Triton
Tank Test Plan

DE-FOA-0001310: Next Generation Marine Energy Systems - Durability & Survivability
Award Number: DE-EE0007346
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Document contributes towards D6, M6

Following drawings provided:
<D6_Tank_Test_Plan_Drawings.pdf>

1. Table of Contents:

2. Summary / Scope

This report summarizes the test plan for the 1:30 Triton physical model. The overall aim of the tank tests is to evaluate system loads and performance in both operational (floating) and survival (submerged) configurations up to the 1-in-50 year design condition.

Test Basin: Oregon State University Large Wave Flume

Schedule:

- *Wave Calibration:* *26 Feb – 02 Mar 2018*
- *Device Installation:* *05 Mar – 06 Mar 2018*
- *Testing:* *07 Mar – 15 Mar 2018*
- *Decommissioning:* *16 Mar 2018*

References

Supplementary information may be found in the following documents:

D6_Tank_Test_Plan_Waves.xlsx
D6_Tank_Test_Plan_Instrumentation_List.xlsx
D6_Tank_Test_Plan_Drawings.pdf

3. Test Device

Full-Scale WEC Description

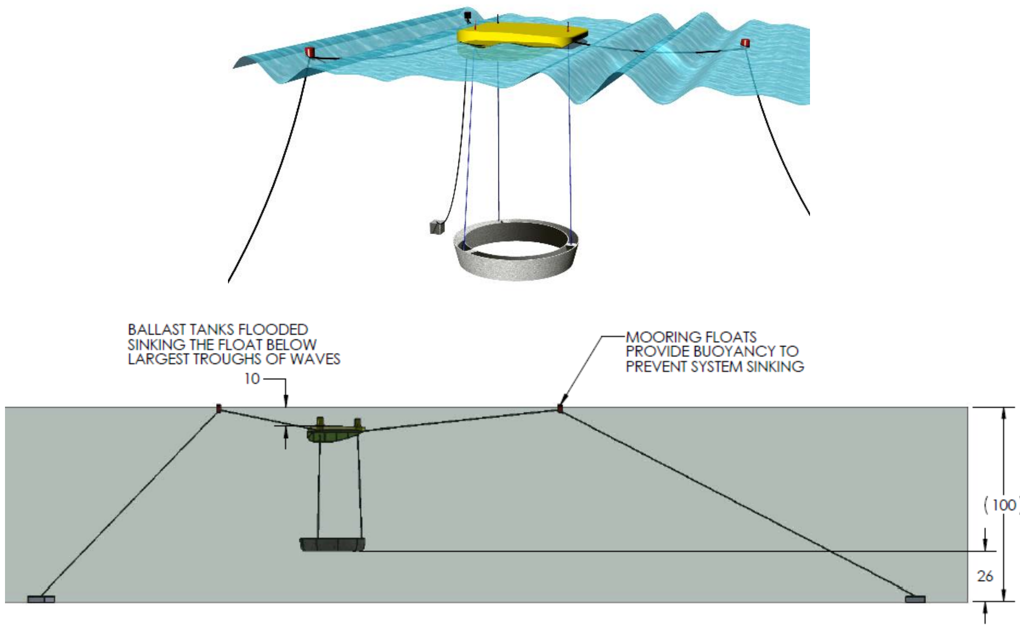

Figure 1*. (Top) Triton WEC in operational mode. Waves propagate right to left. (Bottom) Survival mode.*

The Triton Wave Energy Converter is a two-body, multi-modal point absorber consisting of a surface float connected by three flexible tendons to a submerged reaction ring structure. Mechanical energy is extracted from the environment in the form of wave-induced heave, pitch, roll, surge, and sway motion of the surface float through its reaction against the ring structure. The resulting tension variation in each tendon is transmitted to the power takeout (PTO) housed inside the surface float. The WEC is moored using a three-point inverted catenary arrangement, consisting of three mooring floats. In extreme waves, the WEC enters a submerged survival configuration to reduce wave loads. In this configuration, the surface float is flooded with ballast water until the total system is slightly heavier than neutrally buoyant. This weight is then supported by the three mooring floats as shown in Figure 1.

1:30 Model Description

Detailed geometric drawings may be found in the supplementary file "D6_Tank_Test_Plan_Drawings.pdf"

Surface float dimensions: 1.0 *m* length, 0.77 *m* width, 0.45 *m* height
Reaction ring dimensions: 1.21 *m* OD, 0.22 *m* height

Nominal tendon length: 1.67 *m*

Surface float mass: 24 *kg*
Dry reaction ring mass: 73 *kg*
Underwater reaction ring mass: 48 *kg*

The reaction ring is 3D printed from ABS plastic sections that are bolted together and lead ballasted. The surface float is 3D printed as a hollow shell and reinforced with an outer layer of fiberglass and epoxy. Three representative PTOs are housed inside the surface float, one for each of the three tendons. Each drivetrain comprises a spring-damper element; an extension spring, to support the weight of the reaction ring, and a rotary oil dashpot to represent the power absorption.

To replicate the submerged survival mode, the model surface float will be manually ballasted with lead until the system sinks below the surface and is supported by the mooring floats. Since the maximum depth of the WEC (2.1m) in addition to its expected vertical motion underneath the surface (~1m) is larger than the flume depth (2.7m), the nominal tendon length will be slightly shortened in this configuration to avoid clashes with the floor.

Model Installation

There are three lifting eyes on top of the surface float as shown in "D6_Tank_Test_Plan_Drawings.pdf". The entire WEC (surface float, tendons, reaction structure) will be lifted from these points as one unit and lowered into the water. The WEC will then be towed to the correct location and attached to the mooring. The lifting operation will be performed with the OSU overhead crane or with forks/boom.

There is a sealed hatch on top of the surface float that will be accessed to modify the PTO settings. This will be done with a 1-person kayak or by lifting the model with the overhead crane to an access gantry.

Instrumentation/DAQ

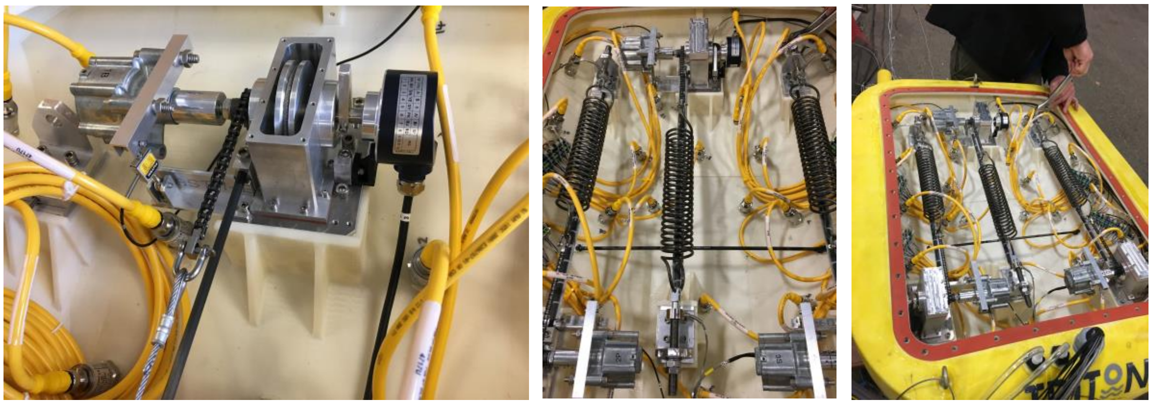

***Figure 2**. Model drivetrain and instrumentation. Bow PTO with encoder and damper shown on left with other images showing layout of return springs and pressure transducers, center and right.*

1. Model instrumentation
    - All instrumentation (except for IMU) will be acquired using the OSU DAQ (National Instruments PXI)
    - The model will contain 48 analog sensors, all -5 to +5VDC
        i. 31 pressure transducers (surface float pressure distribution)
        ii. 14 load cells
            - Tendon force (1 for each of the 3 tendons)
            - Spring force (1 for each of the 3 drivetrains)
            - Damping force (1 for each of the 3 drivetrains)
            - End-stop force (1 for each of the 3 drivetrains)
            - Mooring force (1 for each of the 2 mooring legs)
        iii. OPI will provide power, amplification, and signal conditioning.
        iv. The model will also contain 3 optical rotary encoders to measure displacement of each of the drivetrains
            - OPI will provide an intermediate system to convert the digital signal to a -5 to +5V analog signal.
    - Sensor termination: BNC. OPI will provide bare wire to BNC converters
    - Instrumentation bundle will pass out the rear of the hull through a sealed gland.
    - An IMU will be installed on the reaction structure to measure its motion
        i. OPI will log this data
        ii. OSU will provide a TTL pulse (rising edge) at the start of data acquisition to synchronize the instrumentation data with the IMU

- OPI will provide 10m of cabling to reach between the model and the DAQ.

2. Wave Probes (OSU)
    - Four measurements of wave elevation will be made: 2 upwave of the device, 1 at the device location, and 1 downwave of the device. Wave probes will be 35 cm away from the basin sidewalls – the lateral uniformity of the waves is acceptable and therefore the probes do not need to be centered in the flume. These wave probes will be in place during calibration and device testing. Measurements will be sampled on a concurrent time basis with the WEC instrumentation.
    - Wave calibration will be performed prior to model testing

3. Motion Tracking (OSU)
    - Motion capture (XYZRPY) of the surface float will be performed using the OSU PhaseSpace system. The rigid body motion data will be sampled on a concurrent time basis with the instrumentation. 3 standoffs w/ LED markers will be mounted on the surface float from the 3 PTO towers. OPI will provide standard 3/8" holes to mount the markers.
4. Video
    - OSU will provide underwater cameras to take video of the WEC in operational and submerged survival mode.

In order to quickly detect instrumentation failures, OSU will display real time physical quantities for key sensors on a monitor during testing.

Data will be saved as raw voltages in txt format. OPI will analyze the data after each test for QA and analysis. Data will be transferred via USB drive after each test.

Sampling frequency: 100 Hz.

4. Facility Setup

[Dimensional Information extracted from http://wave.oregonstate.edu/large-wave-flume]

Oregon State University Large Wave Flume
Basin width: 3.7m
Max water depth: 2.7m (still water)
Max Wave: 1.7m @ 5 sec
Period Range: 0.8-12 sec

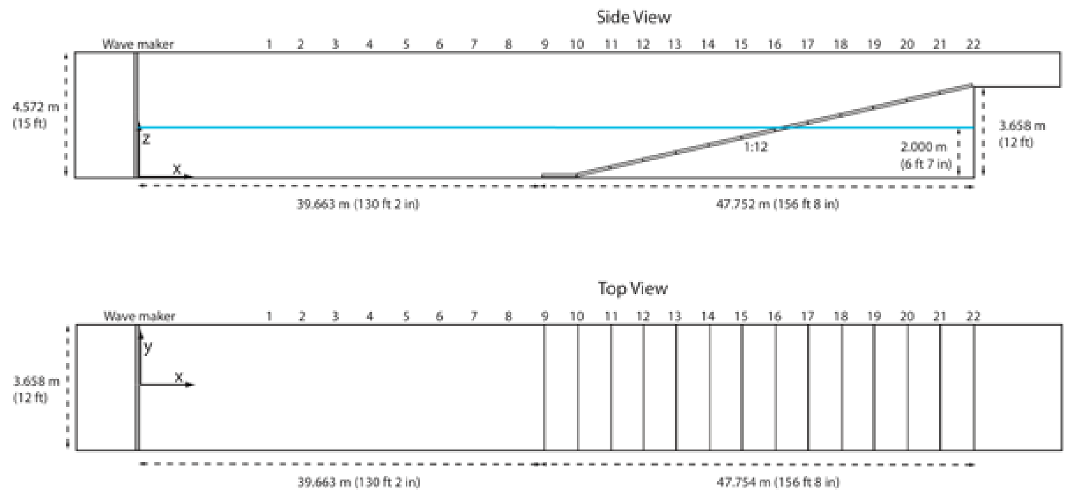

Figure 3. *OSU Large Wave Flume*

Due to the narrow width of the OSU flume, the Triton mooring will be modified to a two-point (bow and stern) configuration with the same general architecture as Figure 1. Each mooring line comprises two sections, an upper section connected from the WEC to a simple line float, and a lower section connected from the line float to the anchor. These lines provide the mooring pretension and restoring forces.

Mooring float locations: On 4.5 *m* diameter circle centered about the WEC
Anchor locations: On a 20 *m* circle centered about the WEC
Mooring line forces. Not expected to exceed 20lb. A 100-200lb clump mass for each mooring leg should be sufficient in the flume. OSU will provide this.

Bathymetry: Flat

5. Test Wave Conditions

Wave types: A range of monochromatic and Bretschneider (ISSC) waves will be tested. Additionally, OPI will test two focused waves, which are discussed further in the Numerical Survivability Report. OSU will recreate these focused wave profiles at the device center using time-series wave elevations provided by OPI.

Spreading: ∞ (long-crested)

Direction: All waves will be tested at 0° incidence to the physical model. If time permits, some tests may be repeated with the model re-moored at a slight angle to replicate off-axis waves.

Changing PTO parameters in the model is challenging and requires access, so we will run all wave conditions that require the same PTO settings before changing settings.

Calibration: OSU will calibrate all waves the week before physical model testing and ensure accuracy of T_p and H_s to within 5%. Time-series wave elevation measurements for an empty basin at the WEC installation location (in addition to the 3 locations described above) will also be made.

Wave Calibration Tests

			Full Scale		1:30 Model Scale		
Reference	**Spectra**	**Spreading (Cos^n)**	**T [s]**	**H [m]**	**T [s]**	**H [mm]**	**Notes**
Regular Waves							
WC-R1	Monochromat	=	**6.0**	**0.70**	**1.10**	**23**	RAO. Steepness = 1/80. Comparison to WEPrize models
WC-R2	Monochromat	=	**7.5**	**1.10**	**1.37**	**37**	
WC-R3	Monochromat	=	**9.0**	**1.58**	**1.64**	**53**	
WC-R4	Monochromat	=	**10.5**	**2.15**	**1.92**	**72**	
WC-R5	Monochromat	=	**12.0**	**2.79**	**2.19**	**93**	
WC-R6	Monochromat	=	**13.5**	**3.48**	**2.46**	**116**	
WC-R7	Monochromat	=	**15.0**	**4.19**	**2.74**	**140**	
WC-R8	Monochromat	=	**9.2**	**9.0**	**1.68**	**300**	Extreme operational. CFD comparison
WC-R9	Monochromat	=	**16.2**	**9.9**	**2.96**	**330**	
			Tp [s]	**Hs [m]**	**Tp [s]**	**Hs [mm]**	**Notes**
Irregular Waves							
WC-W1	White	=	**4 to 25**	**1.0**	**0.73-4.56**	**33**	RAO. May be limited by breaking limit
WC-I1	Bretschneider	=	**7.7**	**0.75**	**1.41**	**25**	Operational power matrix
WC-I2	Bretschneider	=	**9.2**	**1.75**	**1.68**	**58**	Operational power matrix
WC-I3	Bretschneider	=	**10.6**	**0.75**	**1.94**	**25**	Operational power matrix
WC-I4	Bretschneider	=	**12.0**	**1.75**	**2.19**	**58**	Operational power matrix
WC-I5	Bretschneider	=	**13.4**	**2.75**	**2.45**	**92**	Operational power matrix
WC-I6	Bretschneider	=	**16.2**	**2.75**	**2.96**	**92**	Operational power matrix
WC-I7	Bretschneider	=	**9.2**	**4.75**	**1.68**	**158**	Extreme operational. CFD comparison
WC-I8	Bretschneider	=	**16.2**	**5.25**	**2.96**	**175**	Extreme operational. CFD comparison
WC-I9	Bretschneider	=	**19.0**	**6.25**	**3.47**	**208**	Extreme operational
WC-I10	Bretschneider	=	**10.6**	**6.25**	**1.94**	**208**	50-year design contour
WC-I11	Bretschneider	=	**14.8**	**8.25**	**2.70**	**275**	50-year design contour
WC-I12	Bretschneider	=	**19.0**	**9.75**	**3.47**	**325**	50-year design contour
"Focused"							
WC-F1	Prescribed	=					Wave time-series provided in "WC-F1.txt" and "WC-F2.txt". CFD Comparison. Wave time series to be fine tuned so focii is at
WC-F2	Prescribed	=					

Device Tests

Free Decay/Static Tests	**PTO Settings Damping**	**PTO Settings Spring**	**Wave Reference**	**Mooring Configuration**	**Test Duration**	**System Configuration**	**Notes**
ST01	PTO Settings PTO Locked			Free Floating		Floating	Static tests - Inclining - Pitch
ST02				Free Floating			Static tests - Inclining - Roll
ST03				Free Floating			Heave Free Decay - 3x repeats in single
ST04				Free Floating			Pitch Free Decay - 3x repeats in single
ST05				Free Floating			Roll Free Decay - 3x repeats in single
ST06				Moored 0°			Mooring Offset Tests - Surge
Wave Tests	**PTO Settings Damping**		**Wave Reference**	**Mooring Configuration**	**Test Duration**	**System Configuration**	**Notes**
WT01	operational	operational	WC-R1	Moored 0°	20 consistent wave cycles	Floating	
WT02	"	"	WC-R2	Moored 0°			
WT03	"	"	WC-R3	Moored 0°			
WT04	"	"	WC-R4	Moored 0°			
WT05	"	"	WC-R5	Moored 0°			
WT06	"	"	WC-R6	Moored 0°			
WT07	"	"	WC-R7	Moored 0°			
WT08	"	"	WC-W1	Moored 0°	20 minutes	Floating	
WT09	"	"	WC-I1	Moored 0°	12 minutes	Floating	
WT10	"	"	WC-I2	Moored 0°	12 minutes		
WT11	"	"	WC-I3	Moored 0°	12 minutes		
WT12	"	"	WC-I4	Moored 0°	12 minutes		
WT13	"	"	WC-I5	Moored 0°	12 minutes		
WT14	"	"	WC-I6	Moored 0°	15 minutes		
WT15	maximum	maximum	WC-I6	Moored 0°	15 minutes	Floating	
WT16	"	"	WC-I7	Moored 0°	12 minutes		
WT17	"	"	WC-I8	Moored 0°	15 minutes		
WT18	"	"	WC-I9	Moored 0°	20 minutes		
WT19	"	"	WC-R8	Moored 0°	20 consistent wave cycles	Floating	
WT20	"	"	WC-R9	Moored 0°			
WT21*	"	"	WC-F1	Moored 0°	Focused wave time series	Floating	Each test repeated 2-3 times - results compared/averaged
WT22*	"	"	WC-F2	Moored 0°			
WT23	"	"	WC-I7	Submerged Mooring	12 minutes	Submerged	Compare loads for floating vs submerged
WT24	"	"	WC-I8	Submerged Mooring	15 minutes		
WT25	"	"	WC-I9	Submerged Mooring	20 minutes		
WT26	"	"	WC-I10	Submerged Mooring	12 minutes	Submerged	
WT27	"	"	WC-I11	Submerged Mooring	15 minutes		
WT28	"	"	WC-I12	Submerged Mooring	20 minutes		
WT29 - WT35	**If time permits after WT28, additional runs of WC-I1 to WC-I6 with different PTO settings.						

*Repeated tests appended with "_R1", "_R2", etc. For example, first repeat is "WT21_R1". At least 1 irregular condition repeat should be performed each day.