Days Offshore	3

2 VESSELS AND EQUIPMENT

2.1 VESSELS

Table 2: Vessel List

Vessel	Operator	Website	Notes
R/V Beyster	UCSD	https://scripps.ucsd.edu/ships	Primary work vessel
19' Boston Whaler	UCSD	https://scripps.ucsd.edu/ships	Line handling vessel (if necessary)

2.2 EQUIPMENT

Umbilical Cable

Several umbilical cable manufacturers were consulted and various options for umbilical cable form factor and specifications were reviewed. Steel armoring was determined not to be required for electrical shielding purposes or for structural integrity. This is due to the soft sandy seafloor at the deployment site, the anticipated dynamic motion of the umbilical, and weight and size considerations for deployment. The static linear distance of the umbilical cable travel, from SIO pier to the test site, is 536m (1758.5-ft) with an additional 47m (154.2-ft) of dynamic cable section. In order to accommodate both static and dynamic sections of cable, as well as slack sections of cable on the seafloor to prevent linear tension, routing up to the pier and provide spare cable on the pier, a 700m (2296.6-ft) umbilical cable is being deployed.

The below figure illustrates the required minimum umbilical cable length of 627m and how this length is divided up into sections. The additional 73m of cable will remain on a spool on the pier and be available as additional length for any unanticipated events that would require the cable being spliced.

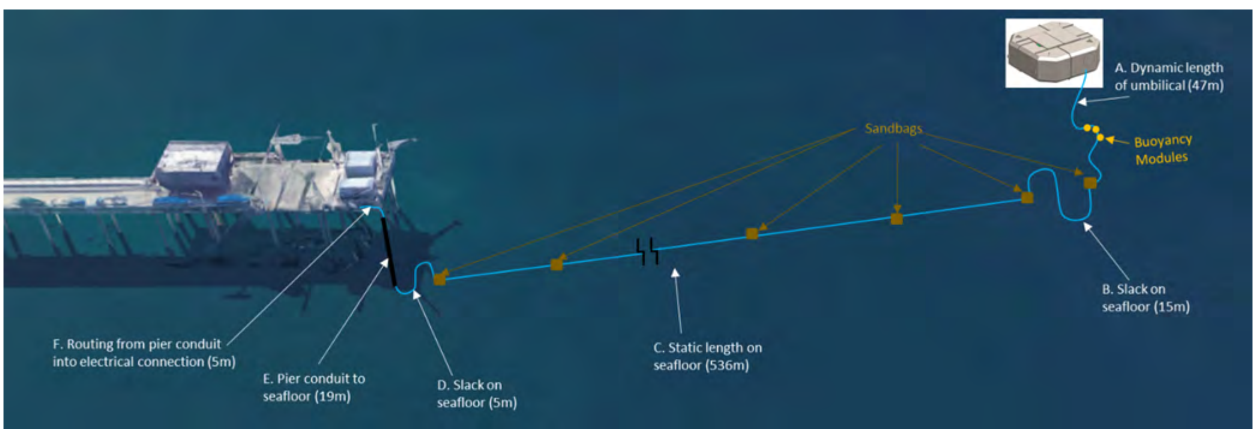


Figure 2: Umbilical Cable Required Length

The selected umbilical cable is rated for 600V and consist of seven insulated power cores sized at $6mm^2$ (~10 AWG), three sets of shielded twisted pairs (STP) ethernet cables at $0.5mm^2$ each, and a Vectran braid strength member. Cable specifications are provided in the figures below.

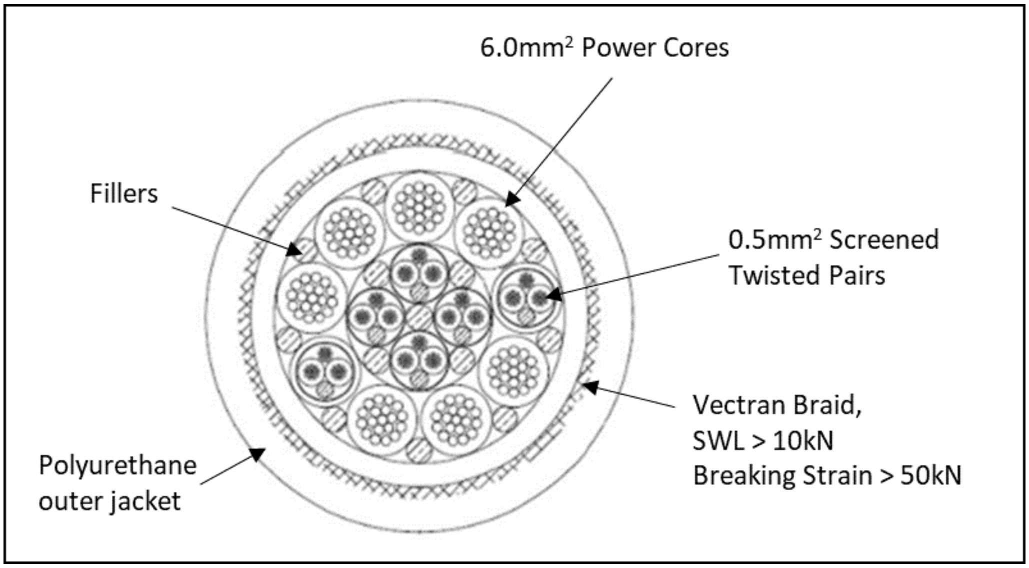


Figure 3: Umbilical Cable Construction

Product Details (Insulated Cores)

Component Description	Qty	Conductor Stranding	Maximum DCR @ 20oC [Ω/Km]	Weight Kgs/Km]	Nominal Diameter [mm]
6.0mm² Insulated Cores	7	84/0.3mm BC	3.2	65.1	4.50mm
0.5mm² Insulated Cores	12	16/0.2mm BC	41.5	2.6	1.75mm

CONSTRUCTION

6.0mm² Power Cores (7 off)

Conductor	Bare Copper to IEC 60228 Class 5
Radial Thickness	0.6mm nominal
Insulation	High Density Polyethylene
Nominal diameter	4.50mm

0.5mm² Twisted Screened Pairs (6 off)

Conductor	Bare Copper to IEC 60228 Class 5
Radial Thickness	0.39mm nominal
Insulation	High Density Polyethylene
Drainwire	0.22mm² 7/0.2mm Tinned Copper
Screen	Polyester / Copper Laminate Tape

Cable Assembly

Construction	
Layer 1	4 x 0.5mm² Twisted Screened Pairs layed around a central filler with additional fillers required to maintain a concentric circular profile.
Layer 2	7 x 6.00mm² Conductors and 2 x 0.5mm² Jacketed Twisted Screened Pairs layed around central bundle with additional fillers required to maintain a concentric circular profile.
Diameter	18.0mm nominal
Bedding	1.5mm radial thickness Polyurethane 85 Shore 'A' Hardness
Vectran braid	Breaking Strain >50kN, SWL >10kN
Outer jacket	Polyurethane 85 Shore 'A' Hardness
Colour	Blue
Radial Wall Thickness	2.0mm nominal
Diameter	26.5mm +/-0.5mm

CABLE CHARACTERISTICS

Cable Weight in Air	960 Kgs/Km
Cable Weight in Seawater	390 Kgs/Km
Bend Radius Static	160 mm
Bend Radius Dynamic	260 mm

Figure 4: Umbilical Cable Specifications

Connector & Strain Termination

The connector and termination solution consist of a molded breakout which separates the strength member from the electrical components and directs into a clevis & pin style strain termination (pictured below). Inside the strain termination housing, the power and ethernet cores are separated out and molded into a hybrid 21-pin connector. This allows for the connector and WEC hull bulkhead penetration to be removed from the mechanical loading on the umbilical cable. Due to the shallow freeboard of the WEC when in floating position (0.32m) and the need for using splash zone connectors (wet-mate connectors were found to be prohibitively expensive), the bulkhead connector on the WEC side is located on the chamfered edge of the hull above the strain termination. This will also help to minimize relative motion between the small boat tied to the WEC and the WEC itself and provide for the safest possible operations when connecting and disconnecting the umbilical cable from the WEC. The figures below present the strain termination, connector and WEC side bulkhead connectors. All dimensions are in mm unless otherwise specified.

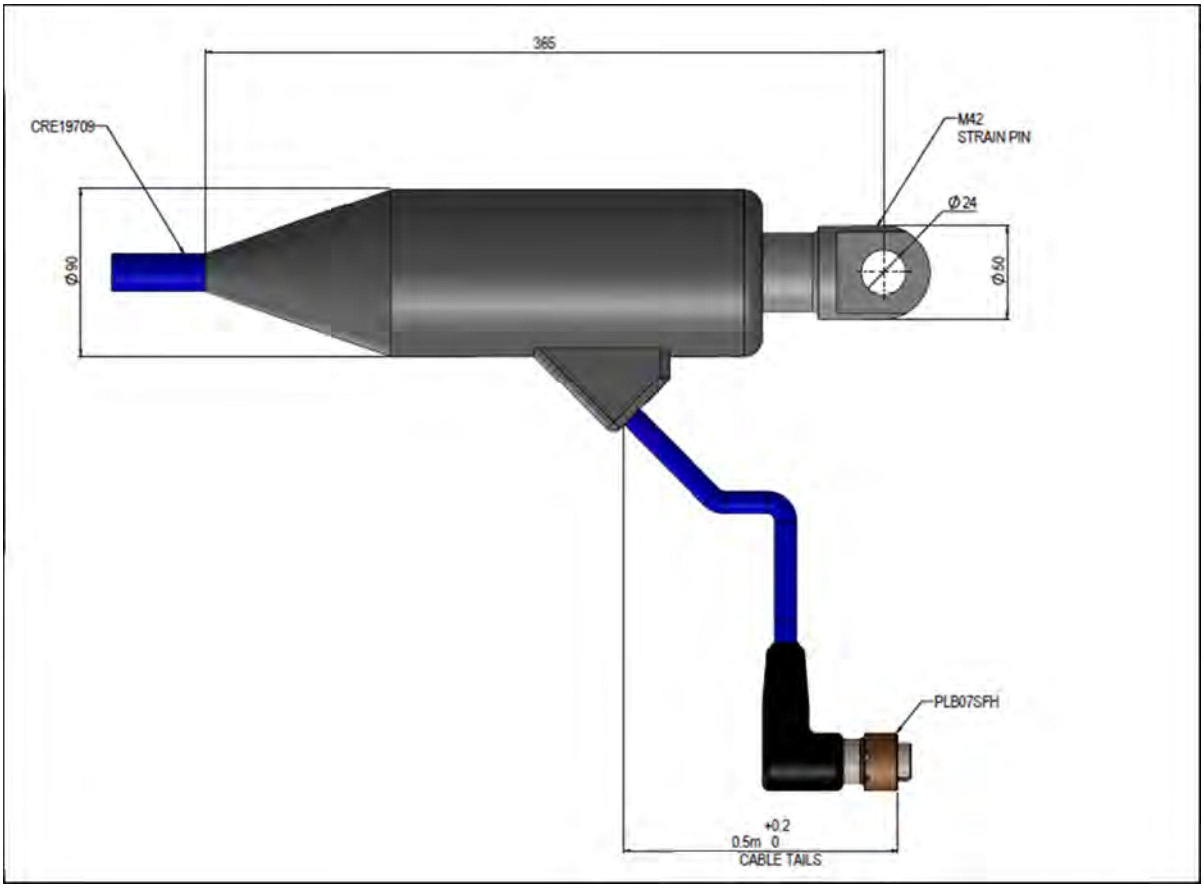
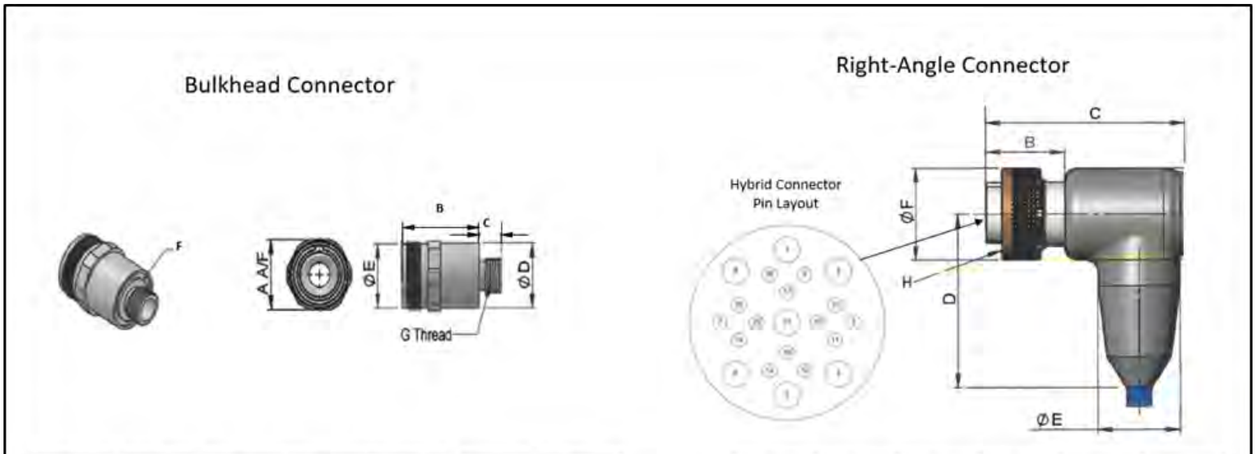


Figure 5: Umbilical Strain Termination & Right-Angle Connector



A	B	C	D	E	F (O-Ring)	G
40	51	22	39	36.75	BS122	1"-12 UNF

B	C	D	E	F	H (O-Ring)
40	96	85	40	45	BS025

Figure 6: Umbilical Connectors

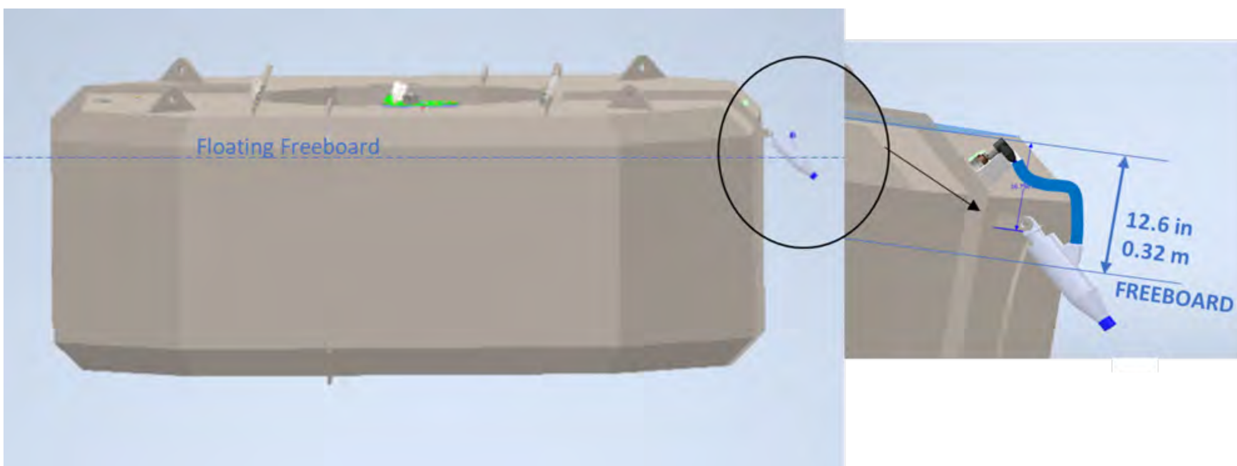


Figure 7: Umbilical Connection to WEC

3 Project Location

3.1 Area of Operations

The umbilical cable shall be laid on the sandy seafloor starting at the end of SIO pier and completing in the vicinity of the location where the umbilical will ultimately be connected to the CalWave WEC. GPS coordinates for these locations are provided below;

Table 3: Umbilical Lay Plan Waypoints

Waypoint		Deg	Min	Depth	
End of SIO Pier	N	32	52.023	33.5	ft
	W	117	15.447	10.2	m
Umbilical Touchdown	N	32	52.0747	75	ft
	W	117	15.7847	22.9	m
Connector Marker Buoy	N	32	52.0702	76	ft
	W	117	15.8144	23.2	m

This area is shown visually in the figure below.

Figure 8: Cable Lay Location

3.2 Location Relative to Test Site and Anchor Positions

Prior to commencing the umbilical lay operation, the anchor location dive survey and anchor installation operations are completed. Additionally, dynamically modelling in Orcaflex is completed to determine the configuration of the 'Lazy S' dynamic umbilical section and the location where the dynamic section of umbilical comes into initial contact with the seafloor (defined as the touchdown point). For the initial umbilical deployment, the dynamic section of umbilical cable will be laid on the seafloor along the same heading as the static section of cable, with the connectors capped and attached to a small marker buoy which will allow for recovery when connecting the umbilical to the WEC.

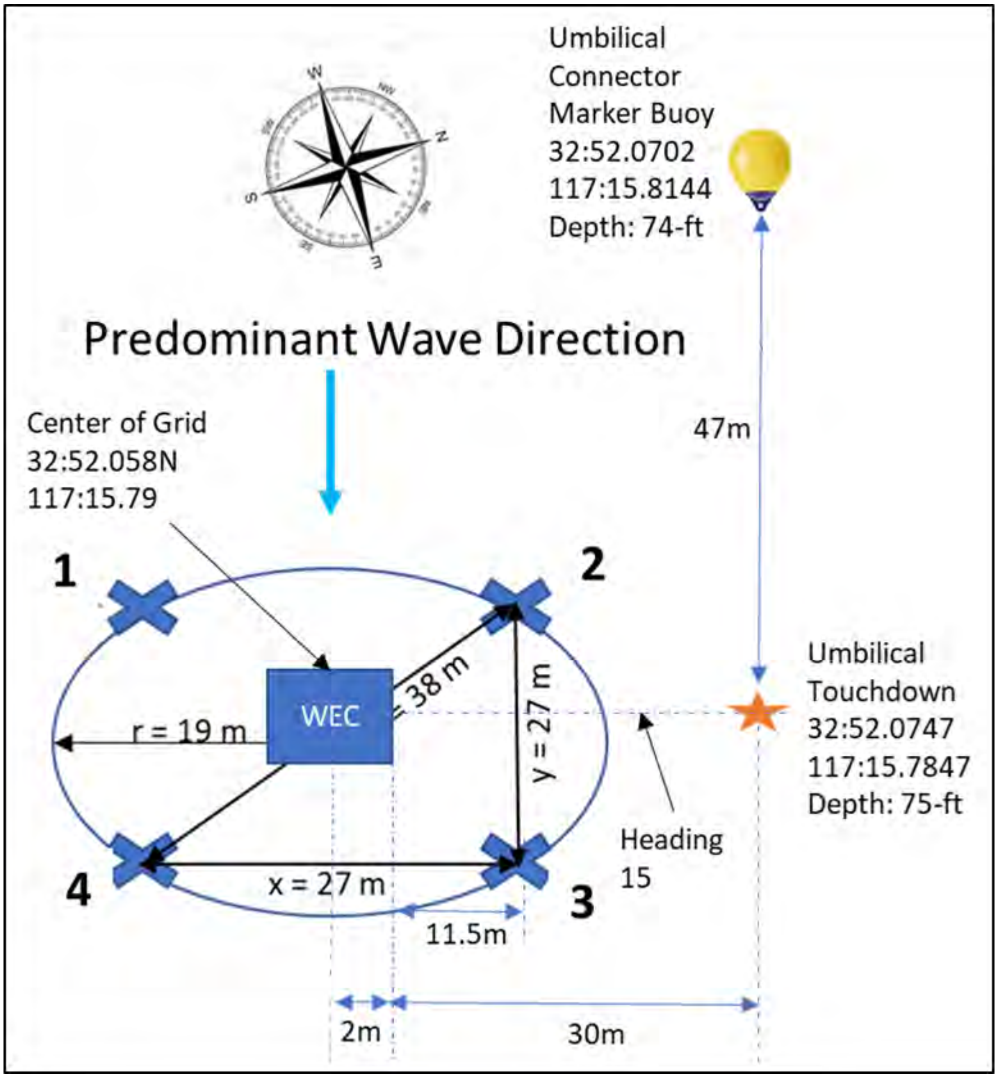


Figure 9: Umbilical Location Relative to Anchor Positions

3.3 Transit Routes

The *vessel* will transit to the test site along the proposed transit route as determined by vessel mobilization location and operations being performed. A list of anticipated transit routes to site is provided below inclusive of the PacTug primary work vessel and UCSD backup safety and line handling vessel.

Table 4: Anticipated Transit Routes.

Vessel	Route	Distance (nm)
R/V Beyster	1 – Point Loma to Test Site	16.5
19’ BW	2 - SIO pier to Test Site	0.3

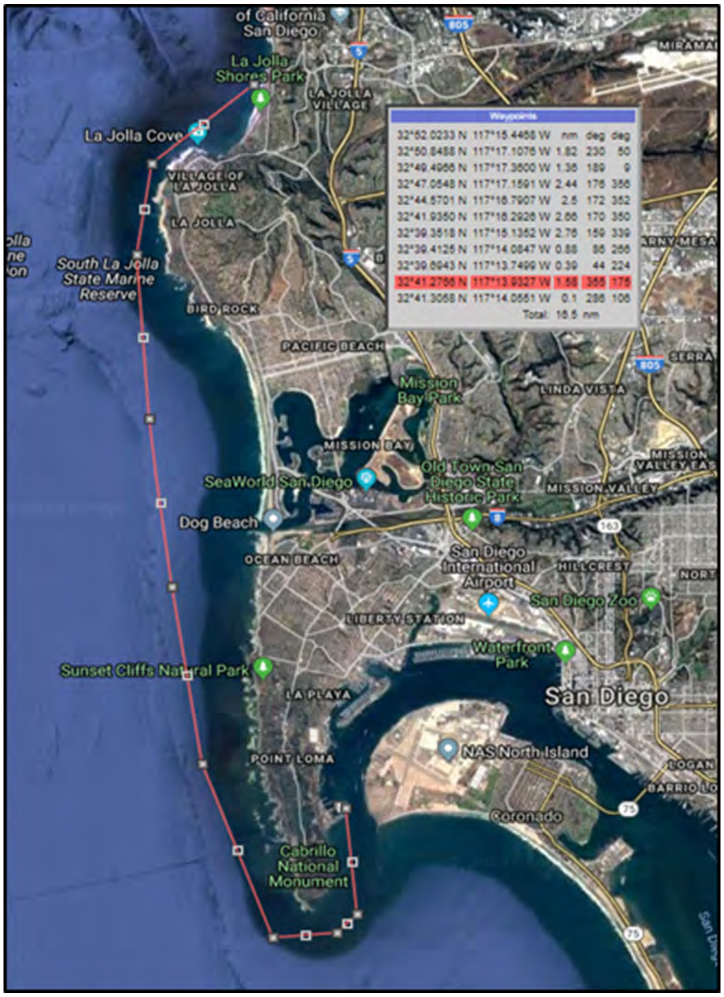


Figure 10: Transit Route 1 - Point Loma to Test Site.

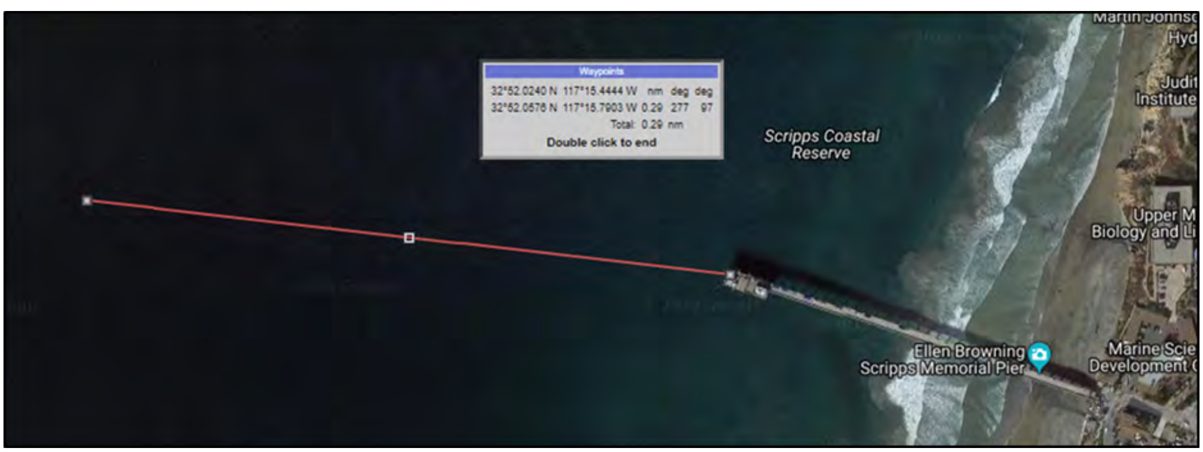


Figure 11: Transit Route 2 - SIO Pier to Test Site

3.4 Site Permits

The following site permits have been approved or are in the submission process.

Table 5: Site Permits.

Permit	Status	Comment
Landowner Permission	Received	UCSD, SIO
Army Corps of Engineers	Approved, 11/05/19	SPL-2019-00424-RRS
California Coastal Commission (wavier)	Approved, 09/28/2018	9-18-0933-W
Fish and Wildlife	Approved, 10/04/2018	SC-013978
CA Water Board	Approved, 8/1/2019	R9-2019-0158
NOAA ITA	Not required	NOAA email response 11/13/2018
State Lands Commission	Not required	SLC phone meeting 10/19/2018
DOE Biological Assessment	Complete	NMFS concurrence letter received 5/9/2019
US Coast Guard PATON	Approved, 02/11/2020	CG-2554 (CoastScout & PATON)

4 VESSELS & OPERATORS

4.1 PRIMARY VESSEL – R/V BEYSTER

The research vessel Bob and Betty Beyster is a purpose-built coastal research vessel designed for efficient operations offshore in Southern California. The Beyster is owned and operated by Scripps Institute of Oceanography (SIO).

Figure 12: R/V Beyster.

This is the primary vessel intended for use during the test period. Provisional contract terms on the use of this vessel has been agreed with UCSD and will be finalized during Budget Period 2.

Vessel Specifications:

- Length: 42 ft
- Beam: 16 ft
- Freeboard: 3 ft
- Stern A frame capacity: 2.5 tons
- Starboard knuckle crane capacity: 660 lbs, 17 ft reach
- Dynamic Positioning System (DPS)
- Deck space: 192 ft^2
- Maximum speed: 38 kts
- Cruising speed: 25 kts
- Hand-deployable Sebotix LBV-300 Mini-ROV
- Acoustic communications transducer

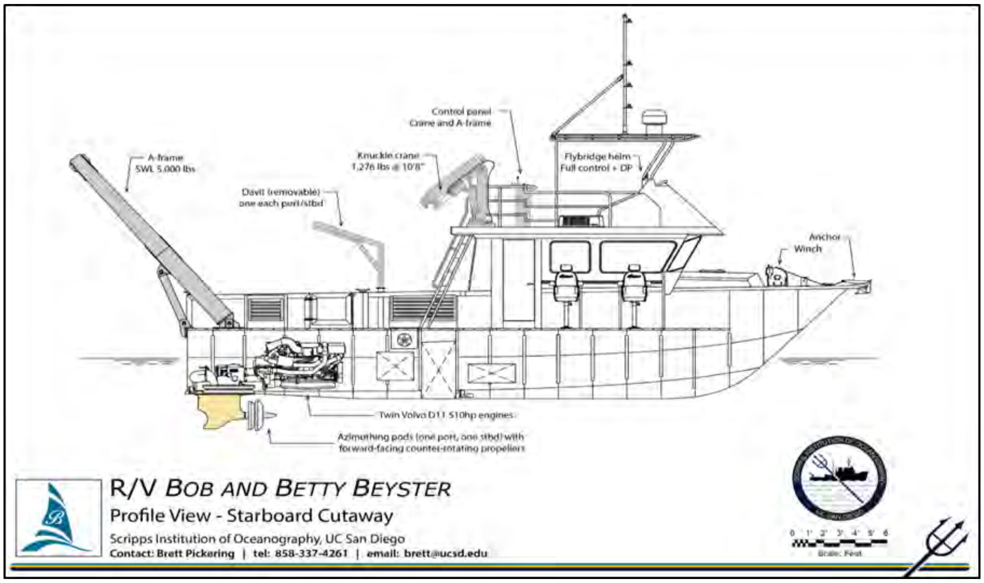


Figure 13: R/V Beyster -Starboard Cutaway

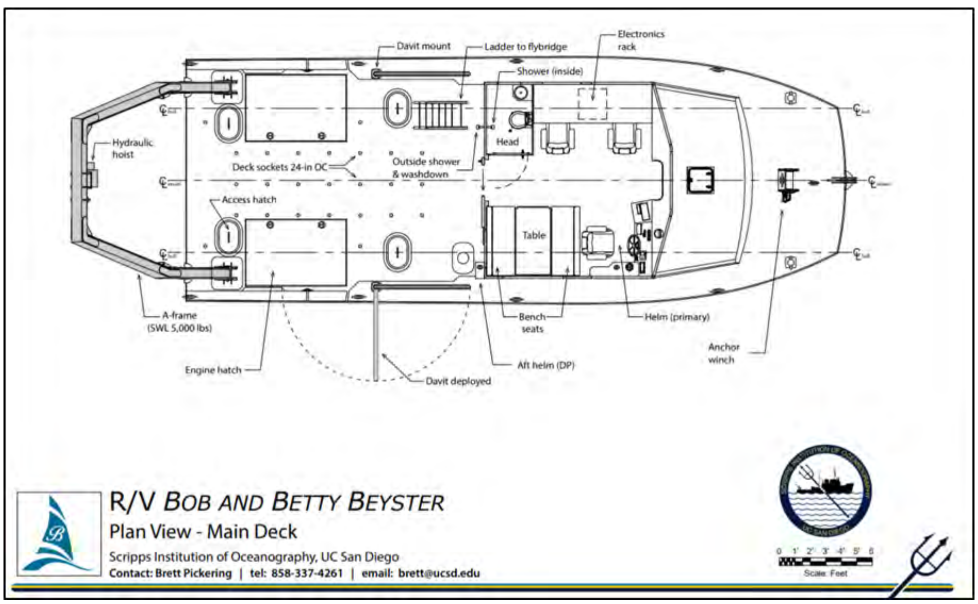


Figure 14: R/V Beyster – Main Deck Plan View

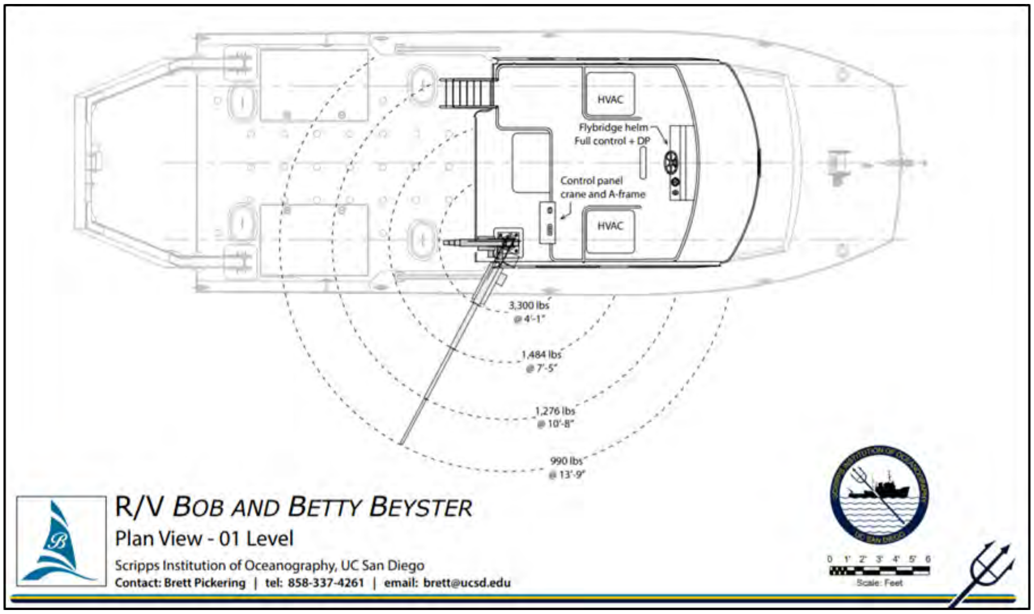


Figure 15: R/V Beyster - Boom Crane Capacity

<u>Vessel Specifications</u>:

- Length: 19.4 ft
- Beam: 8 ft
- Draft: 13 ft
- Weight (w/engine, fuel & water): 2769 lbs
- Maximum weight capacity: 2500 lbs
- Swamped capacity: 4000 lbs
- Persons capacity: 8
- Maximum Horsepower: 150 HP
- Minimum Horsepower: 115 HP

4.2 SUPPORT VESSEL (OPTIONAL) – 19' BOSTON WHALER

A small line handling vessel for operations either independently, or alongside a larger vessel. UCSD owns and operates several 19-ft Boston Whalers located on SIO pier and provisional contracting terms for the use of these vessels have been agreed with UCSD. The USCD small vessels are deployed with the pier crane and skippered by UCSD staff. At 0.3 nm from the pier, this provides the most immediate access to the test site for observations or operations appropriate for a small vessel.

Figure 16: Support Vessel (19' Boston Whaler).

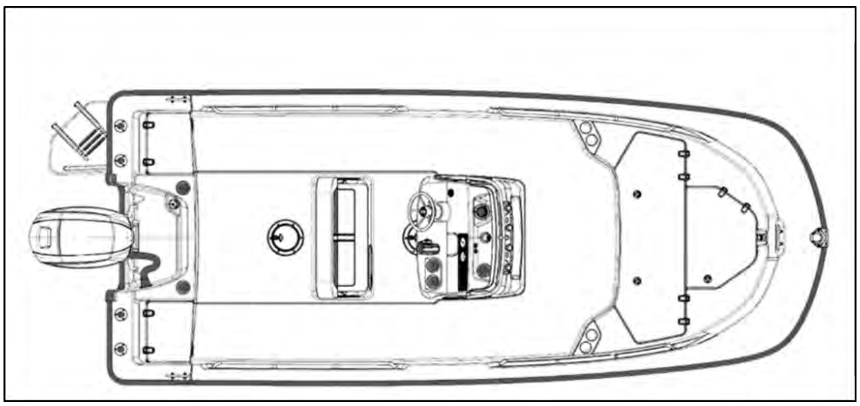


Figure 17: Boston Whaler Specifications.

Vessel Specifications:

- Length: 19.4 ft
- Beam: 8 ft
- Draft: 13 ft
- Weight (w/engine, fuel & water): 2769 lbs
- Maximum weight capacity: 2500 lbs
- Swamped capacity: 4000 lbs
- Persons capacity: 8
- Maximum Horsepower: 150 HP
- Minimum Horsepower: 115 HP

5 Project Operations

5.1 Umbilical Lay

During initial deployment of the umbilical, prior to the WEC deployment, the connector will be capped, wrapped in plastic, and placed inside a weighted housing. This housing is fitted with a lifting eye and laid on the seafloor attached to a small marker buoy, allowing for the umbilical connector end to be recovered from a small vessel during WEC deployment operations. During this initial deployment, and any subsequent period when the umbilical is deployed and not connected to the WEC, the seafloor configuration will be as pictured below.

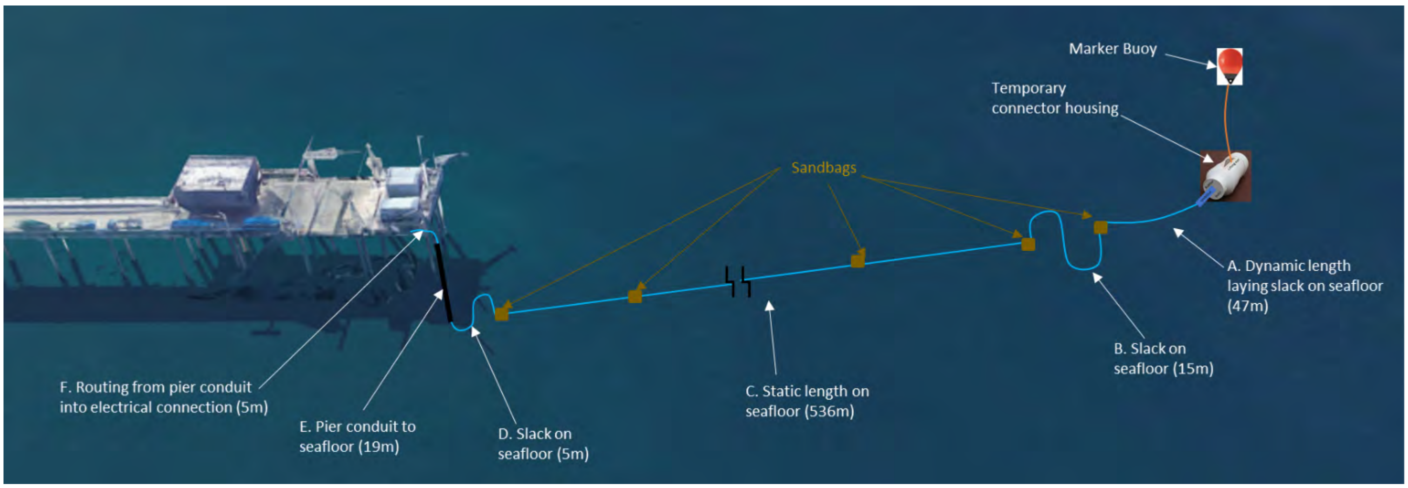


Figure 18: Umbilical Lay Location; WEC not Deployed

5.1.1 Weather Restrictions: Umbilical Cable Installation

The following operation is contingent upon the following weather restrictions:

- Wind speed: <10 kts
- Wave swell: <1 meter
- Current: <1 knot
- Visibility: Daylight hours

5.1.2 Mobilization: Umbilical Cable Installation

Mobilization will occur at R/V Beyster home port in Point Loma. Alternatively, equipment can be mobilized at SIO Pier and transferred to the R/V Beyster using the pier crane. A determination on mobilization location and specifics will be reached in collaboration with CalWave staff, UCSD staff including R/V Beyster operators.

The umbilical cable will arrive from the manufacturer on a wooden drum that is not suitable for deploying at constant speed and tension. In order to prepare the umbilical for deployment, the delivery drum (with terminated end facing out) will be suspended and allowed to rotate. The terminated end of the cable will be wrapped 2-3 times by hand, under tension, and the connector secured off the drum. While maintaining minimal resistance on the delivery drum, the deployment drum will be rotated at a constant speed to wind the umbilical under constant tension. During this operation, the spooler will be stopped as per the marking table to allow colored tape markings to be placed on the cable which will allow for visual verification of adherence to lay table during deployment. Additionally, several places near the ends of the cable will be marked with colored tape to indicate other critical locations (e.g. placement of weights and buoyancy elements). Any time the deployment drum is stopped, care must be taken to ensure constant tension is reapplied prior to restarting the spooling process.

The table below indicates the location along the cable length where marking will be placed and abrasion protection (spiral wrap) will be applied. Prior to mobilizing for deployment, the cable will be measured and marked starting at the strain termination moving back towards the unterminated end of the cable.

Table 6: Cable Marking Locations

Cable Marking Locations									
Position				**Marking Color**		**Distance to strain termination**		**Distance to unterminated end**	
Seq #		**Accessory**			**# wraps**	**m**	**ft**	**m**	**ft**
A1	Conduit entry on pier	Spiral wrap	Start	Red	I	613.1	2011	86.9	285
			Stop	Red	I	611.1	2005	88.9	292
A2	Conduit exit on seafloor	Spiral wrap	Start	Red	II	593.1	1946	106.9	351
			Stop	Red	II	**591.1**	**1939**	**108.9**	**357**
A3	End of slack section near pier	Spiral wrap	Start	Red	III	584.6	1918	115.4	379
			Stop	Red	III	585.6	1921	114.4	375
B	Sandbag placement	Spiral wrap	Start	White	I	484.6	1590	215.4	707
			Stop	White	I	485.6	1593	214.4	703
C	Sandbag placement	Spiral wrap	Start	White	II	384.6	1262	315.4	1035
			Stop	White	II	385.6	1265	314.4	1031
D	Sandbag placement	Spiral wrap	Start	White	III	284.6	934	415.4	1363
			Stop	White	III	285.6	937	414.4	1360
E	Sandbag placement	Spiral wrap	Start	White	IIII	184.6	606	515.4	1691
			Stop	White	IIII	185.6	609	514.4	1688
F	Sandbag placement	Spiral wrap	Start	White	X	84.6	278	615.4	2019
			Stop	White	X	85.6	281	614.4	2016
G1	End of slack section near WEC	Spiral wrap	Start	Blue	I	49.6	163	650.4	2134
			Stop	Blue	I	48.6	159	651.4	2137
G2	Dynamic seafloor touchdown point	Spiral wrap	Start	Red	X	**44.1**	**145**	**655.9**	**2152**
			Stop	Red	X	29.1	95	670.9	2201
N/A	Buoyancy module 1	Spiral wrap at entry & exit	Start	Orange	I	**21.5**	**70**	**678.6**	**2226**
			Stop	Orange	I	21.2	69	678.9	2227
N/A	Buoyancy module 2	Spiral wrap at entry & exit	Start	Orange	II	**20.8**	**68**	**679.2**	**2228**
			Stop	Orange	II	20.5	67	679.5	2229
N/A	Buoyancy module 3	Spiral wrap at entry & exit	Start	Orange	III	**20.2**	**66**	**679.9**	**2230**
			Stop	Orange	III	19.9	65	680.2	2231

The below equipment list is provisional and will be further updated in collaboration with vessel operators.

Table 7: Equipment List: Umbilical Cable Installation

OWNER	DESCRIPTION	SIZE	QTY
R/V Beyster			
CalWave	Marker buoy		1
CalWave	Umbilical cable	26.5mm	1
CalWave	Reel dispenser	4”x9”x28”	2
CalWave	Colored vinyl (electrical) tape for marking umbilical cable – colors TBD		4
CalWave	Shackle (umbilical cable to marker buoy)	0.5”	1
CalWave	Umbilical abrasion protection (spiral wrap)	TBD	TBD
UCSD	Polyprop line (Line #2)		1
UCSD	Downline (to mark dynamic umbilical touchdown)		
UCSD	Seabotix ROV		1
BW 1			
UCSD	Dive gear		1
CalWave	Weight (sandbags)	5-kgs	10
CalWave	Weight (sandbags)	10-kgs	2
CalWave	Lines for attaching sandbags to umbilical cable		TBD
Shore Staff Tools			
UCSD	Polyprop line (Line #1)	TBD	1
CalWave	Umbilical abrasion protection (spiral wrap)	TBD	TBD

The deployment drum will be placed on reel dispenser skids as shown below. The reel dispenser skids shall be sea fastened to the deck of the R/V Beyster and the umbilical cable drum placed on the rollers to allow the umbilical cable to be manually spooled off.

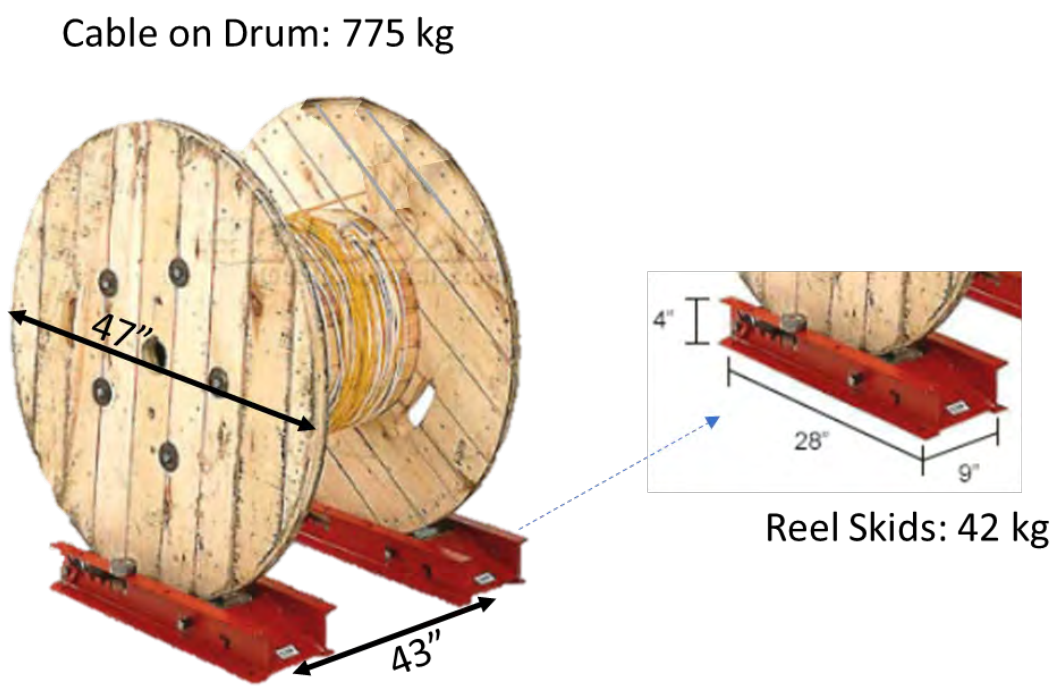


Figure 19: Reel Dispenser Skids

It is not planned to use a cable chute to direct the umbilical overboard. Instead, the umbilical will be lowered off the back of the vessel hand-over-hand. The apparent weight of the suspeneded umbilical cable is calculated to be approximatly 13kgs in the shallow water near the pier, gradually progressing to 21kgs at maximum depth, near the test site. In order to allow on crew member (Crew #1) to maintain focus on paying out the cable with the appropriate angle, a second crew member (Crew #2) will spool the cable off the reel, feeding to Crew #1.

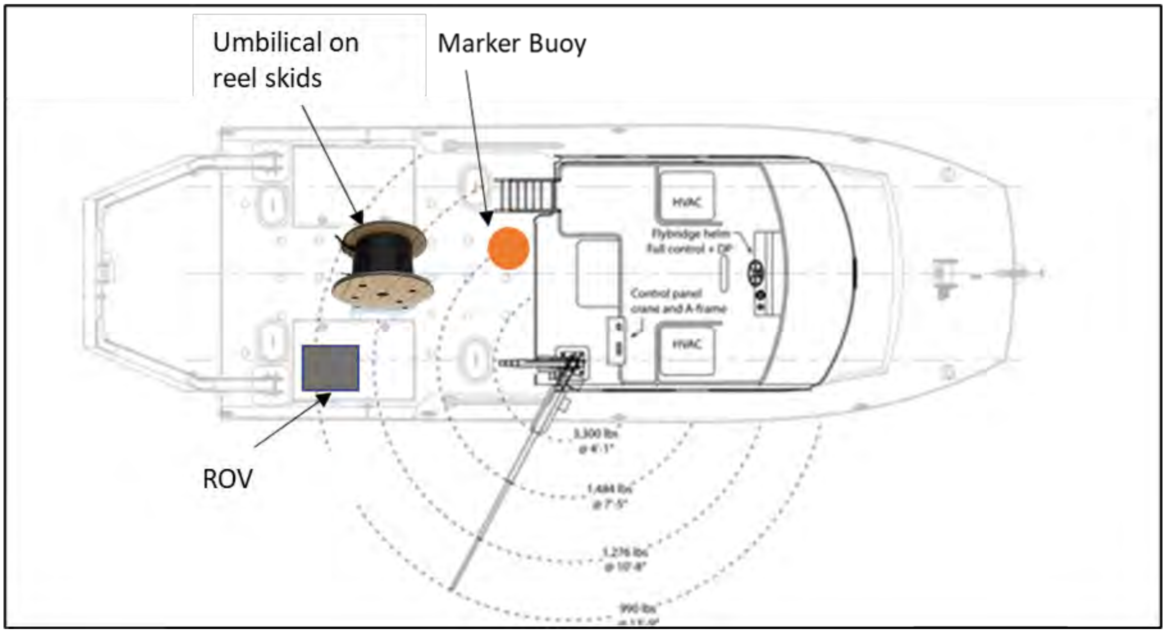


Figure 20: R/V Beyster Deck Layout

5.1.3 Operations Sequence: Umbilical Cable Installation

The following sequence details the scope of work for the umbilical installation evolution. The table below provides a detailed scope of work for the *vessel* to deploy anchors at the SIO test site. The sequence may be altered at the direction of the vessel captain and/or CalWave staff on-board.

Table 8: Sequence: Umbilical Cable Installation

Step #	Line #	Vessel	Assignment
1	*Deploy BW 1 and prepare pier for umbilical*		
1.a	1	*SIO Pier*	• Deploy BW 1 on leeward side of pier • *Pier Staff #1*: Lower line (line #1) through PVC pier routing conduit and secure on pier end, continue holding line
2	*R/V Beyster* transits to SIO pier and positions at foot of pier		
3	Secure unterminated end of umbilical to SIO pier with spooler on vessel		
3.a		*BW 1*	• Deploy divers, radio check with BW 1 Captain and R/V Beyster Crew #2 • Lower sandbags to divers
3.b		*R/V Beyster*	• Crew #1: Slack cable from spooler and pass to Crew #2, maintain hands on spool to ensure controlled spooling off • Crew #2: Feed slack cable to divers as needed maintaining minimum tension by hand
3.d	1	*Dive Team*	• Diver #1: Lay out ~15-ft of slack umbilical on seafloor, securing with 5-kg weights (sandbags)

			• Diver #1: Retrieve line #1 from conduit and connect to unterminated end of umbilical. Once connected, pull on the line to inform Pier Staff #1 umbilical is ready to be lifted. • Diver #1: Guide cable end into conduit and ensure umbilical does not pinch or kink as it is fed into conduit. Continue to feed cable until indicated by two parallel red stripe markings. Once complete ensure abrasion protection (spiral wrap) is in place at conduit entry. • Diver #2: Lay out slack cable on seafloor in 'S' configuration, gradually pulling cable from R/V Beyster and attach sandbag to section indicated by single white stripe marking (will be ~6m of cable length from conduit exit to sandbag).
3.e	1	*SIO Pier*	• Pier Staff #1: Lift line #1 one hand-over-hand to retrieve umbilical. • Pier Staff #2: Route umbilical into monitoring station and spool (will be ~65m of cable in shed). • Pier Staff #1: Once single red stripe marking is visible at top of conduit, secure umbilical to pier by lashing at top of conduit. Ensure abrasion protection (spiral wrap) is in place and conduit exit.
3.f	1	*Dive Team*	• Recover to BW 1
3.g		*SIO Pier*	• Deploy drop camera to monitor slack section of umbilical on seafloor during deployment
4	Vessel transits to SIO test site following lay table		
4.a		*R/V Beyster*	• ROV Pilot: Deploy drop camera or ROV to monitor umbilical as it spools out • R/V Beyster Captain: Proceed to test site along lay table (with sequential way points programmed), maintain vessel speed ~0.2 kts, adjusting as suggested by Crew #2 • Crew #1: Feed cable off reel at constant speed, indicate to R/V Beyster Captain as each subsequent marking comes off reel. ("two blue stripes", "three blue stripes", etc.,) • R/V Beyster: Verify lay table way points against marking being called off by Crew #2 • Crew #1: Lower umbilical over stern of vessel. Monitor and adjust deployment angle of umbilical as it enters water (min angle 10°, max angle 20°). Request vessel adjust speed as necessary to maintain angle limitations.
4.c		*BW 1*	• Deploy divers every 100 m to attach sandbags to the umbilical at marked locations (where the spiral wrap abrasion protection is in place).
4.b		*SIO Pier*	• Monitor drop camera and notify R/V Beyster if slack umbilical cable begins to pull straight
5	Secure terminated end of cable to marker buoy		
5.a	2	*R/V Beyster*	• R/V Beyster Captain: Upon reaching position G on the lay table, use vessel DPS to maintain position • Crew #1: Maintain tension on umbilical

			• Crew #2: Verify the Blue marker is off the spool. • Crew #2: Deploy downline to mark location for divers • Crew #2: Spool off remaining umbilical cable and flake on deck • Crew #2: Attach marker buoy and line to umbilical termination cover, inform Beyster Captain and Crew #1 when ready to proceed • R/V Beyster Captain: Continue on 280 heading • Crew #1: Hand over hand deploy the umbilical maintaining ~15° departure angle • Crew #2: Hold the umbilical termination cover and marker buoy as the umbilical pays out, let R/V Beyster Captain and Crew #1 know when reaching the end of the umbilical • R/V Beyster Captain: Stop vessel and maintain position • Crew #2: Use marker buoy line to lower the umbilical termination cover to seafloor and release the marker buoy overboard
5.b		*BW 1*	• Deploy divers near umbilical touchdown downline marker that R/V Beyster left at Lay Table position G. • Lower 10kg and 5kg sandbags to divers.
5.c		*Dive Team*	• Diver #1: Locate the two single blue wrap marking on the umbilical, swim this section of cable to the deployed downline (without moving downline). • Diver #2: Affix 10kg sandbag to umbilical cable at downline point. Sandbag is attached around the spiral wrap abrasion protection in between the two blue single stripe markings. • Recover to BW 1
5.c		*R/V Beyster*	• Return to Umbilical touchdown point (Lay Table position G), verify accuracy of placement per lay table.

The figure below illustrations the location where the umbilical cable will be routed up on to the pier, via the pre-existing PVC conduit reaching from the pier to the seafloor. Because the umbilical cable is longer than is necessary, approximately 85 meters of cable will need to be routed up through the conduit and spooled in place near the pier observation shed.

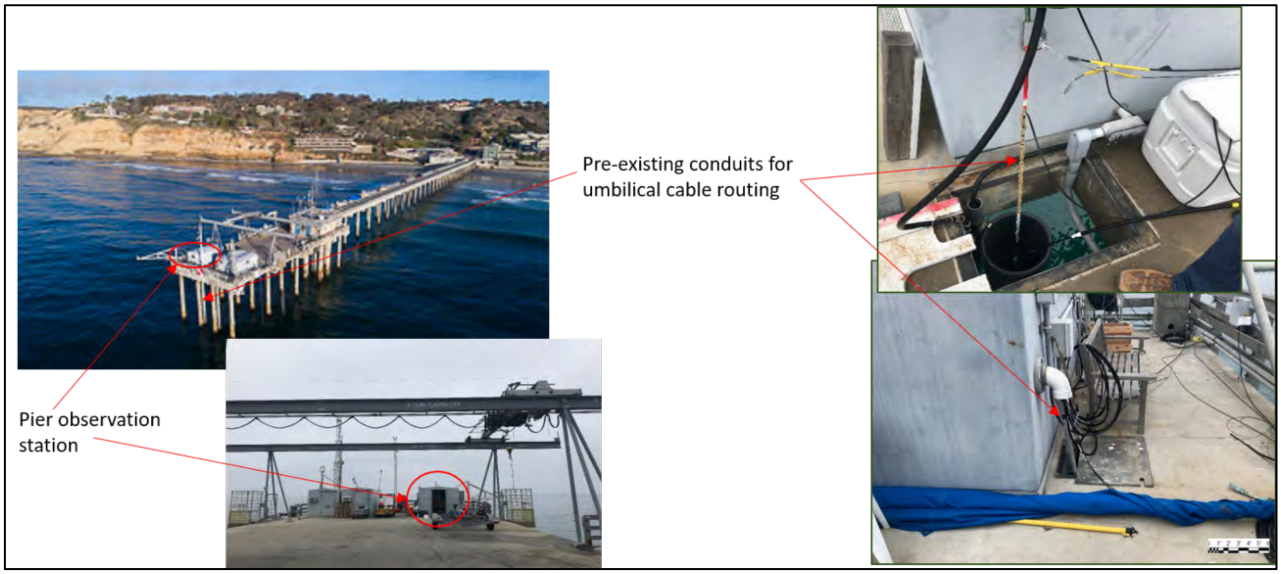


Figure 21: SIO Pier Conduit Routing

Table 9: Umbilical Lay Table

Umbilical Lay Table							
Position	Vessel stern GPS		Marker	Dist. from Pier		Dist. to Touchdown	
Seq #	N	W	Tape	m	ft	m	ft
A	32°52.023'	117°15.447'	Red	0	0	536.0	1759
B	32°52.0328'	117°15.5096'	White I	100	328	436.0	1431
C	32°52.0424'	117°15.5727'	White II	200	656	336.0	1102
D	32°52.0520'	117°15.6358'	White III	300	984	236.0	774
E	32°52.0616'	117°15.6989'	White IIII	400	1312	136.0	446
F	32°52.0712'	117°15.7620'	White X	500	1641	36.0	118
G	32°52.0747'	117°15.7847'	Blue	536	1759	0	0

5.1.4 Estimated Timeline: Umbilical Cable Installation

Only vessel time is added to total time calculation (highlighted activities do not require vessel on-site)
It is anticipated that R/V Beyster will be used for this operation.

Table 10: Timeline: Umbilical Cable Installation

Step #	Activity	Hours
M	Mobilize vessel at home port (Point Loma)	3.0
1	Prepare umbilical cable for deployment	3.0
2	Transit to SIO Pier (16.5nm @ 25kts), position below traverse crane	0.75
3	Secure unterminated end of umbilical to SIO pier with spooler on vessel	0.5
4	Transit to test site via lay table	1.5
5	Secure WEC end of umbilical to marker buoy & deploy	0.5
T	Transit to home port	0.75
DM	Demobilize vessel	3.0
	Total Time Estimate (hrs)	**10.0**
	Total Time On-Site (excluding mob/demob & transit to/from site)	**2.5**

Anticipated as a one-day operation, not inclusive of pre-dive route survey. During umbilical lay it is critical that once the lay operation commences, vessel movement is consistent and maintained throughout operation.

5.1.5 Demobilization: Umbilical Cable Installation

Upon completion of the umbilical cable installation, the R/V Beyster will return to SIO pier to unload the empty umbilical drum and cable spooler. Umbilical drum will be taken off the spooler and retained in storage, while the cable spooler will be returned.

6 References

6.1 An Analysis Tool for the Installation of Submarine Cables in an S-Lay Configuration Including "In and Out of Water" Cable Segments, JMSE, Vol 8, Issue 1, Jan 2020

https://www.mdpi.com/2077-1312/8/1/48/htm#cite

7 CALCULATIONS

7.1 CATENARY EQUATIONS

Deployment catenary dimensions, loads and angles were calculated using the above referenced analysis guidelines

Base Dimensions

Depth (min)	D_min	10	m		
Depth (max)	D_max	22.5	m		
Horizontal tension	H	0.200	kN	20.4	kg
Weight in seawater	q1	390	kg/km	0.39	kg/m
Weight in air	q2	960	kg/km	0.96	kg/m
Height above water	c	1.5	m		
Bend radius dynamic	MBR_d	260	mm		
Bend radius static	MBR_s	160	mm		

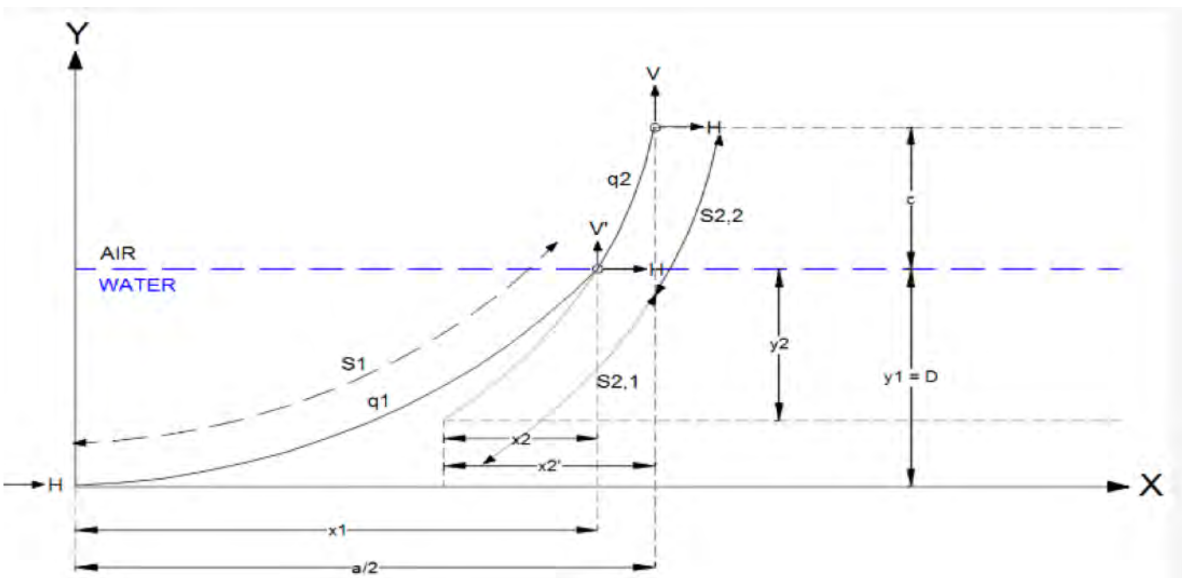


Figure 22: Catenary Calculation Layout

The below calculations are shown for the maximum depth, 22.5m.

3.1. STEP 1: Determination of the Submerged Catenary Curve

For y = y1 = D and q = q1, x1 is determined using Equation (1):

$$x = \frac{H}{q} \operatorname{arccosh}\left(\frac{y * q}{H} + 1\right).$$

For x = x1, S1 and V' are determined using Equations (2) and (3):

$$S = \frac{H}{q} \sin h\left(\frac{q * x}{H}\right),$$

$$V = H * \sin h\left(\frac{q * x}{H}\right),$$

3.1 Submerged Catenary Curve					
Horizonal distance	x1	46.9	m		
Catenary length	S1	53.5	m		
Vertical tension	V1	0.205	kN	20.9	kg
Safety Factor_tension	**SF**	**49**			

3.2. STEP 2: Iterative Procedure to Define the "Correct" Catenary Curve in Air Which Can Be Combined with the Submerged One

3.2 Iterate					
	y2	3.5	m		
	x2	19.03	m		
	V2	0.204	kN	20.8	kg

3.3. STEP 3: Determination of Various Parameters for the Catenary Curve in Air

For y2′ = y2 + c, x2′ is determined using Equation (1).
For x = x2′, V is determined using Equation (3′).

$$\frac{V}{H} = \sin h\left(\frac{q * x}{H}\right), \tag{3'}$$

$$\tan\theta = \frac{V}{H} = \sin h\left(\frac{q * x}{H}\right), \tag{4}$$

3.3 Catenary in Air					
	y2'	5.0	m		
	x2'	14.30	m		
	V2'	0.055	kN	5.65	kg
	tan(ɵ)	0.27695			
departure angle	ɵ	15.5			

exit angle	Ø	74.5

3.4. STEP 4: Determination of the Combined Catenary Curve Configuration (In and out of Water)

For x = x2 and q = q2, S2,1 is determined using Equation (2).
For x = x2′ and q = q2, S2 is determined using Equation (2).

$$\mathrm{S2,2} = \mathrm{S2} - \mathrm{S2,1}, \tag{5}$$

$$\mathrm{S} = \mathrm{S1} + \mathrm{S2,2}, \tag{6}$$

$$\mathrm{a}/2 = \mathrm{x1} + (\mathrm{x2}' - \mathrm{x2})\,, \tag{7}$$

3.4 Combined Catenary

	S2, 1	21.7	m		
	S2	15.4	m		
	S	47.2	m		
layback	a/2	42.20	m		
Tangential Internal Force	T_air	0.21	kN	21.16	kg
	T_water	0.29	kN	29.14	kg

The results are illustrated below.

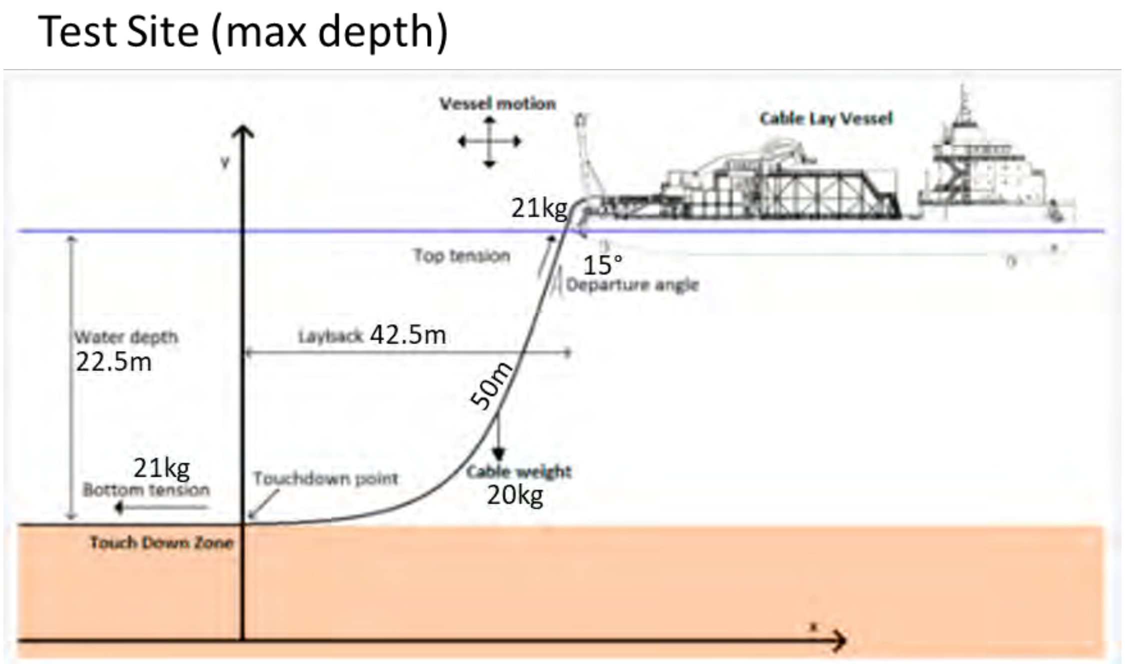


Figure 23: Catenary Dimensions at Max Depth

The same calculations were performed for minimum operational depth (at SIO pier), 10 meters.

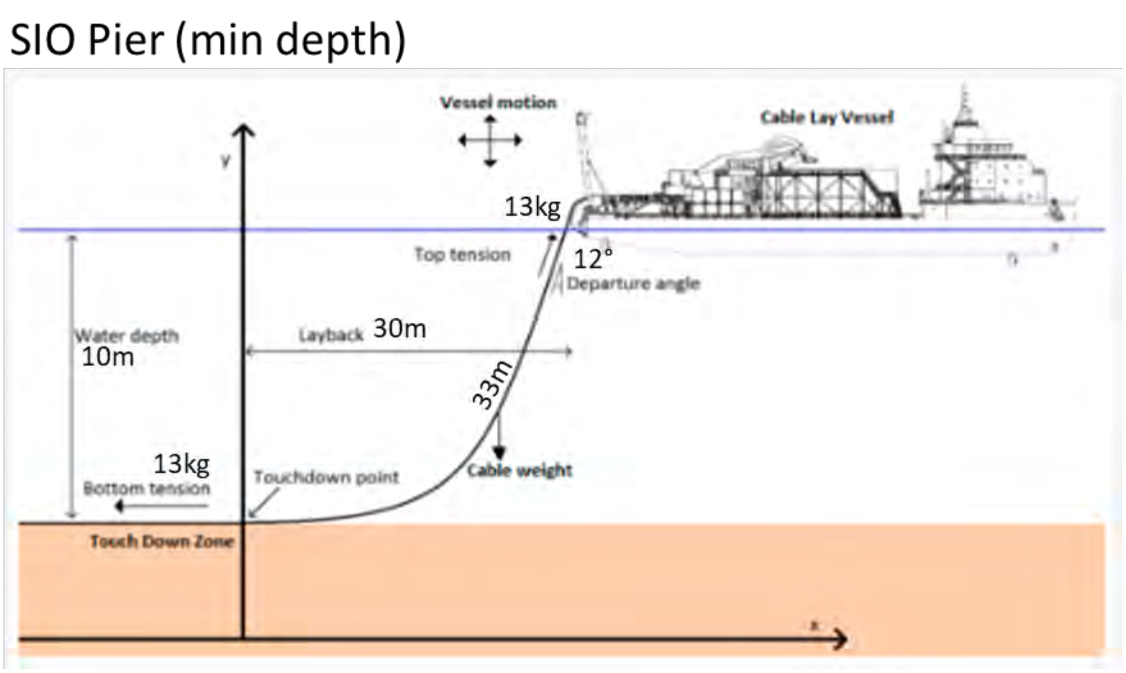


Figure 24: Catenary Dimensions at Min Depth

8 HAZID

8.1 Administrative

Date of planned operation:

Date of HAZID briefing:

Attendees:

*by signing below, I attest that I have read and understand the operational plan and agree to operate safely and in accordance with this plan.

Name	Company	Signature
	CalWave	
	CalWave	
	UCSD	
	UCSD	
	UCSD	
	UCSD	

Planned Vessel Crew

Vessel	Name	Company	Role
R/V Beyster		UCSD	Captain
R/V Beyster		CalWave	Crew #1
R/V Beyster		CalWave	Crew #2
BW 1		UCSD	Captain
BW 1		UCSD	Diver #1
BW 1		UCSD	Diver #2

Vessel Call Times (DATE)

Vessel	Port	Crew Arrival Time	Departure Time
R/V Beyster	Point Loma		
BW 1	SIO Pier		

8.2 Risk Categories

Severity	Consequences: People	Consequences: Assets	Consequences: Environment	Consequences: Reputation	Increasing Probability: 1 Never heard of in the industry	2 Heard of in the industry	3 Has happened in the organization or more than once per year in the industry	4 Has happened at the location or more than once per year in the organization	5 Has happened more than once per year at the location
0	No injury or health effect	No damage	No effect (no or temporary impact - days)	No impact (local media, no significant concern)	L	L	L	L	L
1	Slight injury or health effect (first aid or medical treatment)	Slight damage	Slight effect (local scale, short term damage – weeks)	Slight impact (short term local concern)	L	L	L	L	L
2	Minor injury or health effect (restricted work case or LTI)	Minor damage	Minor effect (local scale, short term damage – months)	Minor impact (short term national mention)	L	L	L	M	M
3	Major injury or health effect (partial disability)	Moderate damage	Moderate effect (local scale, medium terms damage – years)	Moderate impact (medium term national concern)	L	L	M	M	H
4	< 3 fatalities, or permanent total disabilities	Major damage	Major effect (local scale, long term damage – decades)	Major impact (regional or persistent national concern)	L	M	M	H	H
5	> 3 fatalities	Massive damage / total loss	Massive effect (regional scale, permanent damage)	Massive impact (global concern and media coverage)	M	M	H	H	H

L	Low Risk
M	Medium Risk
H	High Risk

Figure 25: Risk Categories

8.3 Risk Identification and Mitigation

Table 11: Summary of Identified Risks

Umbilical Lay					
	Consequence				
Prob.	**1**	**2**	**3**	**4**	**5**
5	0	0	0	0	0
4	0	0	0	0	0
3	0	0	1	1	0
2	0	0	2	4	7
1	0	0	0	0	1

Umbilical Lay			
Total risks	High	Medium	Low
16	0	14	2
	0%	*88%*	*13%*

Table 12: HAZID

ID	Hazard Category	Scenario	Likely Threats	Top Events	Controls in Place	C	P	RPT	Rank	Comments	Action Party	Closed?
X.0300	Secure for sea											
X.0301	Pier side work	Personnel working at Point Loma and Scripps piers, transferring from pier to vessel	Slips, trips, falls	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0302	Lifting operations	Personnel safety	Crush injury	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0303	Lifting operations	Equipment failure	Connection equipment or line failure	Injury to personnel, loss of equipment	Equipment inspections, operator training	5	1	5	Low			
X.0304	Lifting operations	Inclement weather	Delays, additional cost	Schedule delays incurring additional cost	Flexible deployment window	3	2	6	Low			
X.0310	Vessel operations											
X.0311	Working offshore	Personnel safety	Slips, trips, falls	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0312	Transfer of personnel from pier to vessel	Personnel safety	Fall or crush injury transiting the pier ladder	Injury to personnel	UCSD transfer procedures and controls	5	2	10	Med			
X.0320	Dive operations											
X.0321	Diving near vessels & structures	Diving near pier to route umbilical from seafloor to pier	Injury from diver contact with vessels & structures, particularly when surfacing	Injury to personnel	UCSD dive procedures and controls	5	2	10	Med			
X.0322	Diving at depth	Diver safety	Diving up to 75-ft depth	Injury to personnel	UCSD dive procedures and controls	5	2	10	Med			
X.0330	Routing Umbilical to Pier											
X.0331	Abrasion of umbilical due to contact with the conduit	Diver passing umbilical up through pier conduit	Damage to umbilical	Equipment damage, project delays, budget overrun	Operational pre-briefing, spiral wrap on cable, additional length of cable in case splicing is required	3	3	9	Low			
X.0332	Seawater contact with umbilical conductors	Unterminated end of umbilical not adequately sealed	Damage to umbilical	Equipment damage, project delays, budget overrun	Heat shrink boot over unterminated end of cable	4	2	8	Low			

X.0340	Laying Umbilical											
X.0341	Exceeding bend radius	Vessel motion causes umbilical to exceed bend radius during deployment	Damage to umbilical	Equipment damage, project delays, budget overrun	Monitor umbilical during deployment, maintain minimum vessel speed	4	2	8	Low			
X.0342	Over tensioning umbilical	Vessel motion causes over tensioning of umbilical during deployment	Damage to umbilical	Equipment damage, project delays, budget overrun	Monitor umbilical during deployment, limit vessel speed, pre-briefing of over boarding technique	4	3	12	Med			
X.0343	Umbilical damage on seafloor	Umbilical laid on or near existing structure or equipment	Damage to umbilical	Equipment damage, project delays, budget overrun	Pre-dive lay route, review possibility of divers placing sandbags on cable as it is laid	4	2	8	Low			
X.0344	Laying umbilical overboard	Personnel safety	Pinch or crush injury	Injury to personnel	HSE plan, operational pre-briefing	5	2	10	Med			
X.0350	Lowering Connector											
X.0351	Seawater contact with connector	Connector cap and cover do not adequately seal seawater from connector	Damage to connector	Equipment damage, project delays, budget overrun	Ensure proper fit of dust cover. Additionally bag and cover strain termination end of cable. Minimize time connector deployed on seafloor	4	2	8	Low			
X.0352	Loss of marker buoy	Marker buoy disconnects from umbilical Marker buoy becomes entangled	Improper connector usage Watch circle overlap with other deployed buoys	Equipment damage, project delays, budget overrun	Watch circle overlap review	3	2	6	Low			

CWPT Open Water Demonstration

DE-EE0008097.0005

Task 5.4 Comprehensive IO&M and Testing Plan

9.5 WEC Tow Plan

Version 2.5 - April 2020

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CONTENTS

FIGURES

TABLES

1 Introduction

This report focuses on the WEC Tow Planning for the open water demonstration to be conducted in collaboration with University of California, San Diego (UCSD) near the Scripps Institute of Oceanography (SIO) pier, in a water depth of approximately 70 ft (21.3 m).

All operations are being coordinated with University of California, San Diego (UCSD) Scripps Institute of Oceanography (SIO) staff as well as local vessel operators and marine operations contractors. Alternate vessels have been identified for use during different aspects of the CalWave technology deployment and test period.

The details outlined in these procedures are contingent upon several factors, such as operational conditions, vessel ability, safety, efficiency, etc. Due to these factors, this plan is subject to change. Adjustments to sequences for the preset installation and connection can be made in the field with the use of Management of Change (MOC) process. The respective management personnel must be contacted and contribute to determining a safe and effective method of performing operations. The current and weather conditions must be deemed favorable before starting operations.

Before the start of any operations, all vessels and individuals involved will hold operational procedure review and safety meetings to prepare for upcoming operations. All equipment will be checked at this time and the equipment will be verified for availability for upcoming operations.

The vessel captain and CalWave representatives will approve deviations that become unavoidable in the field during the installation process. VHF working channels will be identified at this time.

This document comprises of the overall methodologies of safe operations offshore, includes vessel specifics, and operations planning for the following planned evolutions:

Table 1: Planned Offshore Operations

Activity	Days
WEC Deployment Tow Operation	1
WEC Recovery Tow Operation	1
WEC Emergency Recovery & Tow Operation	-
Total Planned Operational Days Offshore	2

2 VESSELS AND EQUIPMENT

2.1 VESSELS

Table 2: Vessel List

Vessel	Operator	Website	Notes
R/V Beyster	UCSD	https://scripps.ucsd.edu/ships	Primary work vessel
BW1	UCSD	https://www.bostonwhaler.com/family-overview/outrage-boat-models/190-outrage/	Line handling vessel
M/V Cooper	C&W Dive Services	http://www.cwdiving.com/CWVessels.htm	Backup vessel
Jag	Pacific Maritime Group	https://www.pacificmaritimegroup.com/fleets/jag/	Backup vessel

2.2 EQUIPMENT

CalWave provided equipment vs equipment provided by vessel to be specifically identified in mobilization section of individual operations.

Towing bridal connecting WEC to tow line:

As the center of gravity (and center of buoyancy) are significantly below the waterline, to maintain stability during tow, the tow point will be submerged approximately 1 meter below the waterline. This will require a towing bridal to be permanently attached during the WEC deployment to allow access for towing operations. This will consist of a short tow line connected between the tow point and the above lift point when the WEC is not under tow. For towing operations, this line is then connected to a larger tow package.

The figures below show the location and dimensions of the WEC tow point.

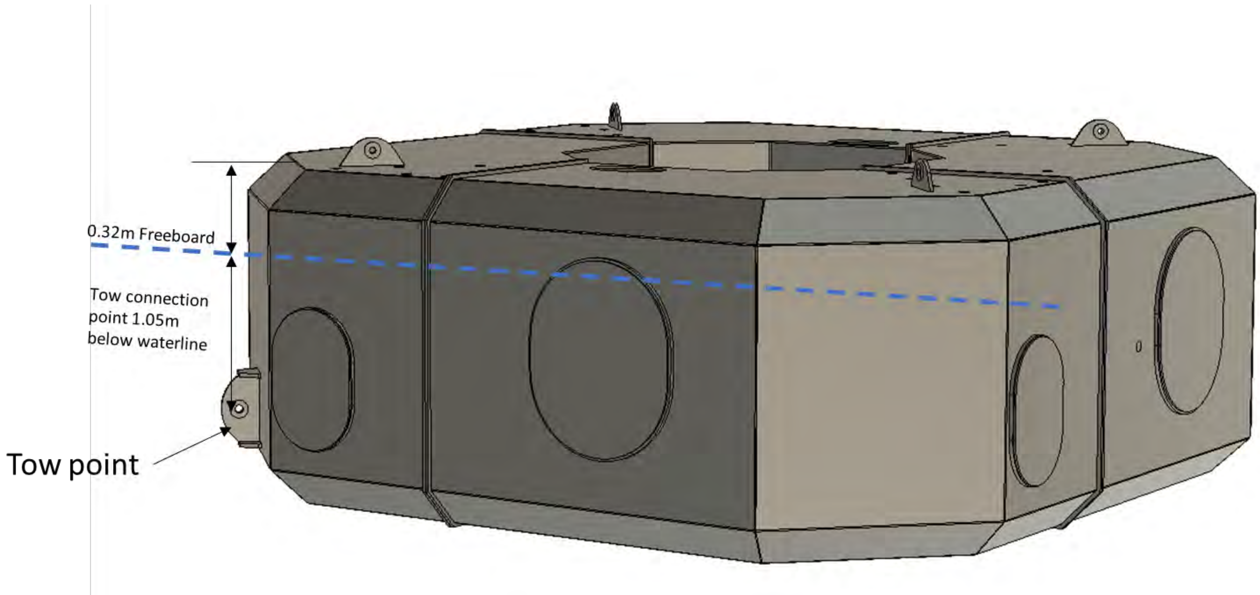


Figure 1: WEC Tow Point

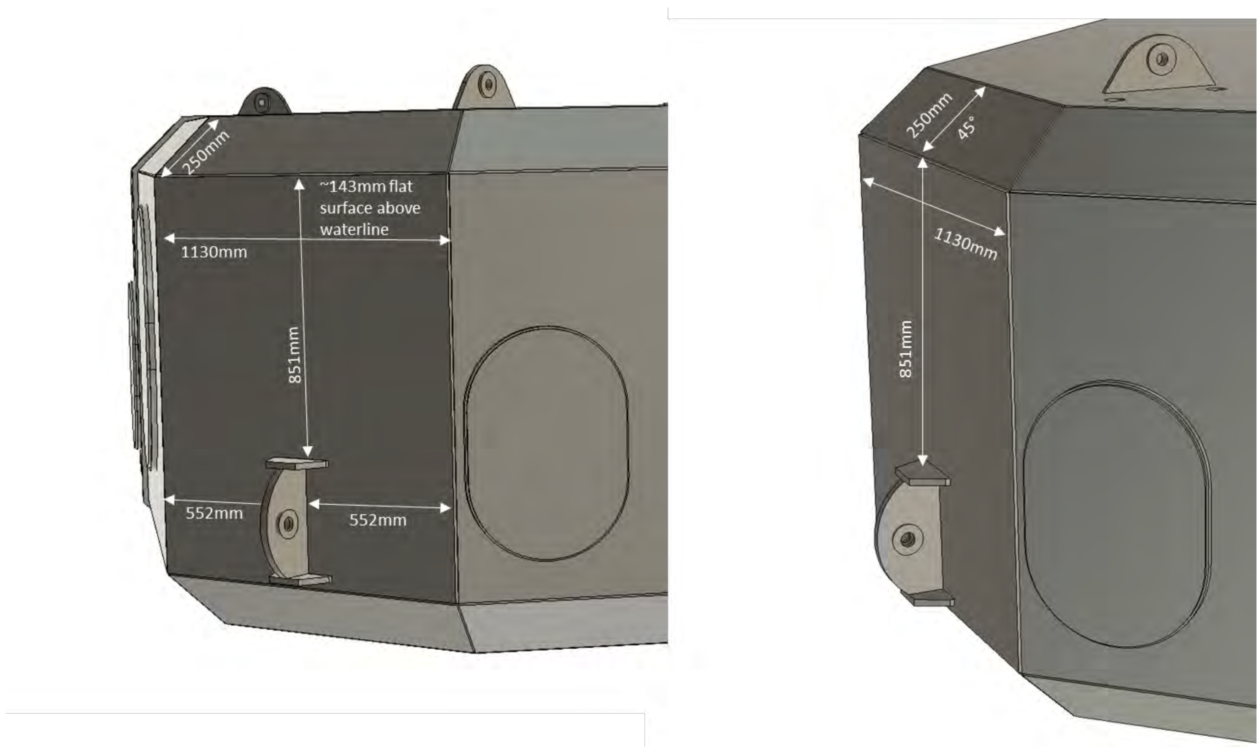


Figure 2: Tow Point Dimensional Location

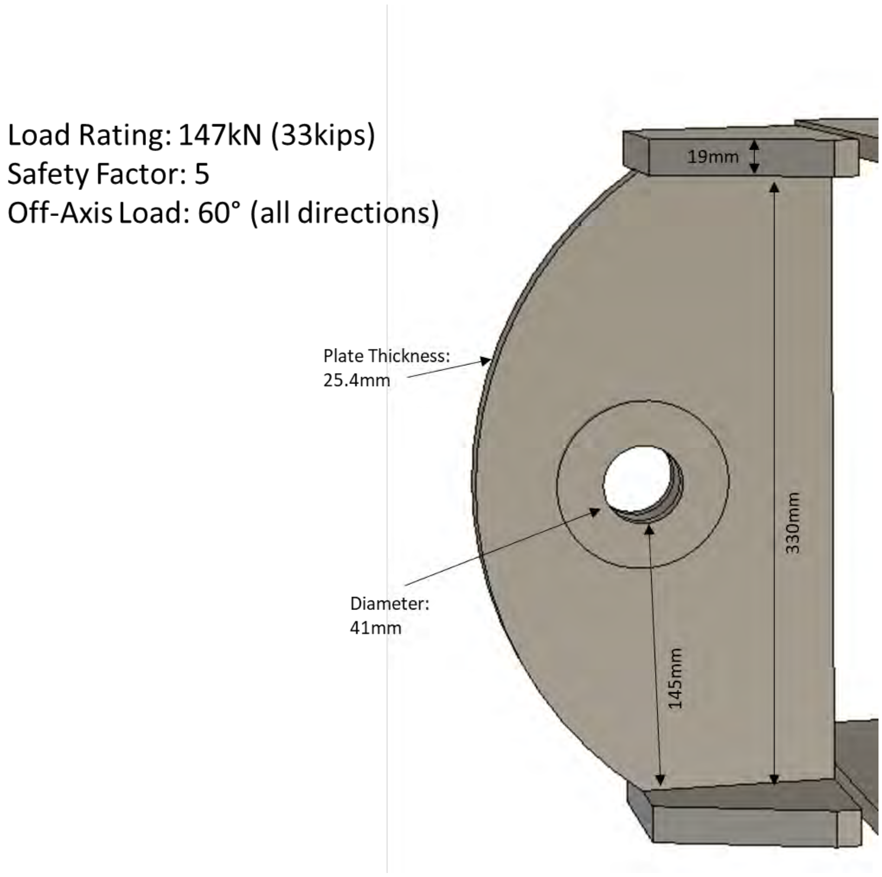


Figure 3: Tow Point Dimensional Drawing

The U.S. Navy Towing Manual, figure 4-7, page 4-14 provides recommended minimum dimensions for padeyes to be used for towing. It is worth noting that the anticipated load for WEC towing is likely to be significantly less than 33,000-pound design load (provisionally estimated at 3,200 pounds). The below pictured representative example is illustrated for the design load of 33,000-lb load, with ¼" weld thickness and 1" plate thickness, and shows that for these assumptions the padeye dimensions of 1.625" hole diameter (d), length from hole edge to plate edge (L) of 2.573" and length of padeye (l) of 13" appropriately correspond to recommended dimensions.

d = 1.625”
F = 33,000 lbs
L = 2.573”
t = 1”
T = ¼”
l = 13”

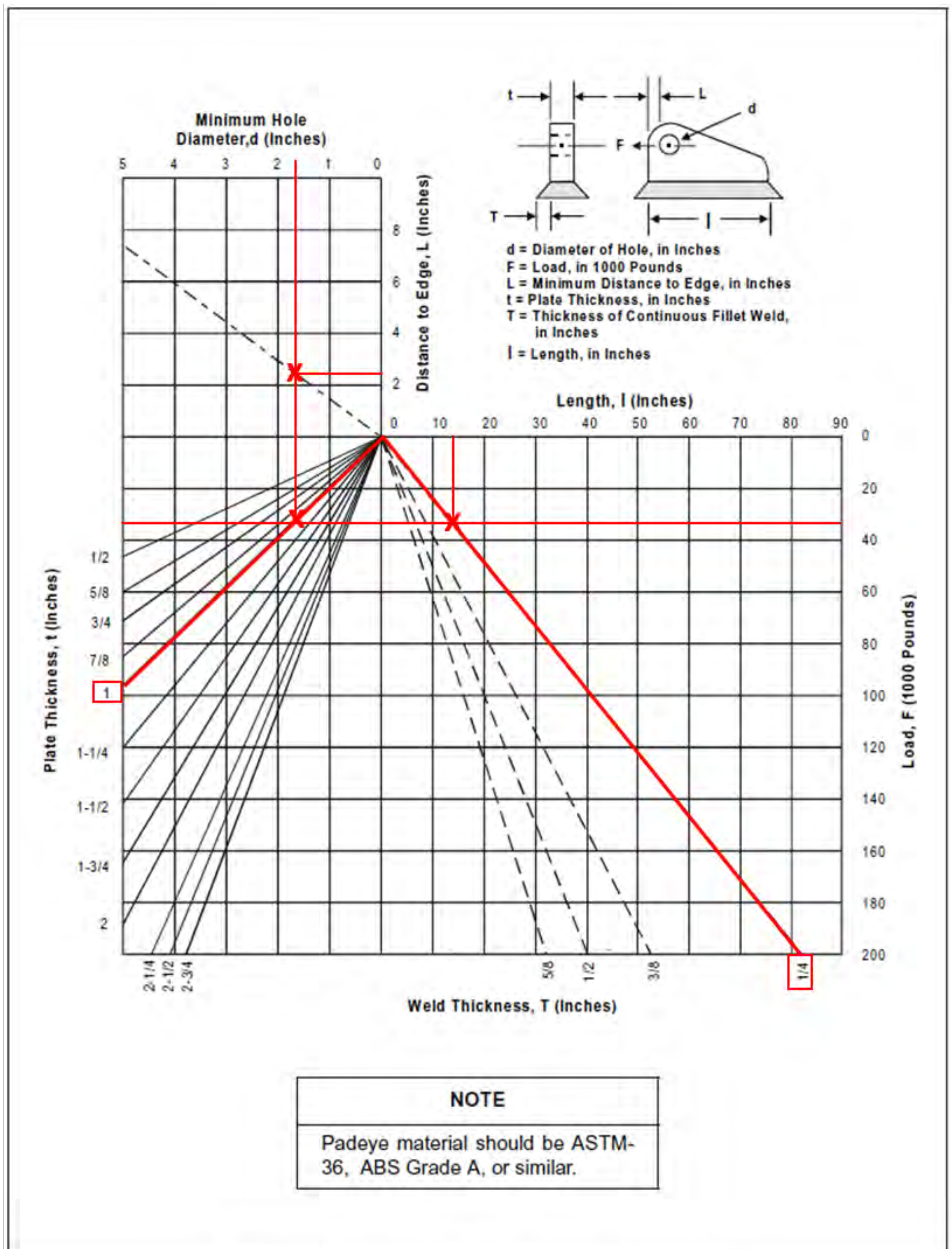


Figure 4-7. Minimum Padeye Design Requirements.

Figure 4: Minimum Padeye Design Requirements

The padeye structure is designed to account for an off-access loads up to +/- 30° in any direction.

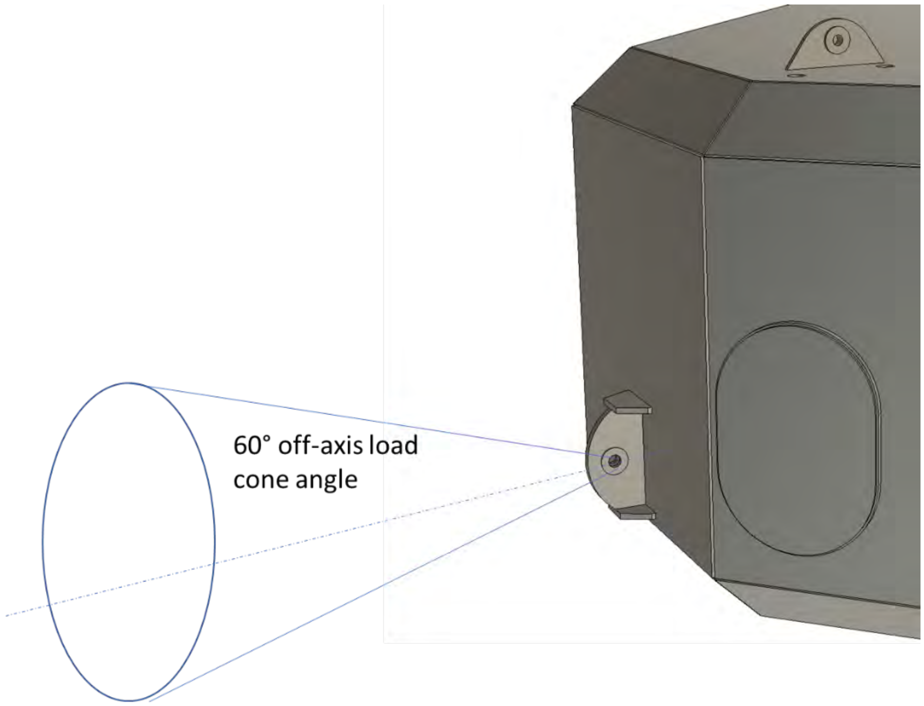


Figure 5: Tow Point Design Load Angle

3 PROJECT LOCATION

3.1 AREA OF OPERATIONS

The specific area for the WEC deployment is approximately 540 meters from the Scripps Institute of Oceanography (SIO) pier, at a heading of 276.9 (SEE), with an average depth of 21.4 meters and a slope of up to 5%. This area, including GPS coordinates for the SIO Pier, the center of the operating area and the four anchor locations are shown below.

Anchor#		Deg	Min	Sec	Depth	
1	N	32	52	3.162	68	ft
	W	117	15	48.054	20.73	m
2	N	32	52	4.008	72	ft
	W	117	15	47.784	21.95	m
3	N	32	52	3.78	71	ft
	W	117	15	46.782	21.64	m
4	N	32	52	2.93	67	ft
	W	117	15	47.052	20.42	m

Figure 6: Deployment Area

This area has been agreed with the site owner (SIO), all necessary permits for the deployment have been obtained and the site has been surveyed.

3.2 TRANSIT ROUTES

The *vessel* will transit to the test site along the proposed transit route as determined by vessel mobilization location and operations being performed. For transit operations involving equipment under tow, contingency planning for towline failure will be included in operational planning and hazard identification.

A list of anticipated transit routes to site is provided below.

Table 3: Anticipated Transit Routes.

Vessel	Route	Distance (nm)
R/V Beyster	Primary – Home Port to Driscoll's Mission Bay	10.1
R/V Beyster	Primary – Driscoll's Mission Bay to Test Site	8.9
M/V Cooper DM Tapper	Backup – National City to Test Site	22.2

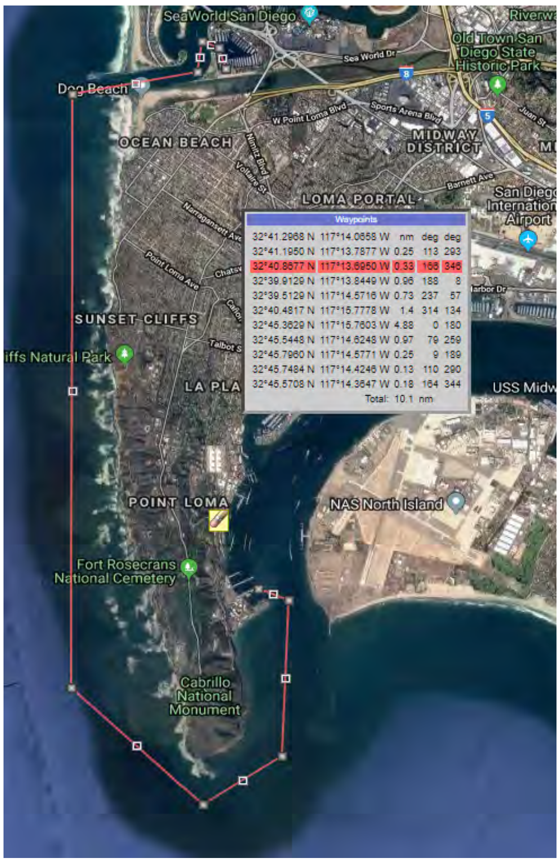


Figure 7: Home Port (Point Loma) to Tow Pickup (Mission Bay)

Figure 8: Primary Tow Route - Driscoll's Mission Bay to Test Site

Figure 9: Backup Tow Route: National City to Test Site

3.3 Weather Windows

"Weather Windows" are to suitable times for marine operations, defined here by:

- Daylight Hours – simplified to 0700-1700 local time
- Wave Height Threshold – Hs: 1m
- Current Threshold: 1 m/s
- Wind Speed Threshold: 10 knots
- Duration – number of consecutive hours meeting the first two criteria

The above weather window restrictions are based on Scripps pier small boat launching guidelines. On a case-by-case basis, the restrictions may be further broadened by agreement with Scripps & CalWave staff and any other vessel operators and/or divers. It is anticipated that the operational limits will be determined by the WEC deployment/recovery operation, not necessarily by the towing operation.

Historic wave data can provide estimates of weather windows for each month of the planned deployment at various threshold levels. For example, if a particular marine operation requires 6 hours of daylight with waves less than 1m Hs, this would be possible 28 days in July, but only 19 days in April. Expected weather windows for each month at various significant wave height thresholds are presented in Table 4. There are fewer working days with significant wave height below 50cm, but considerably more available days if the wave height restriction is relaxed to 1m.

Table 4: Weather windows at the deployment site.

Expected Operational Days at Scripps Nearshore "Operational" = 6 continuous hours of daylight below Hs Threshold												
Threshold Hs (m)	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug,**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
2.5	28	26	28	28	28	28	28	28	28	28	27	28
2.0	28	26	28	28	29	28	28	28	28	28	27	28
1.5	27	25	26	26	27	28	28	29	28	28	26	26
1.0	23	21	20	19	22	25	28	28	25	26	23	22
0.5	8	4	7	2	2	4	9	8	7	4	10	7

If a marine operation can be conducted up to 1m of significant wave height, one could expect 19 days in April for such work, and 28 days in July.

4 VESSELS & OPERATORS

4.1 R/V BEYSTER

The research vessel Bob and Betty Beyster is a purpose-built coastal research vessel designed for efficient operations offshore in Southern California. The Beyster is owned and operated by Scripps Institute of Oceanography (SIO). This is the primary vessel anticipated for towing operations.

Figure 10: R/V Beyster.

This is the primary vessel intended for use during the test period. Provisional contract terms on the use of this vessel has been agreed with UCSD and will be finalized during Budget Period 2.

Vessel Specifications:

- Length: 42 ft
- Beam: 16 ft
- Freeboard: 3 ft
- Stern A frame capacity: 2.5 tons
- Starboard knuckle crane capacity: 660 lbs, 17 ft reach
- Dynamic Positioning System (DPS): Volvo DPS
- Deck space: 192 ft^2
- Maximum speed: 38 kts
- Cruising speed: 25 kts
- Engines: 2x Volvo Penta D11 510hp
- Hand-deployable Sebotix LBV-300 Mini-ROV
- Acoustic communications transducer

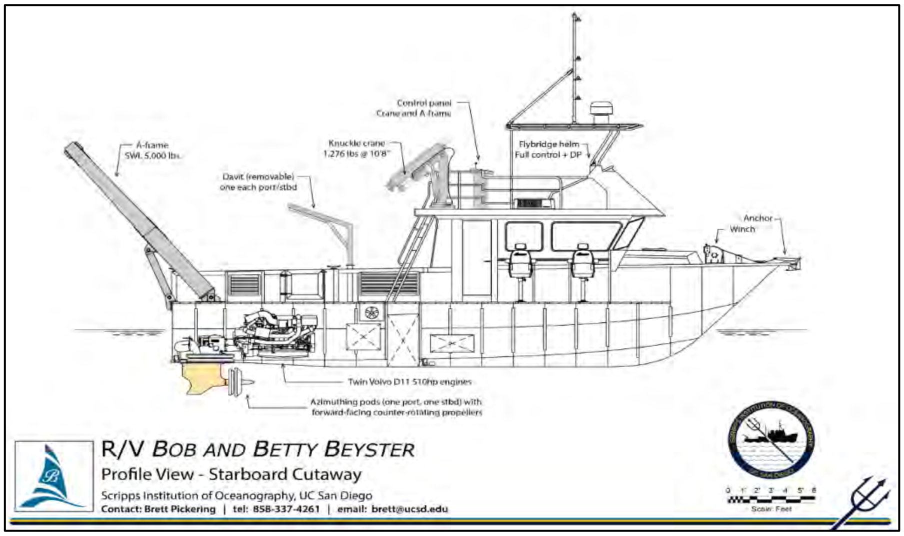


Figure 11: R/V Beyster -Starboard Cutaway

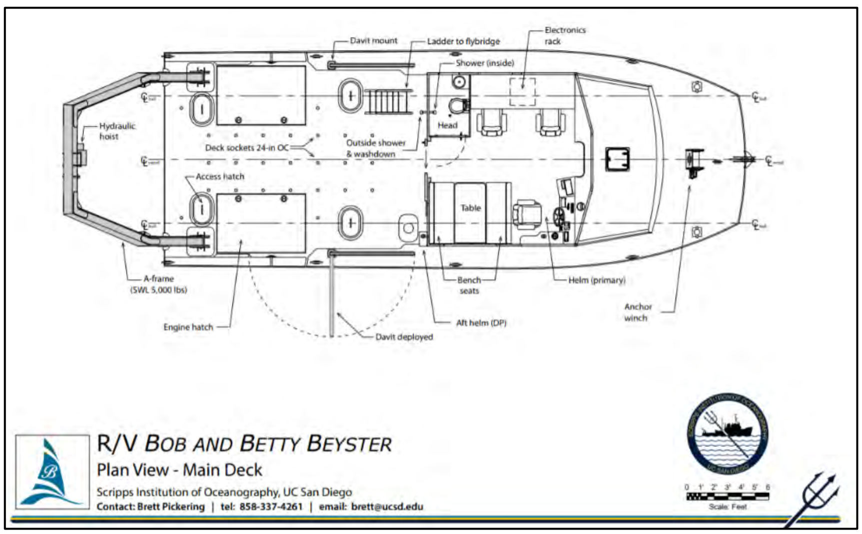


Figure 12: R/V Beyster – Main Deck Plan View

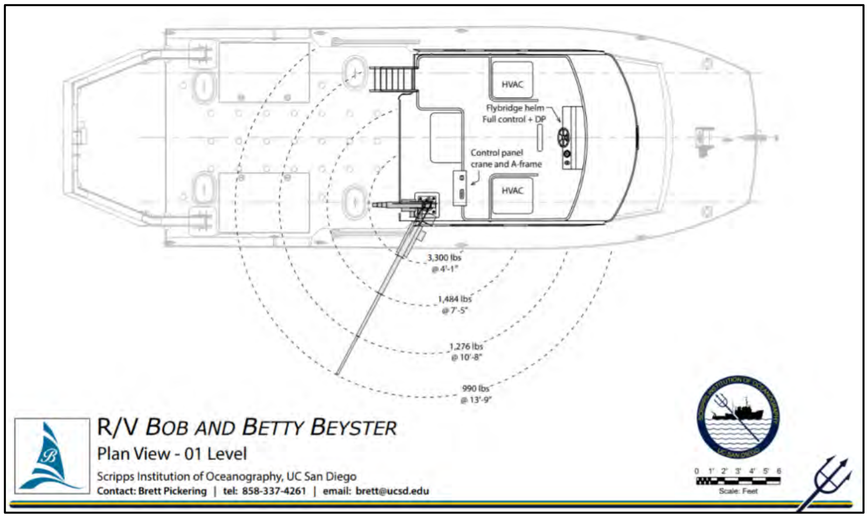


Figure 13: R/V Beyster Boom Crane Capacity

4.2 Support Vessel (19' Boston Whaler)

A small line handling vessel for operations either independently, or alongside a larger vessel. UCSD owns and operates several 19-ft Boston Whalers located on SIO pier and provisional contracting terms for the use of these vessels have been agreed with UCSD. The USCD small vessels are deployed with the pier crane and skippered by UCSD staff. At 0.3 nm from the pier, this provides the most immediate access to the test site for observations or operations appropriate for a small vessel.

Figure 14: Support Vessel (19' Boston Whaler).

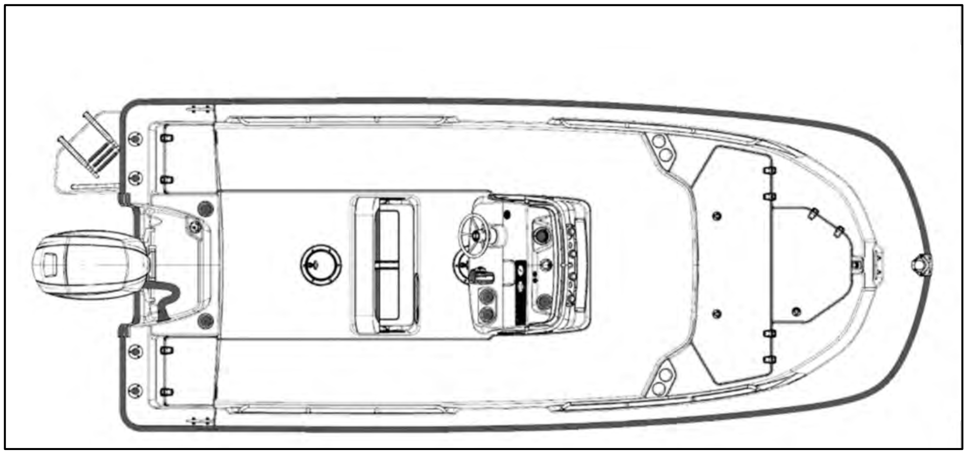


Figure 15: Boston Whaler Specifications.

Vessel Specifications:

- Length: 19.4 ft
- Beam: 8 ft
- Draft: 13 ft
- Weight (w/engine, fuel & water): 2769 lbs
- Maximum weight capacity: 2500 lbs
- Swamped capacity: 4000 lbs
- Persons capacity: 8
- Maximum Horsepower: 150 HP
- Minimum Horsepower: 115 HP

5 Project Operations

5.1 WEC Tow to Site

In preparation for WEC installation (and during transportation), the mooring belts will be wrapped under and around the hull and secured to the top of the hull with standard lift/tie off hardware. Connection hardware for the PTO Mooring Belt is suitable for connection with standard marine shackles.

Securing the PTO Mooring Belt in this configuration will allow vessel crew access to disconnect the belt from the attachment point for connection with the mooring lines.

Final design of towing points and tow configuration is pending further review with vessel and offshore operations contractors in collaboration with naval architects and is anticipated to be validated with dynamic modelling.

The towline working load is taken to be the full weight of the WEC, as the most conservative measure, and significantly oversized for the actual anticipated bollard pull. The towline is anticipated to be Dyneema 12-Strand, 1-1/4" diameter, with working load limit of 33,000 lbs (exceeding the full weight of the WEC of 14.2 tons = 31,297 lbs).

AmSteel®Blue / Dyneema® 12-Strand			
Diameter inches	Diameter mm	Tensile Strength pounds	Working Load pounds
1-0"	25.4	109,000	21,800
1-1/4"	31.8	165,000	33,000
1-1/2"	38.1	228,000	45,600
1-5/8"	41.3	283,000	56,600
1-5/8"	66.7	335,000	56,600
1-3/4"	44.5	335,000	76,200
2-0"	50.8	381,000	76,200

Figure 16: WEC Towline

The towline will be connected to both the vessel (R/V Beyster) and the WEC with a single Y-bridal (shown below). The Y bridals are connected to the vessel and WEC with standard marine shackles (1-1/2" galvanized Crosby shackle has a sufficient working load limit of 17 tons).

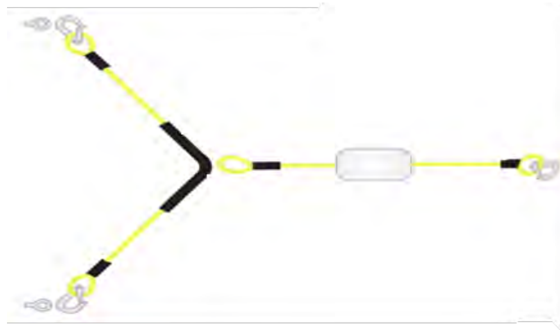


Figure 17: Single Y Tow Bridal

Recommendations for tow configurations include having a bridal distance of at least twice the vessel beam and total tow length of 2-3 times the vessel length. The below figure illustrates the lengths of the bridals and towline for the CalWave WEC being towed by the R/V Beyster.

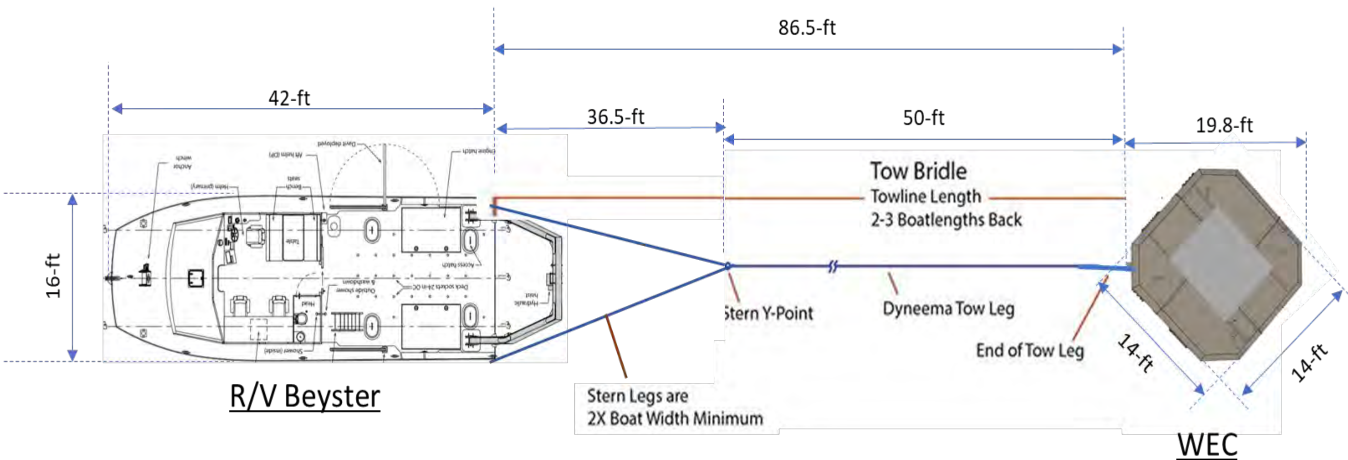


Figure 18: Tow Configuration Lengths

For both the R/V Beyster and the WEC, this bridal configuration results in an approximate 2-2.5° uplift angle at tow point connection. This geometry is shown for the WEC below.

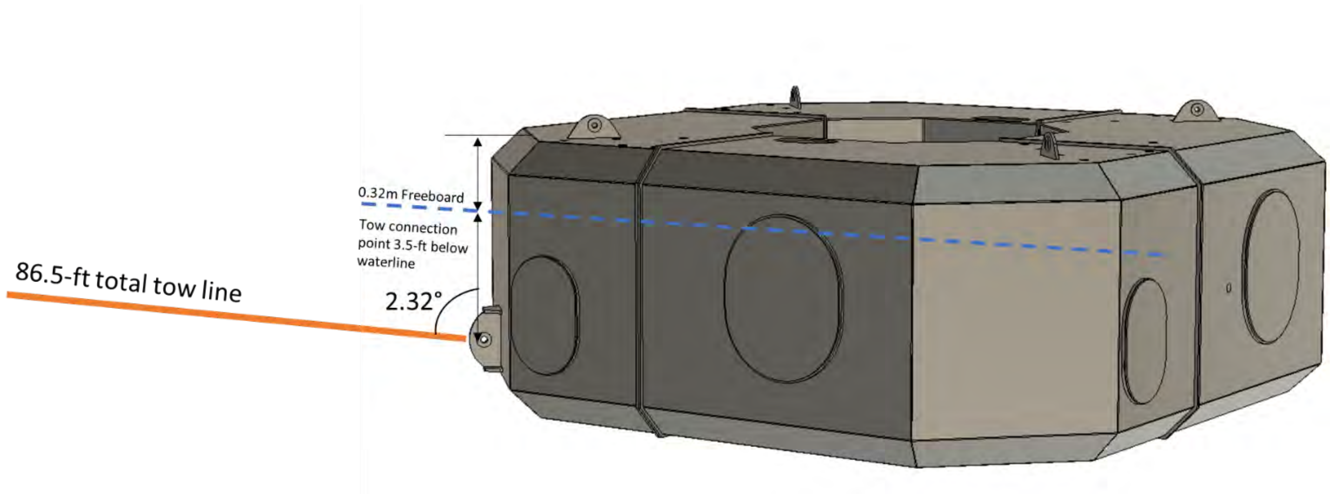


Figure 19: WEC Towline Geometry

Given this geometry, for an 86.5-ft vessel tow bridal distance, the uplift angle is well below the 30° allowable load angle based on the tow point design. Connecting a 36.5-ft tow bridal with a 50-ft of towline creates a total towing length of 86.5-ft, which is ~2.1 times the length of the tow vessel. Rope floats are attached to the towline to ensure a neutrally buoyant line for ease of recovery. 1-1/4" 12 strand Dyneema has a weight of 36.2-lbs/100-ft. Given the shallow angle of the tow bridal, 37.5-ft of line length is required to provide 36.5-ft linear distance from the vessel to the towline connection. This bridal consists of a single 75-ft line connected to the tow vessel on both ends and connected to the towline at its midpoint. Therefore, the towline (50') is anticipated to weight 18.1-lbs. Including the tow bridal, the total line is (50+2*37.5) 125-ft, which has a combined weight of 45.25-lbs. Rope floats are available from Jim Buoy (http://www.jimbuoy.com/pages/marine/floats.htm) sized for 1-1/4" rope with 22-lbs of net buoyancy per module.

5.1.1 Mobilization: WEC Tow

The *R/V Beyster* is the intended primary vessel for this operation. In addition, a safety observer and line handling vessel may be deployed and operated by UCSD staff (19 ft Boston Whaler (*BW 1*), or similar). The vessel will be mobilized with the necessary equipment to complete the scope of work and is anticipated to mobilize from its home berth at Point Loma. If the line handling vessel is additionally used, it will be deployed from SIO pier.

Table 5: Equipment List: WEC Installation & Commissioning

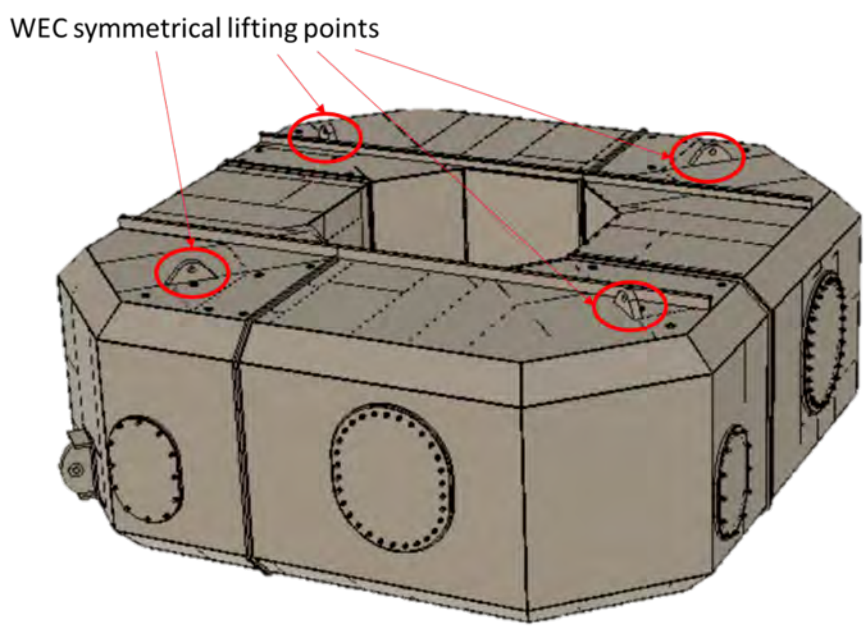
OWNER	DESCRIPTION	SIZE	QTY
R/V Beyster Tools			
CalWave	Towline, 50-ft	1-1/4”	1
CalWave	36.5-ft Tow bridal (WEC side), 75-ft line length	1-1/4”	1
CalWave	Float for towline (Jim Buoy #4401-RF)	22-lb	3
CalWave	Marine shackle (17.2-lbs each)	1-1/2”	4
Boston Whaler			
CalWave	Pins for mooring line connectors	1-3/8”	4
Shore Staff Tools			
Marina	Lifting slings (*CalWave ensure available*)		4
Marina	Lifting shackles (*CalWave ensure available*)		4

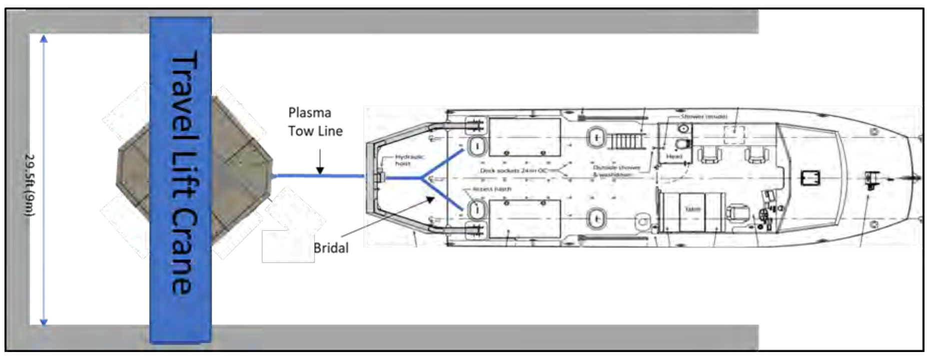
5.1.2 Operations Sequence: WEC Tow

The following sequence details the scope of work for the WEC towing evolution. The sequence may be altered at the direction of the vessel captain or CalWave staff on-board, WEC Operator is assumed to be on-board R/V Beyster.

Prior to WEC towing, the WEC will be powered by the CalWave WEC operator and an on-board diagnostics and communication test will be verified, including a checklist of pre-deployment Go/No-Go requirements and hull integrity checks.

Table 6: Sequence: WEC Astern Tow

Step #	Line #	Vessel	Assignment
1	Transfer WEC from pier to R/V Beyster astern tow		
1.a	Lift slings & tow line	*Shore*	• Mooring belts remain secured to tie off points on the WEC • ***WEC Operator***: Power up WEC and perform function/diagnostic check • ***CalWave Staff #1:*** Attach towing bridal to WEC tow point; keeping clear of pinch points during lift operation • ***CalWave Staff #2:*** Rig four-point lift using marina travel lift crane and WEC lift points  • ***Shore Staff***: Lower WEC to water, removing tension from crane but maintaining connection to lift points

			
1.b	Tow line	*R/V Beyster*	• ***R/V Beyster Captain***: Position inside deployment berth with stern to WEC  • ***WEC Operator:*** Transfers to R/V Beyster
1.c	Tow line	*Shore*	• ***CalWave Staff #1:*** Pass tow line to R/V Beyster • ***CalWave Staff #2:*** Disconnect lift rigging • ***CalWave Staff #1:*** Transfer to R/V Beyster • ***CalWave Staff #2:*** Drive to SIO pier to meet BW 1
1.d	Tow line	*R/V Beyster*	• ***CalWave Staff #1***: Secure tow line to deck hardware in short tow configuration
2	Transit from marina to open ocean		
2.a	Tow line	*R/V Beyster*	• ***R/V Beyster Captain:*** Transit from marina at slow speed (~5kts), depth at marina ~12-15 ft based on tide

			 ● ***CalWave Staff #1:*** Observe WEC during close tow & support Captain with maneuvering ● ***WEC Operator:*** Maintain communication with WEC during tow
3	Transit to test site		
3.a	Tow line	*R/V Beyster*	● ***R/V Beyster Captain:*** Notify crew once in open ocean and ready to transition to long tow ● ***CalWave Staff #1***: Transition from short tow to long tow ● ***R/V Beyster Captain:*** Inform crew and shore staff when approaching test site
3.b	Lift rigging	*BW 1*	● Deploy from SIO pier with CalWave Staff #2
5	Transition WEC from tow configuration to moored on-site		
5.a			● *Details provided in WEC Deployment Plan*

Detailed methodology and sequence for transition the WEC from a towed configuration to test site moorings is provided in subsequent operational planning documentation.

5.1.3 Estimated Timeline: WEC Tow to Site

Only vessel time is added to total time calculation (highlighted activities do not require vessel on-site)

Table 7: Timeline: WEC Tow to Site

Step #	Day 1 - Activity	Hours
M	Mobilize R/V Beyster at home port (Point Loma)	2.0
T	R/V Beyster transit to Mission Bay (10.1 nm @ 25 kts)	0.5
1	Transfer WEC from pier to R/V Beyster astern tow	1.0
2	Transit from Mission Bay to Test Site (8.9 nm @ 6 kts), position at anchor point #2	1.5
3	Deploy BW 1 from SIO pier and transit to site	0.5
4	Transition WEC from towed configuration to on-site moorings	2.0
5	Electrically connect WEC & perform functional checks	5.5
6	BW 1 recovered to SIO pier	0.5
7	Transit to home port (16.5 nm @ 25 kts)	0.75
DM	Demobilize vessel	2.0
	Total Time Estimate (hrs)	**16.25**
	Total Time on Site (excluding mob/demob & transit to/from site)	**8.25**

5.1.4 Demobilization: WEC Towing

Demobilization shall occur at each vessels home port, depending on storage locations of any CalWave owned equipment. Any requirements for lifting equipment, including recovering the line handling vessel to SIO pier will be coordinated in advance with all parties (this section to be updated once equipment and material are further defined). Once control of the WEC is verified as transferred to the SCADA system at the SIO pier, the WEC Operator on-board the R/V Beyster will remain hands-off WEC controls. UCSD will be informed when all vessels have departed the site.

5.2 WEC Tow From Site

The return process is similar to towing the WEC to site. The primary difference is the method for disconnecting the mooring lines and attaching the tow line to the tow point, which is covered in the WEC Deployment Plan.

6 REFERENCES

6.1 U.S. NAVY TOWING MANUAL: SL740-AA-MAN-010, REV 3, 1 JULY 2001

6.2 GL NOBLE DENTON: GUIDELINES FOR MARINE TRANSPORT, 0030/ND

6.3 SHIP OWNERS: LOSS PREVENTION, TUGS AND TOWS – A PRACTICAL SAFETY AND OPERATIONAL GUIDE

7 CALCULATIONS

7.1 REQUIRED BOLLARD PULL

Estimate of required bollard pull

Ref 6.3, page 31

$$BP = \left\{ \frac{\Delta^{2/3} V^3 + (0.06\ B \times D)}{120 \times 60} \right\} \times K$$

BP = required bollard pull (tonnes)

Δ = full displacement of towed vessel (tonnes)

V = tow speed (knots)

B = breadth of towed vessel (metres)

D = depth of the exposed transverse section of the towed vessel including deck cargo, measured above the waterline (metres)

K = a factor that reflects potential weather and sea conditions;

- for exposed coastal tows K = 1.0 to 3.0
- for sheltered coastal tows K = 0.75 to 2.0
- for protected water tows K = 0.5 to 1.5

Based on the above calculations, the table below shows the required bollard pull (static) for various towing speeds ranging from 4 to 10 knots. Dynamic bollard pull due to shock loads (slack/snap events) are not considered in the below calculations. This analysis would require more detailed calculations and/or dynamic modelling in Orcaflex or similar software.

Table 8: Required Bollard Pull vs Tow Speed

D(ton)	V(kts)	B(m)	D1(m)	K	BP(ton)	BP(lbs)
14.2	4	4	0.32	3	0.39	852
14.2	6	4	0.32	3	0.76	1671
14.2	8	4	0.32	3	1.48	3265
14.2	10	4	0.32	3	2.67	5893

BP = ((14.2^ (2/3) x 6^3) / (120*60) + (0.06 x 4 x 0.32)) x 3 = 0.76 ton = 760kg

7.2 Vessel Bollard Pull

The below calculations show estimates for the bollard pull capacity of the primary and backup tow vessel, the line handling vessel is also included only for understanding of capability and is not intended for normal use as a tow vehicle. The safety factors provided in the tables below are in addition to the 3.0 safety factor included in the above required bollard pull table (K) and are therefore labeled 'Additional Safety Factor' or 'Addl. SF'.

Given that the primary and backup tow vessels have high additional safety factors, even at relatively high speed, it is being discussed with the vessel captains if dynamic modelling is needed.

https://www.wartsila.com/encyclopedia/term/bollard-pull

BP(tons) = (T x k1 x k2)/9.81

T = (D x PD)*2/3

k1 = 0.9 (assume 10% losses)

k2 = 1.2 – 1.4 (20-40% addition depending on nozzle)

*all vessels are calculated with k2 = 1.0 due to lack of information on nozzle

T = Thrust (kN)

D = Propeller Diameter (m)

PD = Delivered Power (kW)

Line Handling Vessel (BW1):

The outboard motor(s) of the Boston Whalers are listed with min/max horsepower ratings. Both are calculated for completeness only.

D = 1 ft = 0.3 m (estimated)

PD = 150hp = 111kW (max)

T = (0.3 * 111) * 2/3 = 22.2 kN

BP = (22.2 * 0.9 *1.0)/9.81 = 2.04 tons

Vess. BP	V(kts)	BP(ton)	Addl. SF
2.04	4	0.39	5.3
2.04	6	0.76	2.7
2.04	8	1.48	1.4
2.04	10	2.67	-0.8

PD = 115hp = 86kW (min)

T = (0.3 * 86) * 2/3 = 17,2 kN

BP = (17.2 * 0.9 * 1.0)/9.81 = 1.58 tons

Vess. BP	V(kts)	BP(ton)	Addl. SF
1.58	4	0.39	4.1
1.58	6	0.76	2.1
1.58	8	1.48	1.1
1.58	10	2.67	-0.6

R/V Beyster:

Given the high safety factor

D = 1 ft (x2) = 0.3 m (x2) = 0.6 (estimated)

PD = 1020hp = 760kW (max)

T = (0.6 * 760) * 2/3 = 304 kN

BP = (304* 0.9 * 1.0)/9.81 = 27.9 tons

Vess. BP	V(kts)	BP(ton)	Addl. SF
27.9	4	0.39	72.1
27.9	6	0.76	36.8
27.9	8	1.48	18.8
27.9	10	2.67	10.4

Jag:

D = 1 ft (x2) = 0.3 m (x2) = 0.6 (estimated)

PD = 650hp = 484.7kW (max)

T = (0.6 * 484.7) * 2/3 = 193.9 kN

BP = (193.9 * 0.9 * 1.0)/9.81 = 17.8 tons

Vess. BP	V(kts)	BP(ton)	Addl. SF
17.8	4	0.39	46.0
17.8	6	0.76	23.5
17.8	8	1.48	12.0
17.8	10	2.67	6.7

8 HAZID

8.1 Administrative

Date of planned operation:

Date of HAZID briefing:

Attendees:

*by signing below, I attest that I have read and understand the operational plan and agree to operate safely and in accordance with this plan.

Name	Company	Signature

Planned Crew

Vessel	Name	Company	Role
R/V Beyster		UCSD	Captain
R/V Beyster		CalWave	CalWave Lead
R/V Beyster		CalWave	Line Handling & Observation
R/V Beyster		UCSD	Diver
R/V Beyster		UCSD	Diver
BW 1			
BW 1			

Vessel Call Times

Vessel	Port	Crew Arrival Time	Departure Time
R/V Beyster			
BW 1			

8.2 Risk Categories

Severity	Consequences				Increasing Probability				
					1	2	3	4	5
	People	Assets	Environment	Reputation	Never heard of in the industry	Heard of in the industry	Has happened in the organization or more than once per year in the industry	Has happened at the location or more than once per year in the organization	Has happened more than once per year at the location
0	No injury or health effect	No damage	No effect (no or temporary impact - days)	No impact (local media, no significant concern)	L	L	L	L	L
1	Slight injury or health effect (first aid or medical treatment)	Slight damage	Slight effect (local scale, short term damage – weeks)	Slight impact (short term local concern)	L	L	L	L	L
2	Minor injury or health effect (restricted work case or LTI)	Minor damage	Minor effect (local scale, short term damage – months)	Minor impact (short term national mention)	L	L	L	M	M
3	Major injury or health effect (partial disability)	Moderate damage	Moderate effect (local scale, medium terms damage – years)	Moderate impact (medium term national concern)	L	L	M	M	H
4	< 3 fatalities, or permanent total disabilities	Major damage	Major effect (local scale, long term damage – decades)	Major impact (regional or persistent national concern)	L	M	M	H	H
5	> 3 fatalities	Massive damage / total loss	Massive effect (regional scale, permanent damage)	Massive impact (global concern and media coverage)	M	M	H	H	H

L	Low Risk
M	Medium Risk
H	High Risk

Figure 20: Risk Categories

8.3 Risk Identification and Mitigation

Table 9: Summary of Identified Risks

WEC Tow to Site					
	Consequence				
Prob.	1	2	3	4	5
5	0	0	0	0	0
4	0	0	0	0	0
3	0	1	1	0	2
2	0	0	2	3	5
1	0	0	0	0	1

WEC Tow to Site			
Total risks	High	Medium	Low
15	2	10	3
	13%	*67%*	*20%*

Table 10: HAZID

ID	Hazard Category	Scenario	Likely Threats	Top Events	Controls in Place	C	P	RPT	Rank	Comments	Action Party	Closed?
X.0400	Crane WEC from pier to vessel/quayside											
X.0410	Pier side work	Personal safety	Slips, trips, falls	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0420	Lifting operations	Personal safety	Crush injury	Injury to personnel	HSE plan, PPE	5	2	10	Med			
X.0421	Lifting WEC with shore crane	Lifting eye failure	Overloading of lifting eye Directional loading on lifting eye Lift equipment not adequately inspected	Personal injury Damage to WEC	Visual inspection	5	2	10	Med			
X.0422	Lifting WEC with shore crane	Insufficient or inappropriately placed lifting eyes	Insufficient lift plan incorporated into hull design	Personal injury Damage to WEC	Visual inspection	4	2	8	Med			
X.0423	Lifting WEC with shore crane	Load exceedance of vessel crane	Incorrect weight estimates of WEC	Personal injury Damage to WEC Damage to crane	CAD review Lift test	5	1	5	Low			
X.0430	Lifting operations	Inclement weather	Delays, additional cost	Schedule delays incurring additional cost	Flexible deployment window	3	2	6	Low			

X.0500	Towing WEC to site											
X.0510	Tow device with vessel	Contact with seafloor during tow	Towing during low tide and/or at shallow harbor	Damage to WEC	Tow plan	3	2	6	Low			
X.0511	Tow device with vessel	Vessel traffic during tow	Towing during busy period or from busy port	Delays Increased risk for contact with vessel	Tow plan	2	3	6	Low			
X.0512	Tow device with vessel	Contact with tow vessel	Insufficient tow line distance or arrangement Wave loads during tow Abrupt vessel movement	Damage to WEC Damage to vessel	Tow plan	4	2	8	Med			
X.0513	Tow device with vessel	Slack/snap load on towing line	Insufficient tow line distance or arrangement Wave loads during tow Abrupt vessel movement	Damage to WEC at connection point Damage to vessel	Tow plan	4	2	8	Med			
X.0514	Tow device with vessel	Crack/structural failure	Fatigue during towing	Damage to WEC at connection point Damage to vessel	Tow plan	5	3	15	High			
X.0515	Tow device with vessel	Overturning	Instability during tow	Damage to WEC at connection	Visual observation	5	3	15	High			

				point Damage to vessel								
X.0520	Monitor during towing	Instability during tow	Unanticipated loads during tow	Damage to WEC Increased load on tow lines	Visual inspection (draft marks)	3	3	9	Med			
X.0521	Monitor during towing	Seawater ingress during tow	Structural/seal failure during tow Unanticipated loads during tow Blowout valve failure during tow	Increased loads on tow lines Loss of WEC	Tow winch load cell	5	2	10	Med			
X.0530	Working offshore	Personal safety	Slips, trips, falls	Injury to personnel	HSE plan, PPE	5	2	10	Med			

CWPT Open Water Demonstration

DE-EE0008097.0005

Task 5.4 Comprehensive IO&M and Testing Plan

9.6 WEC Deployment Plan

Version 2.6 - May 2020

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CONTENTS

FIGURES

TABLES

1 INTRODUCTION

This report focuses on the WEC Deployment Planning for the open water demonstration to be conducted in collaboration with University of California, San Diego (UCSD). The plan is intended to be used in concert with the WEC Tow Plan and commences once the WEC and deployment vessel have arrived at the test site with the WEC in an astern tow configuration.

All operations are being coordinated with University of California, San Diego (UCSD) Scripps Institute of Oceanography (SIO) staff as well as local vessel operators and marine operations contractors. Alternate vessels have been identified for use during different aspects of the CalWave technology deployment and test period.

The details outlined in these procedures are contingent upon several factors, such as operation conditions, vessel ability, safety, efficiency, etc. Due to these factors, this plan is subject to change. Adjustments to sequences for the preset installation and connection can be made in the field with the use of Management of Change (MOC) process. The respective management personnel must be contacted and contribute to determining a safe and effective method of performing operations. The current and weather conditions must be deemed favorable before starting operations.

Before the start of any operations, all vessels and individuals involved will hold operational procedure review and safety meetings to prepare for upcoming operations. All equipment will be checked at this time and the equipment will be verified for availability for upcoming operations.

The vessel captain and CalWave representatives will approve deviations that become unavoidable in the field during the installation process. VHF working channels will be identified at this time.

This document comprises of the overall methodologies of safe operations offshore, includes vessel specifics, and operations planning for the following planned evolutions:

Table 1: Planned Offshore Operations

Activity	Days
WEC Installation & Commissioning	1
WEC Inspections & Planned Maintenance Offshore	8
WEC Recovery & Decommissioning	1
Total Planned Operational Days Offshore	10

2 Vessels and Equipment

2.1 Vessels

Table 2: Vessel List

Vessel	Operator	Website	Notes
R/V Beyster	UCSD	https://scripps.ucsd.edu/ships	Primary work vessel
BW1	UCSD	https://www.bostonwhaler.com/family-overview/outrage-boat-models/190-outrage/	Line handling vessel
Jag	Pacific Maritime Group	https://www.pacifictugboats.com/index.php/our-fleet-2/	Backup vessel

See **sections 8 & 10** for vessel details.

2.2 Equipment

CalWave provided equipment vs equipment provided by vessel to be specifically identified in mobilization section of individual operations.

The primary equipment being manipulated during the deployment process is the belt to mooring H-bracket, the two wireless load pins and the umbilical strain termination and connector.

<u>H-Bracket</u>

The mooring lines are connected to the anchors on the seafloor during the anchor installation procedure. During WEC deployment, these mooring lines are connected to the WEC by means of a H-bracket connection with a narrow end attached to the mooring line and a wide end connected to the belt.

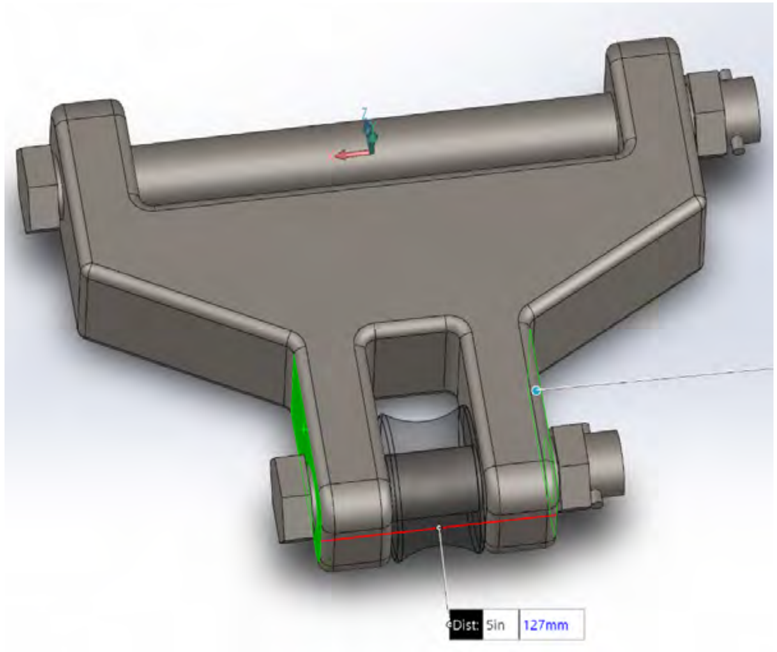
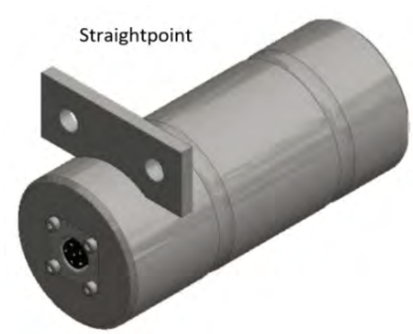


Figure 1 Belt to Mooring H-Bracket

<u>Load Cell</u>

Wireless loadcells will be located on two of the four mooring legs, with a marinized cable connecting it to a subsea transponder.



Loadpin Dimensions (mm):

Diameter (ØD):	34.8
L1:	127
L2:	tba
L3:	50.8

Example of a typical loadpin with single keeper plate and radial glanded cable outlet

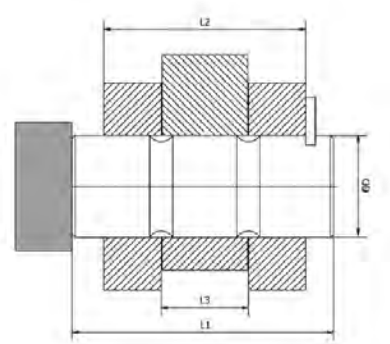
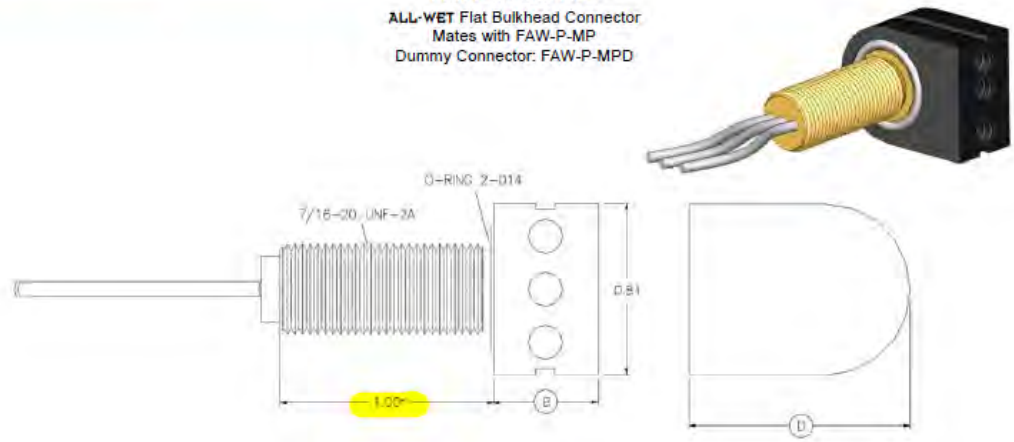


Figure 2 StraightPoint PROJ1202 Subsea Load Pin (w/keeper plate)

PADLOC Bulkhead: FAWM-8P-BC-R/A

ALL-WET SERIES
FAW-S-BC-R/A

ALL-WET Flat Bulkhead Connector
Mates with FAW-P-MP
Dummy Connector: FAW-P-MPD



CONNECTOR	A - LENGTH (INCHES)	B - LENGTH (INCHES)	C - LENGTH (INCHES)	D - LENGTH (INCHES)
FAWL-P/S-BC-R/A	1.34	0.50	0.81	1.05
FAWM-P/S-BC-R/A	1.48	0.63	0.95	1.12

NOTES:
- Thread length is 1.00" standard. If shorter thread is required, specify as follows: FAW-P(or S)-BC-R/A (1/2" thread length).
- Available thread length: 1/2", 3/4" and 1".
- Bulkhead mounting torque: 40 inch pounds.
- Nuts and washer supplied.
- Connectors must be lubricated prior to mating.
- Connectors are designed for installation on one atmosphere vessels. Contact SEACON for recommendations if using compensated vessels.
- Dummy Connectors: Optional.
- Dummy Shorting Plug: Optional.

Figure 3 Load Cell Bulkhead Connector

The subsea transponder is housed in a pressure vessel.

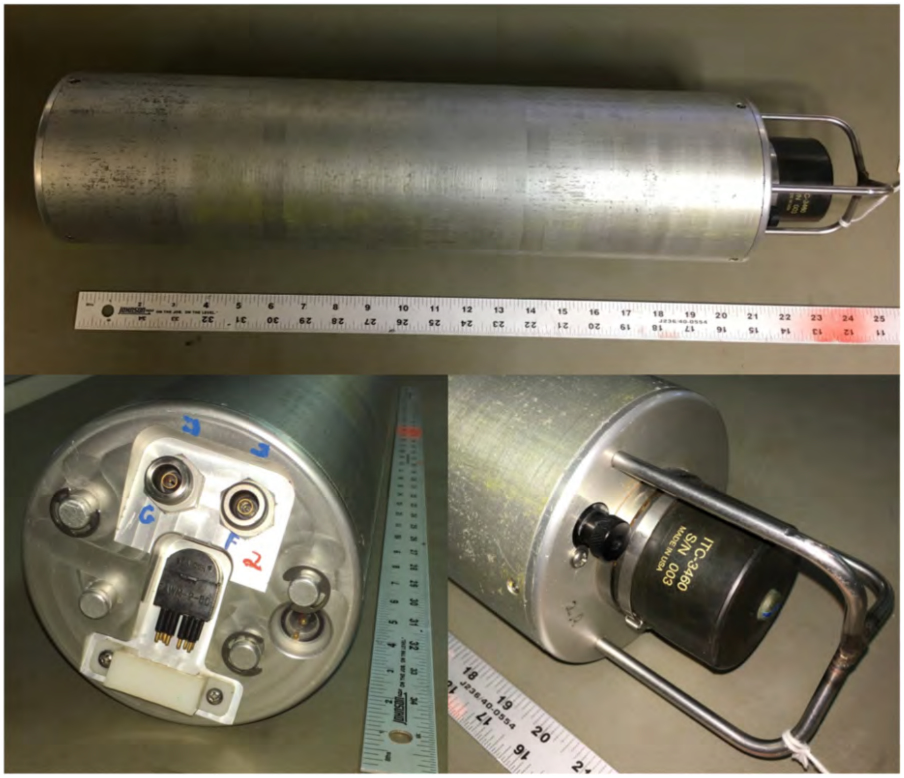


Figure 4 Wireless Load Cell Transponder

The transponder is connected to the H-bracket and mooring line as shown below.

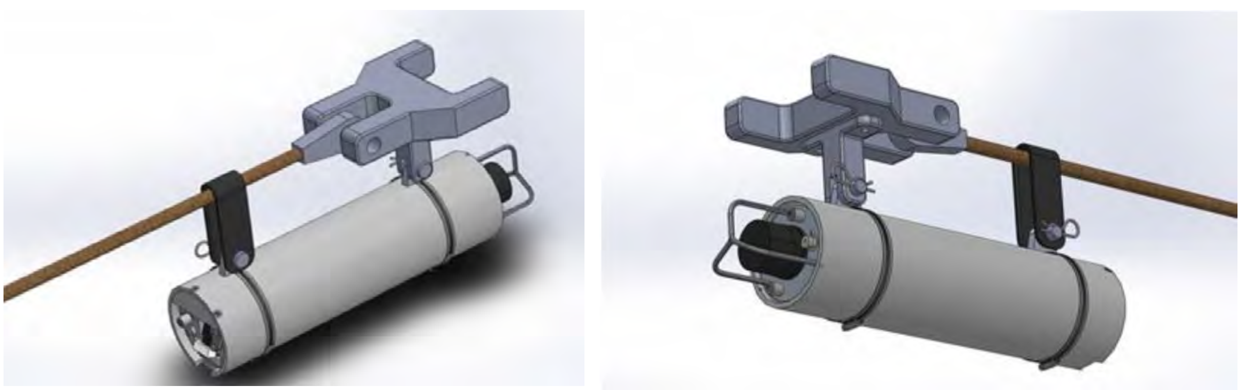


Figure 5 Transponder Connection to H-Bracket

<u>Umbilical Strain Termination</u>

The umbilical is laid on the seafloor as per the Umbilical Lay Plan, with the strain termination and right-angle connector secured to a marker buoy that will be picked up for connection as part of this operation.

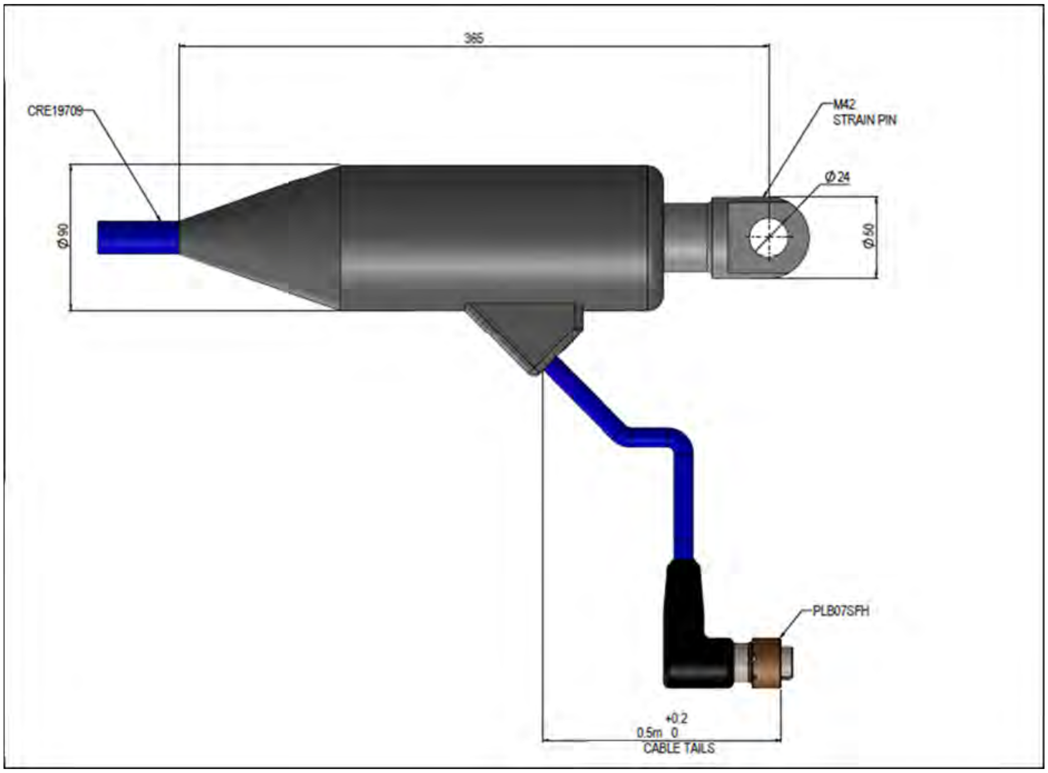
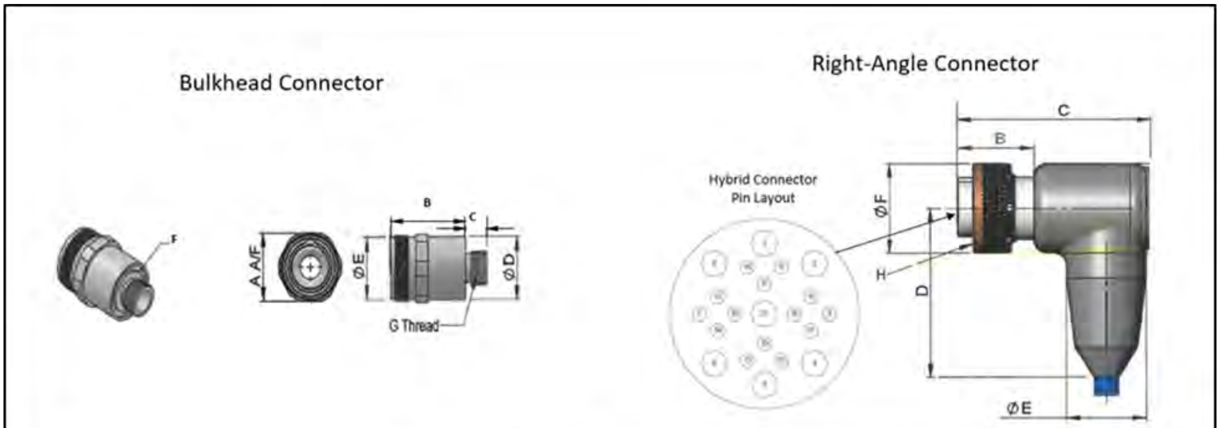


Figure 6 Umbilical Strain Termination & Right-Angle Connector



A	B	C	D	E	F (O-Ring)	G
40	51	22	39	36.75	BS122	1"-12 UNF

B	C	D	E	F	H (O-Ring)
40	96	85	40	45	BS025

Figure 7 Umbilical Right-Angle Connector

3 PROJECT LOCATION

3.1 AREA OF OPERATIONS

The specific area for the WEC deployment is approximately 540 meters from the Scripps Institute of Oceanography (SIO) pier, at a heading of 276.9 (SEE), with an average depth of 21.4 meters and a slope of up to 5%. This area, including GPS coordinates for the SIO Pier, the center of the operating area and the four anchor locations are shown below.

Anchor#		Deg	Min	Sec	Depth	
1	N	32	52	3.162	68	ft
	W	117	15	48.054	20.73	m
2	N	32	52	4.008	72	ft
	W	117	15	47.784	21.95	m
3	N	32	52	3.78	71	ft
	W	117	15	46.782	21.64	m
4	N	32	52	2.93	67	ft
	W	117	15	47.052	20.42	m

Figure 8: Deployment Area of Interest

This area has been agreed with the site owner (SIO), all necessary permits for the deployment have been obtained and the site has been surveyed.

3.2 SHORE SIDE MONITORING AND CONTROL STATION

Shore side monitoring and control will occur at the Ellen Browning Scripps Memorial Pier, operated by Scripps Institute of Oceanography (SIO) at the University of California, San Diego (UCSD). For the duration of the test period, CalWave will be entered into a lease agreement with UCSD and have 24-hr access to the pier facilities.

Figure 9: SIO Pier

Figure 10: Instrumentation Shed – outside

Figure 11: Instrumentation Shed - inside

3.3 Transit Routes

The *vessel* will transit to the test site along the proposed transit route as determined by vessel mobilization location and operations being performed. For transit operations involving equipment under tow, contingency planning for towline failure will be included in operational planning and hazard identification, including considerations for spare towline and/or additional line handling vessel.

A list of anticipated transit routes to site is provided below.

Table 3: Anticipated Transit Routes.

Vessel	Route	Distance (nm)
BW 1	SIO pier to Test Site	0.3
R/V Beyster	Driscoll Mission Bay to Test Site	8.9

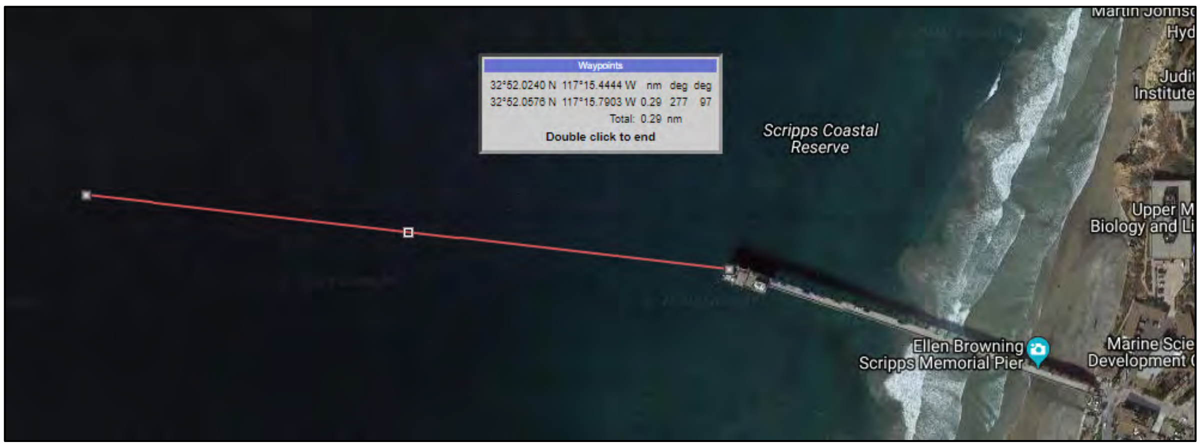


Figure 12: SIO Pier to Test Site.

Figure 13 Tow Route: Driscoll Mission Bay to Test Site

3.4 Weather Windows

"Weather Windows" are to suitable times for marine operations, defined here by:

- Daylight Hours – simplified to 0700-1700 local time
- Wave Height Threshold – Hs: 1m
- Current Threshold: 1 m/s
- Wind Speed Threshold: 10 knots
- Duration – number of consecutive hours meeting the first two criteria

The above weather window restrictions are based on Scripps pier small boat launching and dive operations guidelines. On a case-by-case basis, the restrictions may be further broadened by agreement with Scripps & CalWave staff and any other vessel operators and/or divers.

4 VESSELS & OPERATORS

4.1 R/V BEYSTER

The research vessel Bob and Betty Beyster is a purpose-built coastal research vessel designed for efficient operations offshore in Southern California. The Beyster is owned and operated by Scripps Institute of Oceanography (SIO). This is the primary vessel anticipated for towing operations.

Figure 14: R/V Beyster.

This is the primary vessel intended for use during the test period. Provisional contract terms on the use of this vessel has been agreed with UCSD and will be finalized during Budget Period 2.

<u>Vessel Specifications</u>:

- Length: 42 ft
- Beam: 16 ft
- Freeboard: 3 ft
- Stern A frame capacity: 2.5 tons
- Starboard knuckle crane capacity: 660 lbs, 17 ft reach
- Dynamic Positioning System (DPS): Volvo DPS
- Deck space: 192 ft^2
- Maximum speed: 38 kts
- Cruising speed: 25 kts
- Engines: 2x Volvo Penta D11 510hp
- Hand-deployable Sebotix LBV-300 Mini-ROV
- Acoustic communications transducer

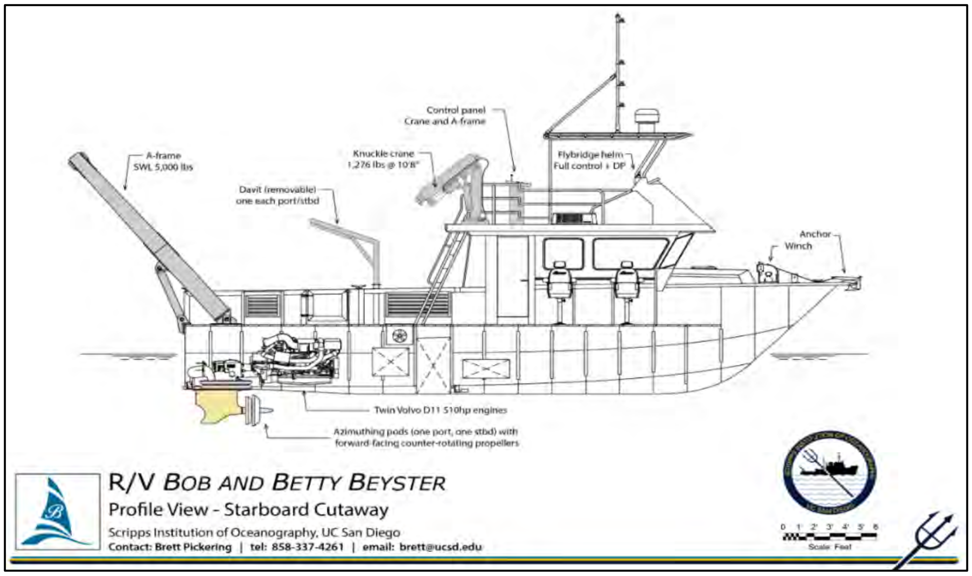


Figure 15 R/V Beyster -Starboard Cutaway

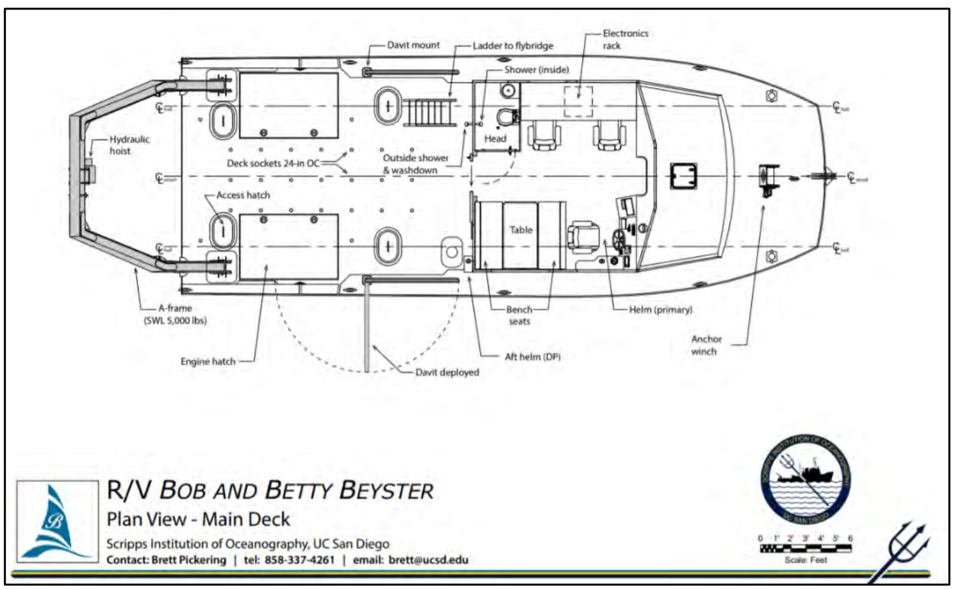


Figure 16: R/V Beyster – Main Deck Plan View

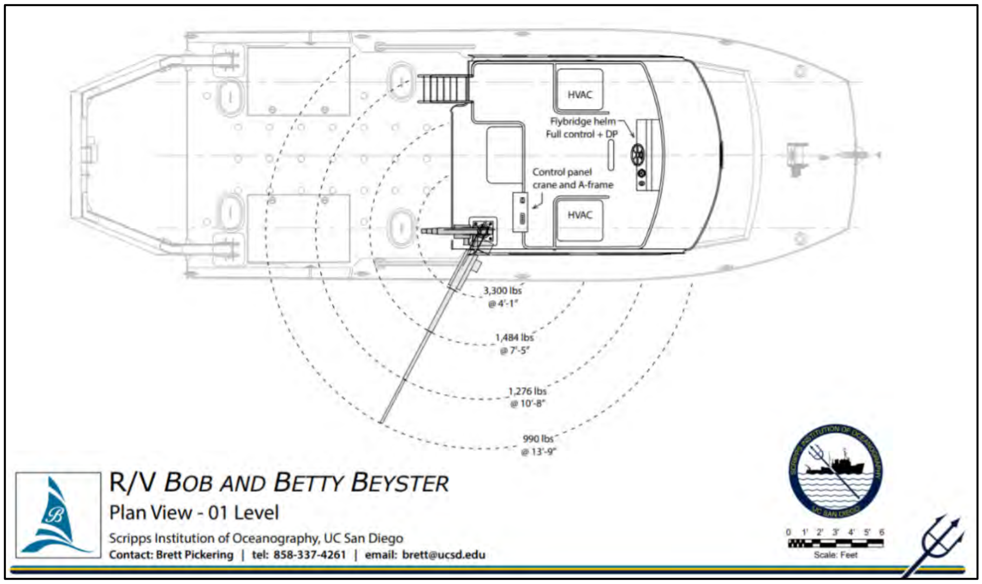


Figure 17: R/V Beyster Boom Crane Capacity

4.2 Support Vessel (19' Boston Whaler)

A small line handling vessel for operations either independently, or alongside a larger vessel. UCSD owns and operates several 19-ft Boston Whalers located on SIO pier and provisional contracting terms for the use of these vessels have been agreed with UCSD. The USCD small vessels are deployed with the pier crane and skippered by UCSD staff. At 0.3 nm from the pier, this provides the most immediate access to the test site for observations or operations appropriate for a small vessel.

Figure 18: Support Vessel (19' Boston Whaler).

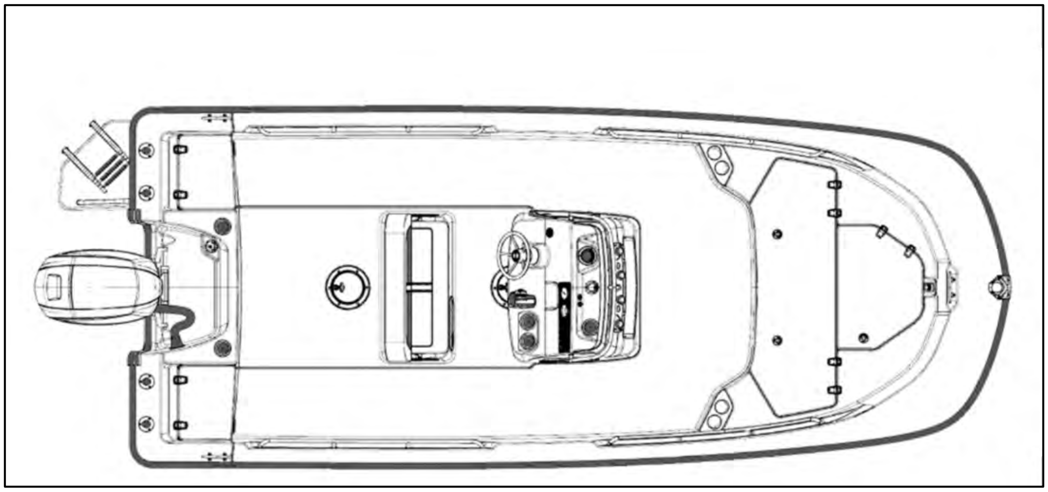


Figure 19: Boston Whaler Specifications.

Vessel Specifications:

- Length: 19.4 ft
- Beam: 8 ft
- Draft: 13 ft
- Weight (w/engine, fuel & water): 2769 lbs
- Maximum weight capacity: 2500 lbs
- Swamped capacity: 4000 lbs
- Persons capacity: 8
- Maximum Horsepower: 150 HP
- Minimum Horsepower: 115 HP

4.3 VESSEL OPERATORS

The primary vessels anticipated for use in this project are owned and operated by UCSD Scripps Institute of Oceanography (SIO). Backup vessel operators include Pacific Tugboat Services and C&W Dive Services.

4.4 DIVE SERVICES PROVIDERS

For the dive services included in this plan, it is the intention to use the Scripps Institute of Oceanography (SIO) research divers. However, use of the UCSD research divers is limited to non-commercial, low-risk, and non-complex diving. For commercial diving services C&W Dive Services and VMS Dive Services are available.

5 Project Operations

5.1 WEC Installation & Commissioning

Prior to WEC Installation & Commissioning, the four anchors will have been deployed and verified in accurate locations to form the mooring grid. The mooring lines are connected to the anchor and tied off to marker buoys. Additionally, the umbilical cable has been laid and placed on the seafloor connected to a marker buoy.

In preparation for WEC installation will be secured to the WEC hull with standard marine hardware. Securing the PTO Mooring Belt in this configuration will allow vessel crew access to disconnect the belt from the attachment point for connection with the mooring lines.

The WEC will be towed to the deployment site by the R/V Beyster, as per the WEC Tow Plan. The R/V Beyster shall be in communication with the shoreside monitoring station. As the R/V Beyster nears the test site, UCSD will deploy a small line handling vessel from SIO pier (BW 1). If it is determined to be preferred, BW 1 may be deployed earlier to assist and monitor the WEC tow.

Due to geometry unique to this project deployment depth and specifics of mooring line to PTO mooring belt hardware, this connection will require being made by diver at ~24 ft depth. For future projects at deeper deployment depths, diver intervention is not anticipated as necessary for mooring line connections.

5.1.1 Mobilization: WEC Installation & Commissioning

The *R/V Beyster* is the intended primary vessel for this operation. In addition, a safety observer and line handling vessel will be deployed and operated by UCSD staff (19 ft Boston Whaler (*BW 1*), or similar). The vessel will be mobilized with the necessary equipment to complete the scope of work and is anticipated to mobilize from its home berth at Point Loma.

Table 4 Equipment List: WEC Installation & Commissioning

OWNER	DESCRIPTION	SIZE	QTY
R/V Beyster Tools			
CalWave	Tow bridal, rope & hardware (per WEC Tow Plan)	various	1
Line Handling Vessel (BW 1)			
CalWave	Pins for mooring line side of H-bracket (incl spare)	1-3/8”	5
CalWave	Pins for belt side of H-bracket (incl spare)		5
CalWave	Mooring H-Brackets		2
CalWave	Umbilical Buoyancy elements	300 x 150 mm	4
CalWave	Vinyl marking tape (red, white, blue)	Standard	3

CalWave	Tape measure	6-ft minimum	1
CalWave	Electrical multi-meter	standard	1
CalWave	Pressurized air (for blowing out connectors)		1
UCSD	Dive support equipment		
Shore Staff Tools			
CalWave	SCADA hardware		1

5.1.2 Operations Sequence: WEC Installation & Commissioning

The following sequence details the scope of work for the WEC installation and commissioning evolution. Table below provides a detailed scope of work for the *R/V Beyster* to deploy the CalWave WEC at the SIO test site. The sequence may be altered at the direction of the vessel captain or CalWave staff on-board, WEC Operator is assumed to be on-board R/V Beyster.

Prior to WEC installation and commissioning, the WEC will be powered by the CalWave WEC operator and an on-board diagnostics and communication test will be verified, including a checklist of pre-deployment Go/No-Go requirements.

Depending on predominant wind direction, currents, or other considerations at the time of marine operations, the vessel captain and CalWave staff may determine to connect the mooring lines in an alternate sequence. The below methodology assumes wind direction from the west, leading to a decision to connect mooring line #2 first.

The figure below roughly illustrates the relative size of the connection hardware and a diver. It is anticipated divers will be deployed using SCUBA from the line handling vessel. Each connection is anticipated to take less than 10 minutes at a depth of less than 30 feet. All hardware is anticipated to be less than 20 lbs.

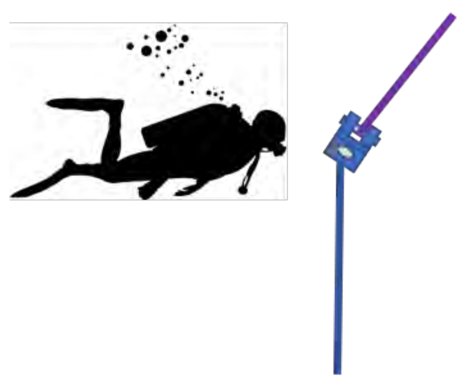
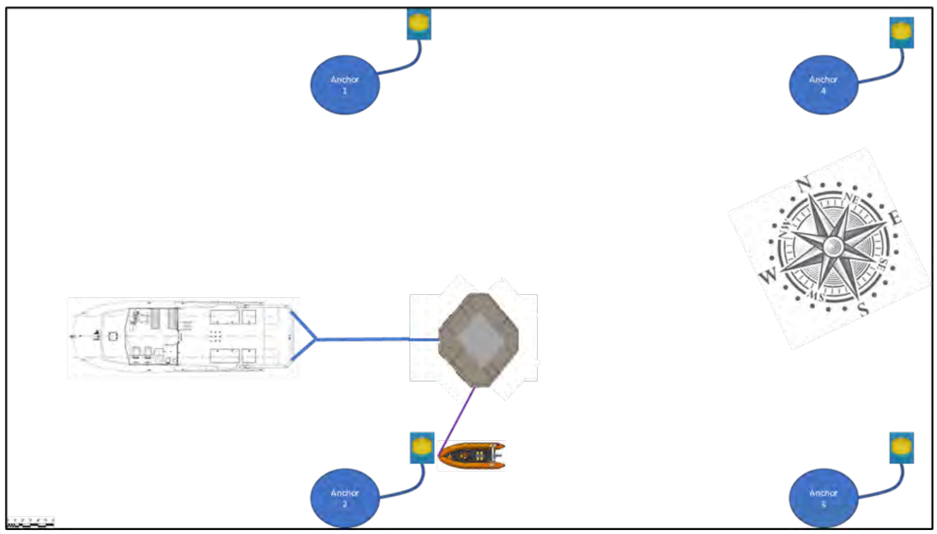
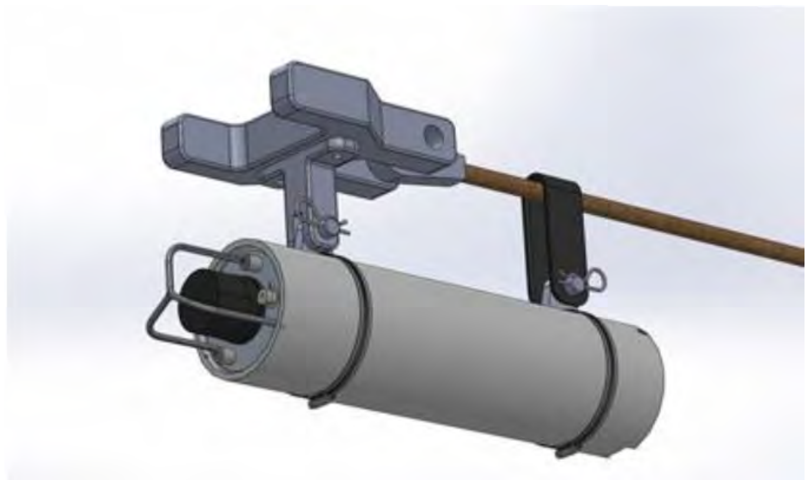
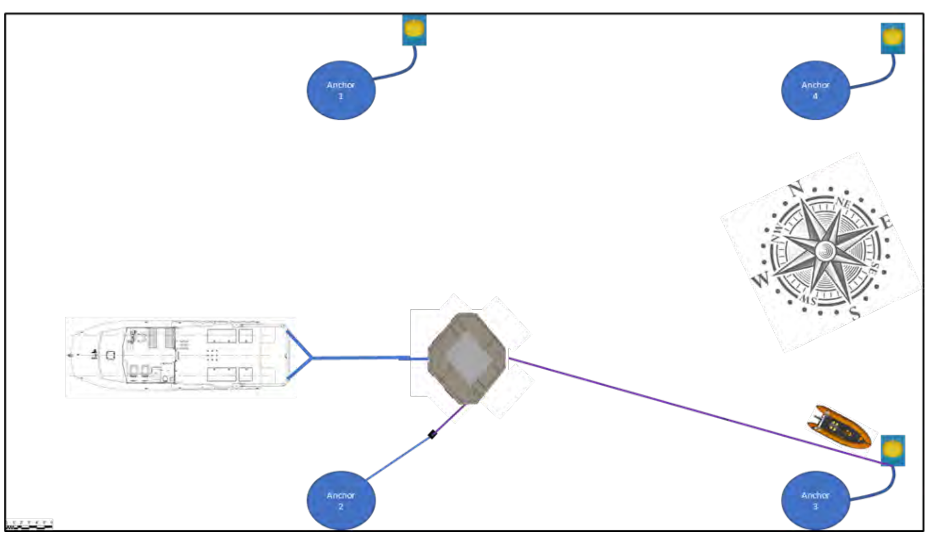
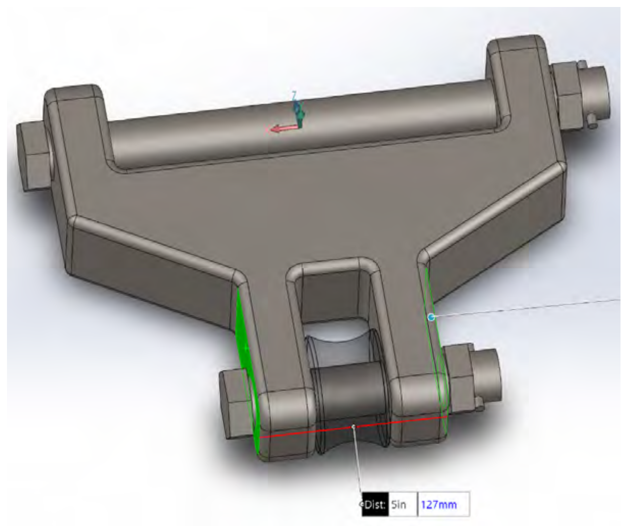


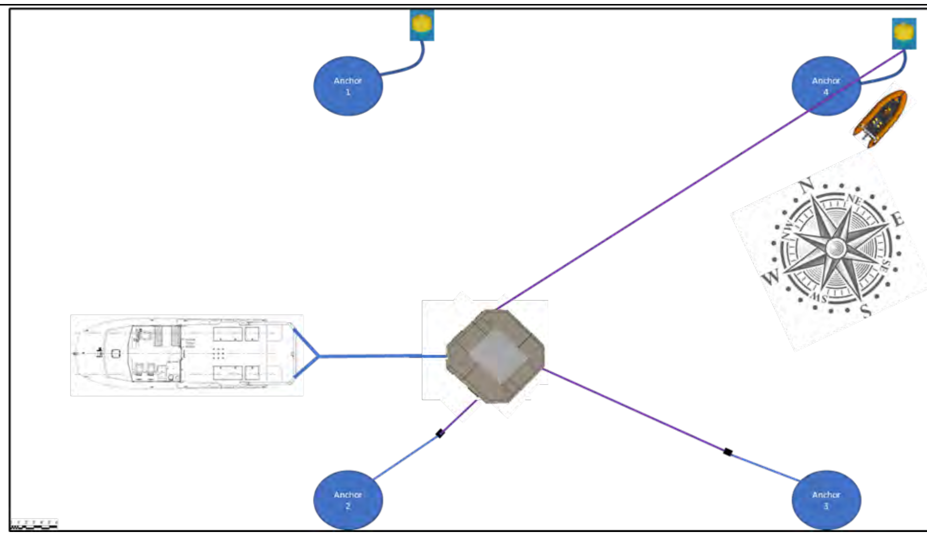
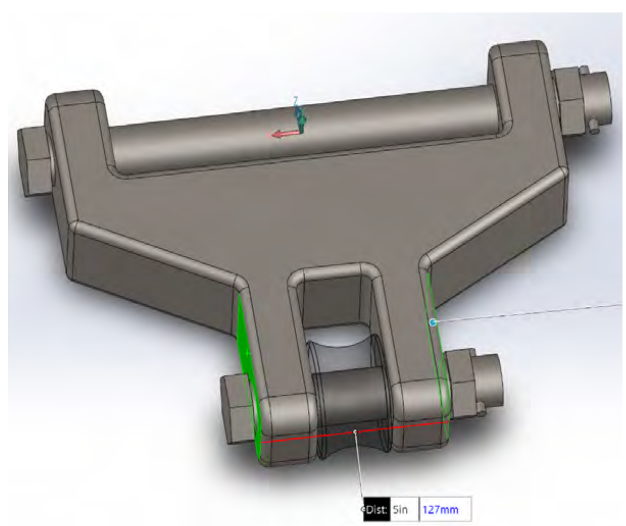
Figure 20: Diver Connection – Relative Dimensions

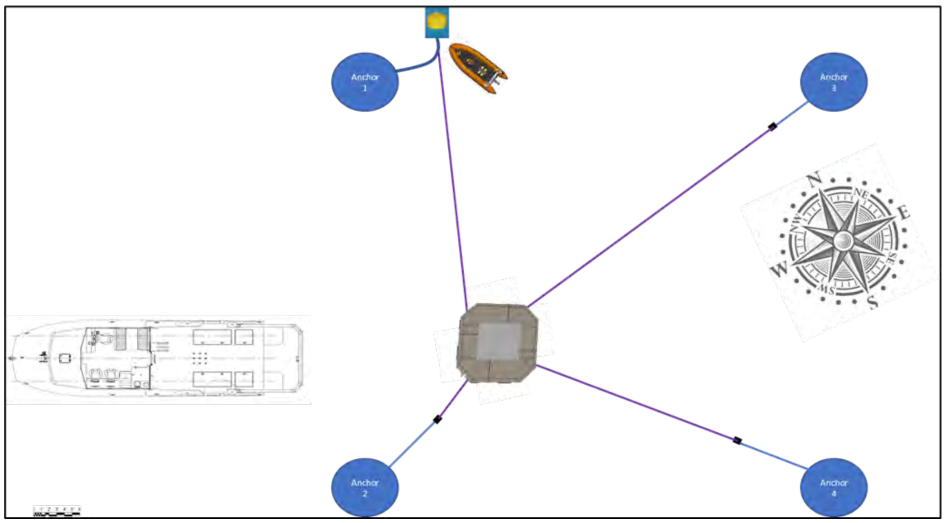
Table 5: Sequence: WEC Installation & Commissioning

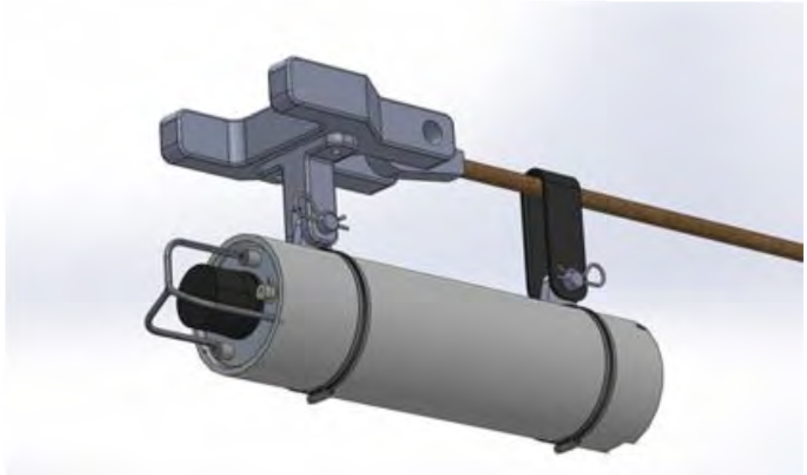
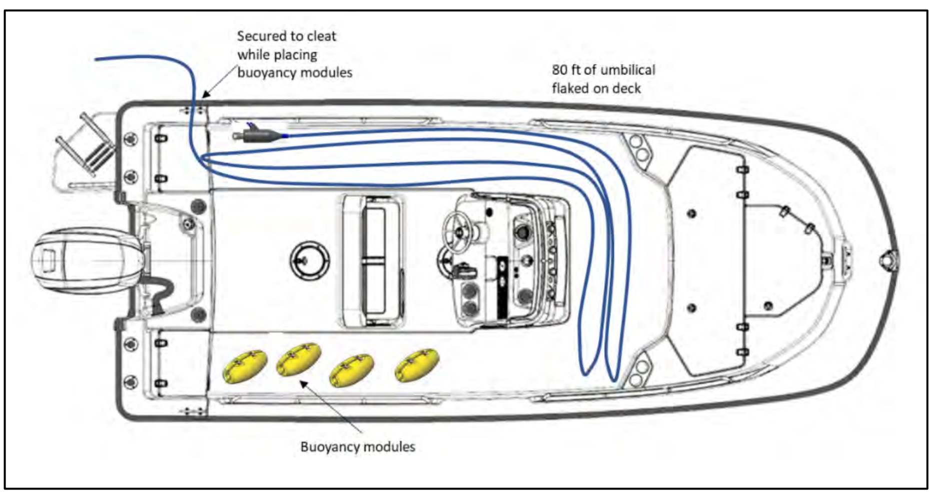
Step #	Line #	Vessel	Assignment
T	Deploy BW 1 from SIO Pier, transit to test site (R/V Beyster on-site as per WEC Tow Plan)		
1	Attach mooring line #2 to PTO #2 from astern tow		
1.a	tow	*R/V Beyster*	• R/V Beyster Captain: Positions on the windward side of Anchor #2 approximately aligned with the mooring buoy
1.b	#2	*BW 1*	• BW1 Captain: Position alongside port side of WEC (from R/V Beyster perspective) • Crew #1: Disconnect mooring belt #2 from tie down point on WEC and secure to vessel hardware
1.c	#2	*R/V Beyster*	• WEC Operator: Release tension on mooring belt #2, spooling out approx. 14 ft of belt 
1.d	#2	*BW 1*	• BW 1 Captain: Position next to marker buoy #2 • Deploy divers • Crew #1: Transfer mooring belt #2 to Diver #1 • Crew #2: Secure marker buoy #2, preparing to take on-board once disconnected • Diver #2: Dive to approx. 24-ft depth along marker buoy line. Disconnect marker buoy #2 and connects mooring belt #2 to mooring line #2 • Diver #1: Dive with belt (with H-bracket connected to belt) to meet Diver #2 • Diver #2: Disconnect marker buoy and connect mooring belt using H-bracket and 1-3/8" pin • Diver #2: Secure wireless load cell transponder • Crew #2: Recover marker buoy to vessel • Diver #2: Recover to vessel

			• Diver #1: Inspect belt #2 (hand-over-hand) to ensure no twists or kinks in belt and recover to vessel • BW 1 Captain: Recover Diver #1 at WEC 
1.e	#2	*R/V Beyster*	• WEC Operator: Verify divers clear of WEC, apply minimal tension on mooring belt #2
2	Attach mooring line #3 to PTO #3 from astern tow		
2.a	#3	*BW 1*	• BW 1 Captain: Position aft of WEC (in relation to R/V Beyster) • Crew #1: Disconnect mooring belt #3 from tie down point on WEC and secure to vessel hardware
2.b	#3	*R/V Beyster*	• WEC Operator: Release tension on mooring belt #3, spooling out approx. 50 ft of belt 
2.c	#3	*BW 1*	• BW 1 Captain: Position next to marker buoy #3 • Deploy divers

			● Crew #1: Transfer mooring belt #3 to Diver #1 ● Crew #2: Secure marker buoy #3, preparing to take on-board once disconnected ● Diver #2: Dive to approx. 24-ft depth along marker buoy line. Disconnect marker buoy #3 and connects mooring belt #3 to mooring line #3 ● Diver #1: Dive with belt (with H-bracket connected to belt) to meet Diver #2 ● Diver #2: Disconnect marker buoy and connect mooring belt using H-bracket and 1-3/8" pin, ● Crew #2: Recover marker buoy to vessel ● Diver #2: Recover to vessel ● Diver #1: Inspect belt #3 (hand-over-hand) to ensure no twists or kinks in belt and recover to vessel ● BW 1 Captain: Recover Diver #1 at WEC 
2.d	#3	*R/V Beyster*	● WEC Operator: Verify divers clear of WEC, apply minimal tension on mooring belt #3 to bring mooring line #3 to windward side of anchor #3
3	Attach mooring line #4 to PTO #4 from astern tow		
3.a	#4	*BW 1*	● BW 1 Captain: Position on stbd side of WEC (in relation to R/V Beyster) ● Crew #1: Disconnect mooring belt #4 from tie down point on WEC and secure to vessel hardware
3.b	#4	*R/V Beyster*	● WEC Operator: Releases tension on mooring belt #4, spools out approx. 65 ft of belt

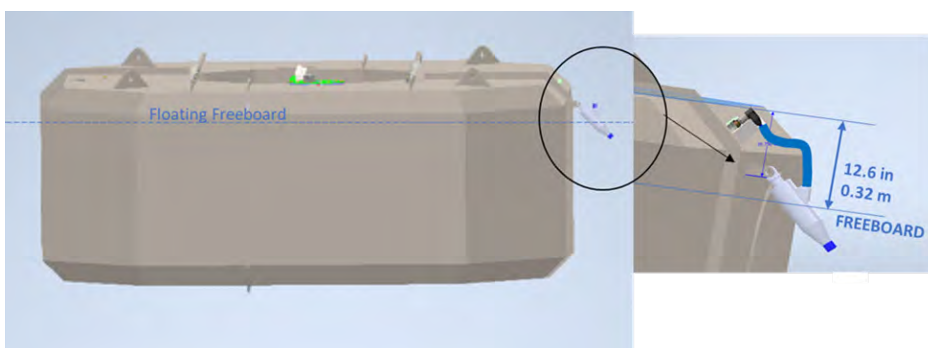
			
3.c	#4	*BW 1*	● BW 1 Captain: Position next to marker buoy #4 ● Deploy divers ● Crew #1: Transfer mooring belt #4 to Diver #1 ● Crew #2: Secure marker buoy #4, preparing to take on-board once disconnected ● Diver #2: Dive to approx. 24-ft depth along marker buoy line. Disconnect marker buoy #4 and connects mooring belt #4 to mooring line #4 ● Diver #1: Dive with belt (with H-bracket connected to belt) to meet Diver #2 ● Diver #2: Disconnect marker buoy and connect mooring belt using H-bracket and 1-3/8" pin, ● Crew #2: Recover marker buoy to vessel ● Diver #2: Recover to vessel ● Diver #1: Inspect belt #4 (hand-over-hand) to ensure no twists or kinks in belt and recover to vessel ● BW 1 Captain: Recover Diver #1 at WEC 

3.d	#4	*R/V Beyster*	• WEC Operator: Verify divers clear of WEC, apply minimal tension on mooring belt #4 to bring mooring line #4 to windward side of anchor #4
4	Attach mooring line #1 to PTO #1 from astern tow		
4.a	#1	*BW 1*	• BW 1 Captain: Position vessel to allow access to tow line connection • Crew #1: Disconnect tow line • Disconnect mooring belt #1 from tie down point on WEC • Secure mooring belt #1 to vessel cleat
4.b	#1	*R/V Beyster*	• Beyster Crew #1: Recover tow line (hand-over-hand) • WEC Operator: Releases tension on mooring belt #1, spool out approx. 40 ft of belt 
4.c	#1	*BW 1*	• BW 1 Captain: Position next to marker buoy #1 • Deploy divers • Crew #1: Transfer mooring belt #1 to Diver #1 • Crew #2: Secure marker buoy #1, preparing to take on-board once disconnected • Diver #2: Dive to approx. 24-ft depth along marker buoy line. Disconnect marker buoy #1 and connects mooring belt #1 to mooring line #1 • Diver #1: Dive with belt (with H-bracket connected to belt) to meet Diver #2 • Diver #2: Disconnect marker buoy and connect mooring belt using H-bracket and 1-3/8” pin, • Crew #2: Recover marker buoy to vessel • Diver #2: Recover to vessel • Diver #1: Inspect belt #1 (hand-over-hand) to ensure no twists or kinks in belt and recover to vessel • BW 1 Captain: Recover Diver #1 at WEC • BW 1 Captain: Transfer divers to R/V Beyster

			
4.d	#1	*R/V Beyster*	● WEC Operator: Verify divers clear of WEC, apply minimal tension on mooring belt #1 to bring WEC to center of mooring grid
5	Recover umbilical cable		
5.a	U	*SIO Pier Staff*	● Pier Staff: Verify umbilical cable disconnected at pier side
5.b	U	*BW 1*	● BW 1 Captain: Position next to umbilical termination marker buoy and retrieve ● Crew #1: Recover umbilical cable termination to vessel and secure ● Crew #2: Remove protective cover and blow out with pressurized air ● Crew #2: Use multi-meter to verify umbilical cable is de-energized ● Crew #1: Pull in 80 ft of umbilical cable (hand over hand) and flake on deck, vessel tracks back to avoid tension on the umbilical. Three sets of orange tape markings on cable indicate when sufficient cable is recovered (if tape has come off, measure back from termination)  ● Crew #2: Attach three buoyancy elements to pre-marked locations along umbilical cable

<table>
<tr><td></td><td></td><td></td><td>
<table>
<tr><th colspan="7">Cable Marking Locations</th></tr>
<tr><th></th><th>Accessory</th><th></th><th>Marking Color</th><th># wraps</th><th colspan="2">Distance to strain termination</th></tr>
<tr><th></th><th></th><th></th><th></th><th></th><th>m</th><th>ft</th></tr>
<tr><td rowspan="2">Buoyancy module 1</td><td rowspan="2">Spiral wrap at entry & exit</td><td>Start</td><td>Orange</td><td>I</td><td>21.5</td><td>70</td></tr>
<tr><td>Stop</td><td>Orange</td><td>I</td><td>21.2</td><td>69</td></tr>
<tr><td rowspan="2">Buoyancy module 2</td><td rowspan="2">Spiral wrap at entry & exit</td><td>Start</td><td>Orange</td><td>II</td><td>20.8</td><td>68</td></tr>
<tr><td>Stop</td><td>Orange</td><td>II</td><td>20.5</td><td>67</td></tr>
<tr><td rowspan="2">Buoyancy module 3</td><td rowspan="2">Spiral wrap at entry & exit</td><td>Start</td><td>Orange</td><td>III</td><td>20.2</td><td>66</td></tr>
<tr><td>Stop</td><td>Orange</td><td>III</td><td>19.9</td><td>65</td></tr>
</table>
Crew #1: Redeploy umbilical with buoyancy modules attached while tracking vessel to WEC connection point on WEC
</td></tr>
<tr><td>6</td><td colspan="3">Electrically connect umbilical cable</td></tr>
<tr><td>6.a</td><td>U</td><td>R/V Beyster</td><td>WEC Operator: Verify umbilical isolation relay is open</td></tr>
<tr><td>6.b</td><td>U</td><td>BW 1</td><td>

BW 1 Captain: Position alongside WEC umbilical connection point and tie off to WEC (between mooring lines #3 & #4)
Crew #1: Disconnect local WEC isolation breaker
Crew #2: Connect umbilical cable strain termination to WEC (pin connection)
Crew #1: Remove protective covering from WEC side bulkhead connectors
Crew #1: Blow out connectors with pressurized air
Crew #2: Verify WEC side connectors deenergized with multi-meter
Crew #2: Connect umbilical connectors to WEC bulkhead connectors (screw in type connectors)



Crew #2: Replace protective covering
BW 1 Captain: Position clear of WEC once communication verified

</td></tr>
<tr><td>6.c</td><td></td><td>SIO Pier Staff</td><td>Shore Staff: Verify umbilical is electrically connected and BW 1 is clear of WEC, close circuit breaker on pier side</td></tr>
<tr><td>6.d</td><td></td><td>R/V Beyster</td><td>WEC Operator: Verify shore breaker closed, close umbilical relay
WEC Operator: Verify communication to WEC via SCADA</td></tr>
</table>

			• WEC Operator: Verify SCADA control locally and with shore staff on SIO pier (maintain SCADA control on R/V Beyster), perform pre-submergence checks
7	WEC lowered to operational depth		
7.a		*R/V Beyster*	• WEC Operator: Operate PTOs to submerge WEC, perform operational depth checks • WEC Operator: Submerge WEC to survival depth, perform survival depth checks • WEC Operator: Return WEC to operational depth, perform operational depth checks and transfer from manual to automatic control • WEC Operator: Transfer SCADA control to shore staff
7.b		*SIO Pier Staff*	• Shore Staff: Monitor SCADA and maintain communication with WEC operator on R/V Beyster
8	WEC submerged function checks		
8.a		*SIO Pier Staff*	• Shore Staff: Verify manual operation and basic function checks at submergence depth (via checklist) • Shore Staff: Transfer to automatic control and verify full system function checks • Shore Staff: Transition to survival depth and verify function checks • Shore Staff: Transition back to optimal operating depth
8.b		*R/V Beyster*	• WEC Operator: Monitor SCADA and maintain communication with WEC operator at SIO Pier • WEC Operator: Inform R/V Beyster Captain when functional checks complete and ready to depart site • WEC Operator: Transfer to BW 1
9	Line support vessel recovered to SIO pier		
10	R/V Beyster returns to home port		

5.1.3 Estimated Timeline: WEC Installation & Commissioning

Only vessel time is added to total time calculation (highlighted activities do not require vessel on-site)

Table 6: Timeline: WEC Installation & Commissioning – Astern Tow

Step #	Day 1 - Activity	Hours
T	Deploy line support vessel from SIO pier and transit to site	0.5
1	Attach mooring line #2 to PTO #2	0.5
2	Attach mooring line #4 to PTO #4	0.5
3	Attach mooring line #3 to PTO #3	0.5
4	Attach mooring line #1 to PTO #1	0.5
5	Recover umbilical cable	0.5
6	Electrically connect umbilical	0.5
7	WEC lowered to operational depth	0.5
8	WEC submerged functional checks	4.0
9	Line support vessel recovered to SIO pier	0.5
10	*Transit to home port (16.5 nm @ 25 kts)*	*0.75*
DM	*Demobilize vessel*	*2.0*
	Total Time Estimate (hrs)	**10.75**
	Total Time on Site (excluding mob/demob & transit to/from site)	**7.5**

5.1.4 Demobilization: WEC Installation & Commissioning

Demobilization shall occur at each vessels home port, depending on storage locations of any CalWave owned equipment. Any requirements for lifting equipment, including recovering the line handling vessel to SIO pier will be coordinated in advance with all parties (this section to be updated once equipment and material are further defined). Once control of the WEC is verified as transferred to the SCADA system at the SIO pier, the WEC Operator on-board the R/V Beyster will remain hands-off WEC controls. UCSD will be informed when all vessels have departed the site.

6 WEC OPERATION & TEST PLANNING

Operations will be monitored via the SCADA system located on the SIO pier and connected to the WEC via the umbilical cable. There is also ability to communicate with the WEC in the instance the umbilical cable becomes disconnected by WiFi and acoustics. Data collection will occur both on-board of the WEC as a high-level summary and on shore with the SCADA system. All data acquisition takes place inside the WEC.

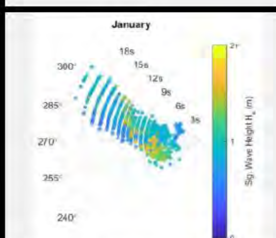
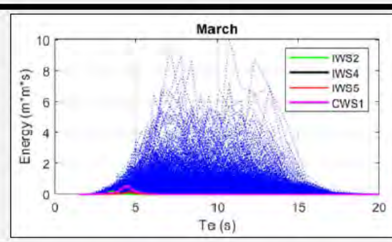
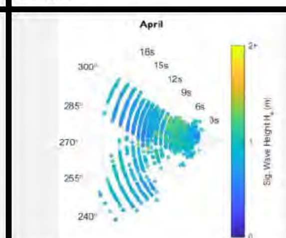
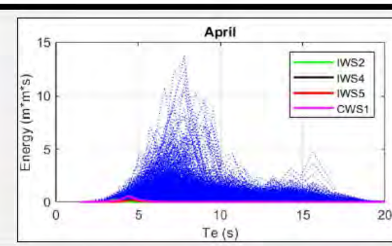
WEC operation is autonomous and does not require regular operator intervention. Nevertheless, throughout the deployment the operator does have the ability the manually control aspects of the WEC operation if necessary, including depth change operations.

6.1 PRELIMINARY OPERATION AND TEST PLANNING

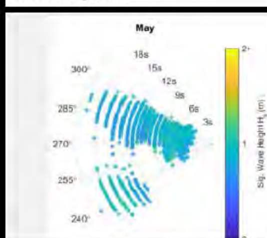
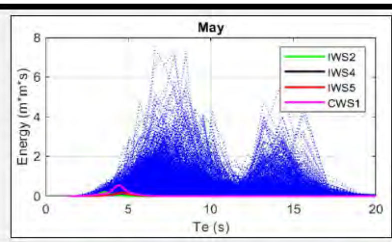
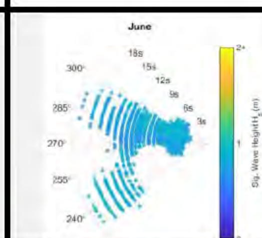
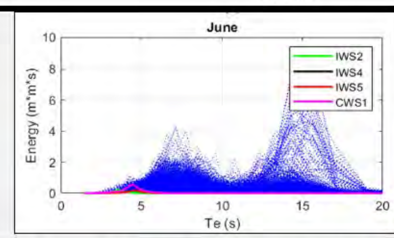
Based on CalWave's preliminary resource characterization and the device capability to execute a variety of self-system-tests, in field system identification, as well as different stages of autonomous control, a preliminary operation and test plan was created. For the eight target deployment months March to October the plan lists the primary objective of the device, secondary objectives, a high-level reference to the device control strategy chosen to achieve the specific objectives as well as a summary of the targeted outcome.

The preliminary operational plan in the following is broken down into deployment weeks to increase the level of planning details. As device objectives and thus operation is closely linked to the expected wave resource, for each deployment month the power spectrum and Hs-Tp-Direction rose is referenced. Data for each month is derived from about 6 years of hindcast wave data from the nearby CDIP 201 buoy.

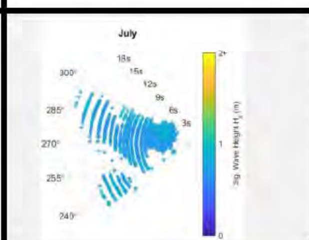
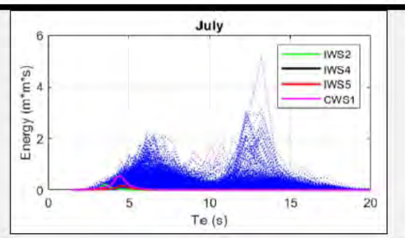
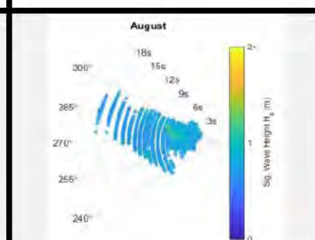
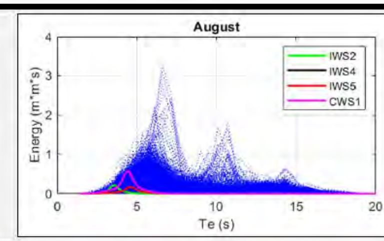
CalWave X-5 Demonstration at Scripps - (Preliminary) Operational Plan

Deployment Month	1 (March)				2 (April)			
Deployment Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Primary Ojective	System Check & Idle Mode & Survivability	Depth Change and Load Management	Submerged in field SID	Slow ramp-up of device oscillation and PTO forces.	[Baseline CTRL] Operation in high energetic waves at conservative subm. depths	[Baseline CTRL] Power absorption optimization high energetic waves at var. subm. depths	[Advanced CTRL] Operation in high energetic waves at conservative subm. depths.	[Advanced CTRL] Power absorption optimization in high energetic waves at var. subm. depths
Secondary Objective	Sensor surveilance, Surveilance of desired buoyancy chamber flooding	Sensor surveilance, Surveilance of desired buoyancy chamber flooding	Sensor surveilance, Surveilance of desired buoyancy chamber flooding	Sensor surveilance, Surveilance of desired buoyancy chamber flooding	Reoccuring system & subm. depth control & load management system check	Autonomous submergence depth control depending on wave excitation with constraints	Test single DOFs device DOF control (e.g. Suppress surge, suppress heave, suppress pitch)	Autonomous submergence depth control depending on wave excitation.
Device Control Objective	PTO force and Absorber motion attenuation. System is kept in safe/idle state.	Stable transition of submergence depths Reliable operation of Load Management Mechanism	Open loop control for in field SID via PTO actuation and IMU reading (deep submergence to minimize wave excitation)	PTO frame controller Gradual increase of device & PTO forces using decreasing submergence depth / load management mechanism.	PTO frame controller under stroke surveillance and power limitations. Optimization of PTO parameter	PTO frame controller under stroke surveillance and power limitations. Optimization of PTO parameter	Advanced Abs-frame controller under stroke surveillance and power limitations. Optimization of advanced control parameter	Advanced Abs-frame controller under stroke surveillance and power limitations. Optimization of advanced control parameter
Target Outcome	Confirmation of device stability and observation of pressure hull status Confirmation of idle PTO forces (e.g. Pre-Tension) Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly	Confirmation of device depth change capability. Confirmation of Load Management Mechanism Control Confirmation of GasSpring / Pre-tension consistency and estimate validation	Comparison of SID results for PTO subsystems and global device impedance with beginning of deployment results, PTO bench test results, and hydrodynamic model results. Confirmation of ability to control each DOF of the absorber body with the PTO units. Confirmation of IMU behavior and sensor fusion for Advanced CTRL	Confirmation of expected force to displacement ratios on PTO in baseline control mode. Confirmation of expected absorber watch-circle and rotational displacements.	Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly Confirm device ability to absorb power from long waves and relatively high wave heights at using submergence depth and load management capabilities. (Baseline Controller) Confirmation that both, actuation and generation power for energy intense waves is in range of regular design operating states via load management	Confirm device ability to absorb power from long waves and relatively high wave heights at using submergence depth and load management capabilities. (Baseline Controller) Confirm that device submergence depth controller works autonomously as expected in conservative submergence depth band.	Confirm device ability to absorb power from long waves and relatively high wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirmation that both, actuation and generation power for energy intense waves is in range of regular design operating states via load management	Confirm device ability to absorb power from long waves and relatively high wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirmation that both, actuation and generation power for energy intense waves is in range of regular design operating states via load management
Wave Climate (CDIP 201 Buoy)								
Overview	**High energetic waves, device check and commissioning**				**High energetic waves, conservative operation gradually approaching design loads**			

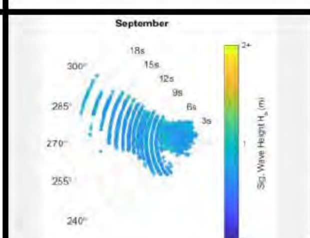
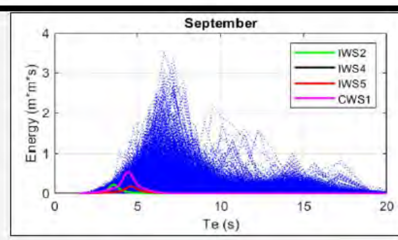
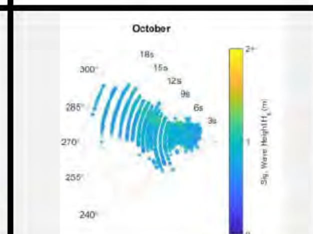
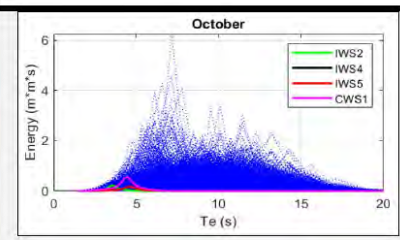
CalWave X-5 Demonstration at Scripps - (Preliminary) Operational Plan

Deployment Month	3 (May)				4 (June)			
Deployment Week	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Primary Ojective	[Baseline CTRL] Operation in medium energetic waves with full load exposure	[Baseline CTRL] Operation in medium energetic waves with full load exposure	[Advanced CTRL] Power absorption optimization in medium energetic waves with selective wave directions	[Advanced CTRL] Power absorption optimization in medium energetic waves with selective wave directions	[Advanced CTRL] Power absorption optimization in multiple wave directions with different DOF tunings	[Advanced CTRL] Power absorption optimization in multiple wave directions with different DOF tunings	[Advanced CTRL] Power absorption optimization in multiple wave directions with different DOF tunings	[Advanced CTRL] Power absorption optimization in multiple wave directions with different DOF tunings
Secondary Objective	Reoccuring system & subm. depth control & load management system check	Parameter vs. Performance tradeoff mapping	Parameter vs. Performance tradeoff mapping	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	Reoccuring system & subm. depth control & load management system check	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	Mid - deployment in field SID for PTO and total device
Device Control Objective	System assessment routine (depth changes, geometry control, individual PTO checks) Baseline Tether-frame controller. Power limitations for load capacity optimization.	Baseline Tether-frame controller Power limitations for load capacity optimization.	Advanced Abs-frame controller Power limitations for load capacity optimization	Advanced Abs-frame controller in addition to PTO load distribution controller. Power limitations for load capacity optimization.	Advanced Abs-frame controller. Power limitations for load capacity optimization.	Advanced Abs-frame controller in addition to PTO load distribution controller. Power limitations for load capacity optimization.	Advanced Abs-frame controller in addition to PTO load distribution controller. Power limitations for load capacity optimization.	Open loop in field SID via PTO actuation and IMU reading (deep submergence to minimize wave excitation)
Target Outcome	Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly Confirm device ability to absorb power from long waves and medium wave heights at using submergence depth and load management capabilities. (Baseline Controller) Confirmation that both, actuation and generation power for medium energy intense waves is in range of regular design operating states via load management	Confirm device ability to absorb power from long waves and medium wave heights at using submergence depth and load management capabilities. (Baseline Controller) Explore tradeoffs and PTO as well as load management parameter mapping spaces for cost efficient operation (load vs. performance) (Baseline Controller)	Confirm device ability to absorb power from long waves and medium wave heights at using submergence depth and load management capabilities. (Advanced Controller) Explore tradeoffs and PTO as well as load management parameter mapping spaces for cost efficient operation (load vs. performance) (Advanced Controller)	Confirm device ability to absorb power from long waves and medium wave heights at using submergence depth and load management capabilities. (Advanced Controller) Use add-on controller for load balancing across the individual PTO units.	Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly Confirm device ability to absorb power from medium - long waves and medium wave heights at using submergence depth and load management capabilities. (Advanced Controller)	Confirm device ability to absorb power from medium - long waves and medium wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium - long waves and medium wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Comparison of SID results for PTO subsystems and global device impedance with beginning of deployment results, PTO bench test results, and hydrodynamic model results. Confirm device ability to absorb power from long waves and medium wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.
Wave Climate (CDIP 201 Buoy)								
Overview	Medium energetic waves, control optimization and control space exploration				Medium energetic waves, multi DOF tuning, advanced controller optimization and testing			

CalWave X-5 Demonstration at Scripps - (Preliminary) Operational Plan

Deployment Month	5 (July)				6 (August)			
Deployment Week	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Primary Ojective	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)
Secondary Objective	Reoccuring system & subm. depth control & load management system check	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	Reoccuring system & subm. depth control & load management system check	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization
Device Control Objective	System assessment routine (depth changes, geometry control, individual PTO checks) Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.	System assessment routine (depth changes, geometry control, individual PTO checks)	Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.
Target Outcome	Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly. Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller)	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.
Wave Climate (CDIP 201 Buoy)								
Overview	Target to medium energetic waves, multi DOF tungin, device performance assessment				Target to medium energetic waves, device performance assessment			

CalWave X-5 Demonstration at Scripps - (Preliminary) Operational Plan

Deployment Month	7 (September)				8 (October)			
Deployment Week	25	26	27	28	29	30	31	32
Primary Ojective	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Advanced CTRL] Optimized power absorption for target design waves (IWS & CWS waves)	[Fully autonomous CTRL] Optimized power absorption with controller autonomous depth, load management, and performance optimization.	[Fully autonomous CTRL] Optimized power absorption with controller autonomous depth, load management, and performance optimization.	[Fully autonomous CTRL] Optimized power absorption with controller autonomous depth, load management, and performance optimization.	End of deployment submerged in field SID for PTO and total device
Secondary Objective	Reoccuring system & subm. depth control & load management system check	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	Reoccuring system & subm. depth control & load management system check	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	PTO units load balancing optimization/PTO metrics optimization. Poincaré & absorber watch-circle maps optimization	Preparation of device decommisioning
Device Control Objective	System assessment routine (depth changes, geometry control, individual PTO checks)	Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.	System assessment routine (depth changes, geometry control, individual PTO checks)	Advanced Abs-frame controller in addition to PTO load distribution controller.	Advanced Abs-frame controller in addition to PTO load distribution controller.	Open loop in field SID via PTO actuation and IMU reading (deep submergence to minimize wave excitation)
Target Outcome	Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller)	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm all sensors and communication (SCADA) as well as safety&load management mechanisms are working correctly Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller)	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Confirm device ability to absorb power from medium-target long waves and medium-target wave heights at using submergence depth and load management capabilities. (Advanced Controller) Confirm add-on controller ability to balance loads & power across the individual PTO units.	Comparison of SID results for PTO subsystems and global device impedance with beginning and middle of deployment results, PTO bench test results, and hydrodynamic model results.
Wave Climate (CDIP 201 Buoy)								
Overview	Target to medium energetic waves, device performance assessment				Target to medium energetic waves, device performance assessment			

6.2 WEC Inspection & Maintenance

For the first month of deployment, the WEC will be continuously monitored from the CalWave shore-based operations station as commissioning and system tests are undertaken (see preliminary operations plan).

Periodical system checks at the beginning of each deployment month will be executed to ensure SCADA communication is working, all sensors are responsive and in range, active control of PTO units is available, load management via geometry control is functional and device submergence depth change capabilities are ensured. These tests are executed as a standard test routing and manually started. This ensures that the wave environment is suited for execution of the standard test protocol.

From then on, the WEC will be monitored periodically by the CalWave on-call duty manager, with automated alarm functionality (e.g. alarms audible/viewable from cell phone or another mobile device). Maintenance trips will occur more or less frequently as is deemed necessary, Boat operations will primarily be provided by R/V Beyster and/or a small vessel (e.g. Boston Whaler).

6.3 Inspection Checklist

The SCADA will continuously monitor critical parameters while the WEC is in operation. Additionally, CalWave will maintain logs to identify any trends that could be of concern.

The following points will be visually inspected on a regular basis with a drop camera or ROV. These inspections are intended to be complete weekly for the first four weeks, and monthly thereafter unless otherwise determined necessary.

- Hull structural damage, biofouling, or corrosion
- Mooring Belts & Lines twists, kinks, biofouling or signs of damage
- Navigation lights in place
- Umbilical cable connection, Lazy S configuration, and touchdown points at WEC and SIO pier
- Evidence of marine mammal interaction
- Anchor evidence of dragging, biofouling, corrosion, and structural integrity
- All connection hardware

6.4 Maintenance & Operations

Prior to deployment of the WEC, an operations agreement will be established with UCSD and local marine contractors that allows for expedient mobilization of the primary vessels (R/V Beyster and 19 ft Boston Whaler) to allow for rapid deployment of resources to the SIO test site should a situation occur where intervention is required. Due to the scale and accessibility of the WEC internal system, there is no human access to the interior of the WEC anticipated while at sea. Any maintenance intervention requiring human access will require towing the WEC to safer harbor. This operational consideration will be reviewed and revised as scale of deployed equipment increases in future projects.

Periodic inspections using a small vessel (Boston Whaler) will use a drop camera or small ROV to observe moorings, anchors, umbilical and WEC hull for signs of corrosion, biofouling or other damage. These inspections are anticipated to occur on a weekly basis during the first month of operation, and monthly thereafter unless a higher frequency is determined necessary. It is additionally anticipated to incorporate a pin style load cell in the umbilical connection to the WEC to provide notification of unanticipated tension, indicating possible marine mammal entanglement or other unanticipated events.

UCSD, as the site owner, will be informed of and given the opportunity to participate in operations. For this scaled demonstration project, it is not initially anticipated that CalWave will own or operate our own vessels.

Shore based monitoring will occur from the SCADA system located in the SIO pier instrumentation shed. CalWave staff will also have virtual access to monitoring and controls functionality from off-site. Upon initial WEC deployment, CalWave staff will monitor the WEC locally for several weeks or until such time as confidence is gained in remote functionality and operational stability to transition to remote monitoring and control. During occasions that CalWave staff are not present locally in San Diego, SIO vessel operators or other local marine operators will be contracted to provide emergency response if necessary.

6.5 WEC Recovery & Decommissioning

WEC Recovery & Decommissioning will occur in the reverse sequence of WEC Installation & Commissioning. During the recovery, respectively decommissioning process detailed documentation will take place for post-review of any changes occurred to the anchors (e.g. biofouling).

6.6 Umbilical Cable Recovery

Umbilical Cable Recovery will occur in the reverse sequence of Umbilical Cable Installation. During the recovery, respectively decommissioning process detailed documentation will take place for post-review of any changes occurred to the anchors (e.g. biofouling).

6.7 Anchor Recovery & Site Decommissioning

Anchor Recovery & Decommissioning will occur in the reverse sequence of Anchor Installation & Commissioning. During the recovery, respectively decommissioning process detailed documentation will take place for post-review of any changes occurred to the anchors (e.g. biofouling).

7 HAZID

7.1 ADMINISTRATIVE

Date of planned operation:

Date of HAZID briefing:

Attendees:

*by signing below, I attest that I have read and understand the operational plan and agree to operate safely and in accordance with this plan.

Name	Company	Signature
	CalWave	
	CalWave	
	CalWave	
	CalWave	
	UCSD	
	UCSD	
	UCSD	
	UCSD	

Planned Crew

Vessel	Name	Company	Role
R/V Beyster		UCSD	Beyster Captain
R/V Beyster		CalWave	WEC Operator
R/V Beyster		CalWave	Beyster Crew #1
BW 1		UCSD	BW 1 Captain
BW 1		CalWave	Crew #1
BW 1		CalWave	Crew #2
BW 1		UCSD	Diver #1
BW 1		UCSD	Diver #2
SIO Pier		CalWave	Shore Staff

Vessel Call Times

Vessel	Port	Crew Arrival Time	Departure Time
R/V Beyster	Point Loma		
BW 1	SIO Pier		
Shore Staff	SIO Pier		

7.2 Risk Categories

Severity	Consequences				Increasing Probability				
					1	2	3	4	5
	People	Assets	Environment	Reputation	Never heard of in the industry	Heard of in the industry	Has happened in the organization or more than once per year in the industry	Has happened at the location or more than once per year in the organization	Has happened more than once per year at the location
0	No injury or health effect	No damage	No effect (no or temporary impact - days)	No impact (local media, no significant concern)	L	L	L	L	L
1	Slight injury or health effect (first aid or medical treatment)	Slight damage	Slight effect (local scale, short term damage – weeks)	Slight impact (short term local concern)	L	L	L	L	L
2	Minor injury or health effect (restricted work case or LTI)	Minor damage	Minor effect (local scale, short term damage – months)	Minor impact (short term national mention)	L	L	L	M	M
3	Major injury or health effect (partial disability)	Moderate damage	Moderate effect (local scale, medium terms damage – years)	Moderate impact (medium term national concern)	L	L	M	M	H
4	< 3 fatalities, or permanent total disabilities	Major damage	Major effect (local scale, long term damage – decades)	Major impact (regional or persistent national concern)	L	M	M	H	H
5	> 3 fatalities	Massive damage / total loss	Massive effect (regional scale, permanent damage)	Massive impact (global concern and media coverage)	M	M	H	H	H

L	Low Risk
M	Medium Risk
H	High Risk

Figure 21: Risk Categories

7.3 Risk Identification and Mitigation

Summary

WEC Deployment & Recovery					
	Consequence				
Prob.	1	2	3	4	5
5	0	0	0	0	0
4	0	0	0	0	0
3	0	1	8	2	0
2	0	0	24	11	8
1	0	0	0	0	0

WEC Deployment & Recovery			
Total risks	High	Medium	Low
55	0	29	26
	0%	*53%*	*47%*

Table 7: HAZID

ID	Hazard Category	Scenario	Likely Threats	Top Events	Controls in Place	C	P	RPT	Rank	Comments	Action Party	Closed ?
X.0600	Connecting mooring lines to PTO belt											
X.0610	Retrieve mooring line from marker buoy	Mooring line disconnects from marker buoy	Inadequately secured hardware Excessive weather prior to connecting to WEC (no tension on moorings) Human error (dropped hardware)	Delay Potential damage to mooring line	Visual inspection	3	2	6	Low			
X.0611	Retrieve mooring line from marker buoy	Personnel safety working offshore	Pinch points between vessel and buoy Potential for man overboard Slips, trips, falls	Human safety	HSE Plan, PPE	5	2	10	Med			
X.0620	Retrieve PTO belt from WEC	Vessel contact with WEC	Inadequate design or plan for connection Wave/wind loads during operation Abrupt vessel movement	Damage to WEC Damage to vessel	Installation plan	4	2	8	Med			
X.0630	Bring mooring lines into tension	PTO fails to operate	Communication fault Hardware fault	Inability to deploy - cost & program delay	Pre-deployment testing	4	2	8	Med			
X.0640	Dive operations											
X.0641	Diving near vessels & structures	Diving near pier to route umbilical from seafloor to pier	Injury from diver contact with vessels & structures, particularly when surfacing	Injury to personnel	UCSD dive procedures and controls	5	2	10	Med			

X.0700	Connecting umbilical to WEC											
X.0710	Retrieve umbilical	Pickup buoy off station	Hardware failure Human error (not securing pin, etc.)	Cost and program delay (required dive operation to retrieve)	Deployment planning Visual inspection	3	1	3	Low			
X.0711	Retrieve umbilical	Umbilical handling	Abrasion Contact with vessel or subsea equipment Exceed minimum bend radius	Damage to umbilical	Deployment planning Visual inspection	3	2	6	Low			
X.0712	Retrieve umbilical	Umbilical interaction with vessel	Umbilical comes up into propeller	Damage to vessel Damage to umbilical	Deployment planning Visual inspection	4	2	8	Med			
X.0713	Retrieve umbilical	Entanglement with other subsea infrastructure and/or lines	Insufficient touchdown anchor Excessive wave loading Unanticipated subsea dynamics	Damage to umbilical Damage to other subsea infrastructure	Drop camera	3	2	6	Low			
X.0720	Electrical testing prior to connection	Damage to communications equipment or other sensitive electronics	Insulation resistance testing inducing current in communications or other sensitive electronics	Repair needed on WEC Cost and program delay	Deployment planning Equipment pre-test	3	2	6	Low			
X.0721	Electrical testing prior to connection	Electric shock	Improper electrical safety Inadequate short circuit protection	Human safety	Safety observer Deployment planning Equipment pre-test	5	2	10	Med			

X.0730	Make electrical connection	Electric shock	Improper electrical safety Improper wiring	Human safety	Safety observer Deployment planning Equipment pre-test	5	2	10	Med			
X.0731	Make electrical connection	Damage to electrical equipment	Short circuit Incorrect electrical system changes since previous connection	Repair needed on WEC Cost and program delay	Safety observer Deployment planning Equipment pre-test	3	2	6	Low			
X.0800	Submerging WEC to operational depth											
X.0810	Bring mooring lines into tension to ensure station keeping prior to vessel moving to observation position	WEC fails to submerge	Insufficient motor capacity Loads higher than anticipated	Inability to deploy - cost & program delay	Deployment planning Equipment pre-test	3	2	6	Low			
X.0811	Bring mooring lines into tension to ensure station keeping prior to vessel moving to observation position	Instability as WEC transitions to submerged position	Communication fault Motor operation and/or loads uneven (anchor spacing not even)	Inability to deploy - cost & program delay	Deployment planning Equipment pre-test	3	2	6	Low			
X.0812	Bring mooring lines into tension to ensure station keeping prior	Communication failure once WEC is submerged	Communication path unreliable when submerged	Inability to deploy - cost & program delay	Deployment planning Equipment pre-test	3	2	6	Low			

	to vessel moving to observation position											
X.0820	Submerge device from surface	Slamming loads on hull prior to submergence	Higher than expected sea state Longer than anticipated to lower Inadequate hull structural analysis	Failure of hull Seawater ingress	Deployment planning Adherence to weather windows	4	2	8	Med			
X.0821	Submerge device from surface	Seawater ingress	Enclosure not properly closed and sealed Seal failure	Failure of electrical equipment Loss of WEC	SCADA monitoring from vessel & pier	4	2	8	Med			
X.0822	Submerge device from surface	Inability to maintain correct depth	Controls failure Hardware failure	Damage to WEC Program delays	SCADA monitoring from vessel & pier	4	2	8	Med			
X.0830	Adjust between submerged depths	Inadequate power to perform operations	Incorrect load estimation Insufficient onboard power	WEC in exposed position if higher sea states occur	Motor current Mooring tension	3	2	6	Low			
X.0831	Adjust between submerged depths	Incorrect pretension in system	Controls failure Sensor failure	WEC in exposed position if higher sea states occur	Mooring tension	2	3	6	Low			
X.0840	Establish gas spring position/pressure	Incorrect gas spring pressure	Accumulator not maintaining pressure Hydraulic leak Communications/software fault Controls fault	Inability to accuratly complete testing	SCADA monitoring from vessel & pier	3	2	6	Low			
X.0900	WEC automated operation											

X.0910	Operating device with basic functionality	Extreme weather - above design considerations and/or arising quickly	The Ultimate Limit States that defines the design basis requirements is dependent on the definition of the extreme sea state.	Higher than design loads and/or occurring prior to ability to transition to survival	Mooring loads	4	3	12	Med			
X.0920	Communication functionality	Loss of communication during operation	Power cycle to communications equipment Service interruption	Loss of situational awareness Loss of operator input ability	SCADA Watchdog timer	3	3	9	Med			
X.0930	Software functionality	Software failure during operation	Power cycle Cable disconnection or failure Failed built in test (BIT)	WEC shutdown Loss of situational awareness Loss of operator input ability	Software BIT	3	3	9	Med			
X.0931	Software functionality - control loop	Uneven PTO operation or unexpected PTO operation	Latency in control software	Delays, inability to stay deployed Risk of WEC damage if not in correct position	SCADA monitoring Pre-deployment testing	3	2	6	Low			
X.0940	Power system functionality	Excessive heat generated in braking resistors	Discrepancy in generated/dissipated heat, compared to expected	WEC shutdown Loss of situational awareness Loss of	Climate control data	3	2	6	Low			

				operator input ability								
X.0950	Hydraulic system functionality	Hydraulic leaks	Loose valve or piping	WEC operating outside of optimal conditions Loss of pretension	Hydraulic pressure	3	2	6	Low			
X.0951	Hydraulic system functionality	Hydraulic temperature higher than expected	Heat generated in friction losses (seals, turns, piping, etc.,)	Increased risk of hydraulic system failure	Hydraulic temperature	3	2	6	Low			
X.0952	Hydraulic system functionality	Hydraulic pressure higher than expected	Controls fault	Increased risk of hydraulic system failure	Hydraulic pressure	3	2	6	Low			
X.0960	Auxiliary systems functionality	Accumulation of condensation greater than expected	Higher humidity than anticipated Lack of air exchange in submerged environment	Damage electrical components	Design hull for sufficient (passive) bilge capacity	3	2	6	Low			
X.0970	Validating full functionality and performance	Corrupt data and/or inability to access data while deployed	Communications failure Software failure	Loss of situational awareness Loss of informed operator input ability	Pre-test of controls and communications	3	2	6	Low			

X.0980	Operating with optimized performance	Reduced power production compared to expectations	Inaccurate modelling WEC build not as designed	Partial loss of credibility Increased difficulty/delay in continued funding	Performance metrics Pre-deployment testing	4	2	8	Med			
X.0981	Operating with optimized performance	Low availability	Component reliability issues Communication issues Lack of weather windows for maintenance	Partial loss of credibility Increased difficulty in acquiring sufficient test data	Data logging Pre-deployment testing	3	3	9	Med			
X.0990	Data post processing	Incomplete data collection during test campaign	Sensor failure Insufficient sensors	Partial loss of credibility Increased difficulty in acquiring sufficient test data	Data logging Pre-deployment testing	3	3	9	Med			
X.0991	Data post processing	Insufficient data collection during test campaign	Low availability of WEC Insufficient weather to test necessary sea states	Partial loss of credibility Increased difficulty in acquiring sufficient test data	Data logging Pre-deployment testing	3	3	9	Med			
X.1000	Tidal adjustment											
X.1010	Adjust PTO/moorings to accommodate tidal variations	Failure of tidal adjustment controls	WEC operating out of optimal position in water column; potentially exposed to higher than design loads	Inability to perform depth change Inability to recover from depth change	Shaft torque Hydraulic pressure	4	2	8	Med			

				Shock loads on system								
X.1100	Transition to/from survival mode											
X.1110	Recover device from emergency survival mode position	Inability to transition WEC from survival back to surface	Corroded or otherwise inaccessible connection point WEC movement beyond safe limits for diver approach	Need to cut mooring line or recover anchor under load in order to retrieve WEC	Pre-deployment testing HSE Plan	4	2	8	Med			
X.1300	Disconnecting umbilical											
X.1310	Electrically disconnect umbilical	Electric shock	Improper electrical safety Improper wiring	Human safety	Safety observer Deployment planning Equipment pre-test	5	2	10	Med			
X.1311	Electrically disconnect umbilical	Damage to electrical equipment	Short circuit Incorrect electrical system changes since previous connection	Repair needed on WEC Cost and program delay	Safety observer Deployment planning Equipment pre-test	3	2	6	Low			
X.1320	Disconnect umbilical	Electric shock	Improper electrical safety Improper wiring	Human safety	Safety observer Operations planning	5	2	10	Med			

X.1321	Disconnect umbilical	Damage to electrical equipment	Short circuit Incorrect electrical system changes since previous connection	Repair needed on WEC Cost and program delay	Safety observer Operations planning	4	3	12	Med			
X.1330	Retrieve umbilical	Pickup buoy off station	Hardware failure Human error (not securing pin, etc.)	Cost and program delay (required dive operation to retrieve)	Safety observer Operations planning	3	2	6	Low			
X.1331	Retrieve umbilical	Damage to umbilical during operation	Abrasion Contact with vessel or subsea equipment Exceed minimum bend radius	Damage to umbilical	Deployment planning Visual inspection	3	2	6	Low			
X.1332	Retrieve umbilical	Umbilical interaction with vessel	Umbilical comes up into propeller	Damage to vessel Damage to umbilical	Deployment planning Visual inspection	4	2	8	Med			
X.1333	Retrieve umbilical	Entanglement with other subsea infrastructure and/or lines	Insufficient touchdown anchor Excessive wave loading Unanticipated subsea dynamics	Damage to umbilical Damage to other subsea infrastructure	Drop camera	3	2	6	Low			
X.1400	Disconnecting mooring lines from PTO											
X.1410	Release tension from mooring lines to allow for disconnection from vessel	Inability to safely recover WEC	Controls failure	Project delays and/or WEC damage	Plan for cutting mooring lines	3	2	6	Low			

X.1420	Disconnect mooring line from winch belt	Mooring line disconnects from bridal	Inadequately secured hardware Excessive weather prior to connecting to WEC (no tension on moorings) Human error (dropped hardware)	Delay Potential damage to mooring line	Visual inspection	3	2	6	Low			
X.1421	Disconnect mooring line from winch belt	Personnel safety working offshore	Pinch points between vessel and WEC Potential for man overboard Slips, trips, falls	Human safety	Safety SOP	5	2	10	Med			
X.1422	Disconnect mooring line from winch belt	Vessel contact with WEC	Inadequate design or plan for connection Wave/wind loads during operation Abrupt vessel movement	Damage to WEC Damage to vessel	Installation plan	4	2	8	Med			
X.1430	Attach mooring line to marker buoy	Mooring line disconnects from marker buoy	Inadequately secured hardware Excessive weather prior to connecting to WEC (no tension on moorings) Human error (dropped hardware)	Delay Potential damage to mooring line	Visual inspection	3	2	6	Low			
X.1431	Attach mooring line to marker buoy	Personnel safety working offshore	Pinch points between vessel and buoy Potential for man overboard Slips, trips, falls	Human safety	Safety SOP	5	2	10	Med			
X.1500	Loss of communication actions											
X.1510	Loss of communication inside WEC (WEC internal	Communications connection, service, or	Climate control (temp, humidity), equipment failure	Loss of ability to control load mitigation	SCADA	3	3	9	Med			

	systems & controls loss of communicatio n)	equipment failure		mechanism s								
X.160 0	Loss of power actions											
X.161 0	Loss of power on-board WEC	Communicatio ns connection, service, or equipment failure Prolonged low sea states	Electrical fault resulting in circuit breaker trip (not remotely resettable) Failure of drive	Loss of ability to control unpowered system (PTO or hatch actuation)	SCADA	3	3	9	Me d			
X.170 0	Loss of one PTO actions											
X.171 0	Transition to lower position in water column with increased tension on remaining operational PTOs	Single PTO system failed offline	Motor/Generator failure Winch or shaft failure Mooring line or PTO belt failure	Loss of control of one PTO	SCADA Mooring line tension	3	3	9	Me d			