# Survivability Enhancement of a Multi-Mode Point Absorber

## Cooperative Research and Development Final Report

## CRADA Number: CRD-16-631

NREL Technical Contacts: Yi-Hsiang Yu and Jennifer van Rij

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Contract No. DE-AC36-08GO28308

**Technical Report**
NREL/TP-5000-77264
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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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**Cooperative Research and Development Final Report**

**Report Date: July 7, 2020**

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

**Parties to the Agreement:** Oscilla Power, Inc. (OPI)

**CRADA Number:** CRD-16-631

**CRADA Title:** Survivability Enhancement of a Multi-Mode Point Absorber

**Joint Work Statement Funding Table showing DOE commitment:**

| Estimated Costs | NREL Shared Resources a/k/a Government In-Kind |
|---|---|
| Year 1 | $75,000.00 |
| TOTALS | $75,000.00 |

**Abstract of CRADA Work**:

The overall goal of the project is to design and validate a survival mode for the Triton wave energy converter (WEC), as shown in Figure 1, which allows for a reduction in system peak structural stresses by 50% compared to those experienced when the heave-plate is deployed in the operational configuration, while simultaneously allowing for a reduction of capital cost by 15% due to the elimination of overdesign to account for uncertainty. In addition, the project will seek to carefully understand performance of the design without survival mode engaged under extreme wave conditions so as to better understand how system loads vary and hence determine conditions where survival mode.

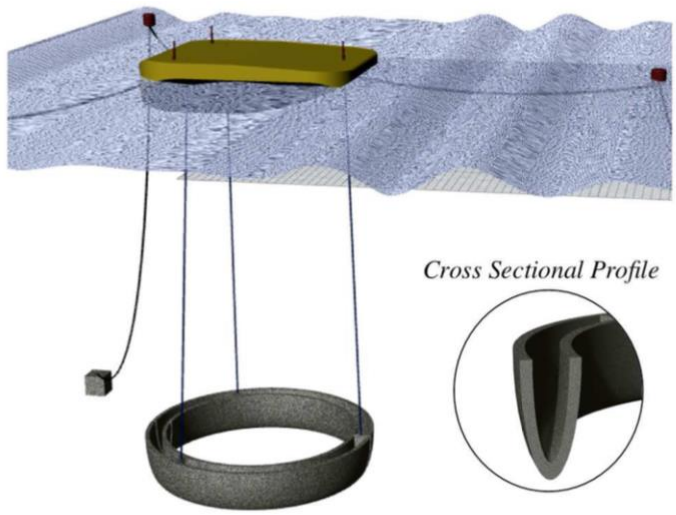


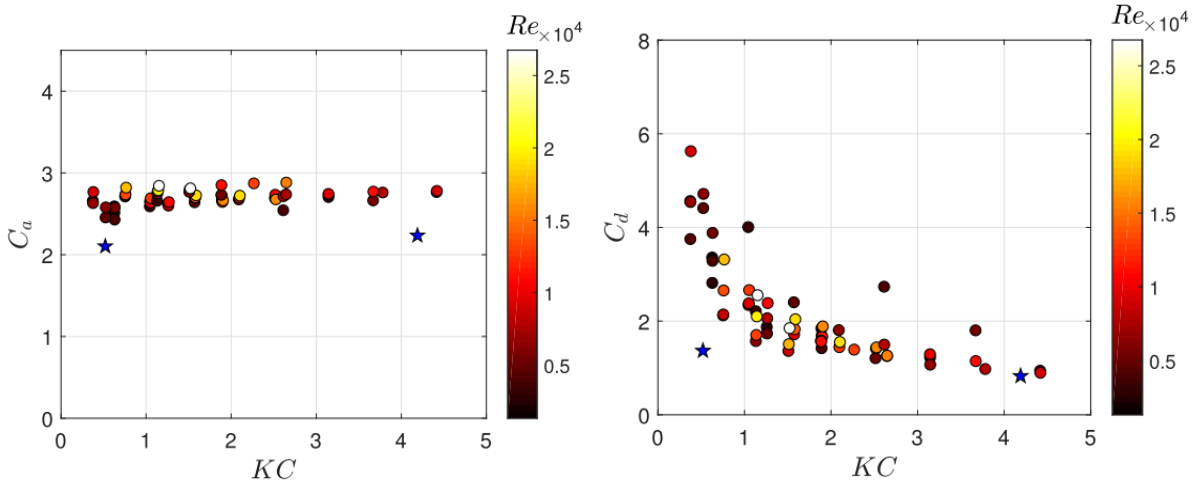

**Figure 1. TRITONTM WEC. Inset shows reaction body cross-sectional profile (elliptical ogive).**

**Summary of Research Results**:

All project tasks, work plans, modeling results and findings are documented within the original CRADA tasks following below.

**Phase I - Task 1: Mid-fidelity Model Hydrodynamic Coefficients**

The hydrodynamic forces acting on an oscillating multi-degree-of-freedom wave energy converter reaction body are characterized using scaled experiments and computational fluid dynamics (CFD) simulations. Curves indicating how the hydrodynamic coefficients vary with Keulegan-Carpenter number (KC) and Reynolds number (Re) at four different scales, ranging from 1:75 to 1:36, are developed for multiple degrees of freedom. Understanding scale dependence is identified as important, as although representative KC numbers can be generated, the dissimilitude between the laboratory and full-scale Reynolds numbers requires careful consideration when inferring full-scale coefficients from the experiments. To address and examine this, CFD is used to replicate a number of these model-scale tests and provide simulations at full-scale. These results provide an important validation of some scaling trends but also reveal interesting discrepancies at low KC. OPI with the National Renewable Energy Laboratory (NREL) have extracted directional hydrodynamic parameters from experimental and CFD measurements, resulting in relations that define the pitch and heave added mass and drag as a function of KC and Reynolds number. More details are described in [1].




(a) Added MoI coefficient (pitch)

(b) Rotational drag coefficient (pitch)

**Figure 2. Experimental measurements for 1:75, 1:60, 1:50 & 1:36 scale geometries in pitch. CFD data points at 1:50 scale**

### Phase I - Tasks 2 & 3: Establish Triton Design Load Cases

WEC systems must survive in a wide variety of conditions while minimizing structural costs, so as to deliver power at cost-competitive rates. Although engineering design and analysis tools used for other ocean systems, such as offshore structures and ships, can be applied, the unique nature and limited historical experience of WEC design necessitates assessment of the effectiveness of these methods for this specific application. A study to predict extreme loading in a two-body WEC using a combination of mid-fidelity and high-fidelity numerical modeling tools is presented. Here, the mid-fidelity approach is a time-domain model based on linearized potential flow hydrodynamics and the high-fidelity modeling tool is an unsteady Reynolds-averaged Navier–Stokes model. In both models, the dynamics of the WEC power take-off and mooring system have been included. For the high-fidelity model, two design wave approaches (an equivalent regular wave and a focused wave) are used to estimate the worst-case wave forcing within a realistic irregular sea state. These simplified design wave approaches aim to capture the extreme response of the WEC within a feasible amount of computational effort. When compared to the mid-fidelity model results in a long-duration irregular sea, the short-duration design waves simulated in CFD produce upper percentile load responses, hinting at the suitability of these two approaches.

OrcaFlex simulations were performed by OPI, and we used the time history estimate the wave and response spectra, from which the Frequency Response Functions (FRFs) for the tendon and mooring line responses were determined.

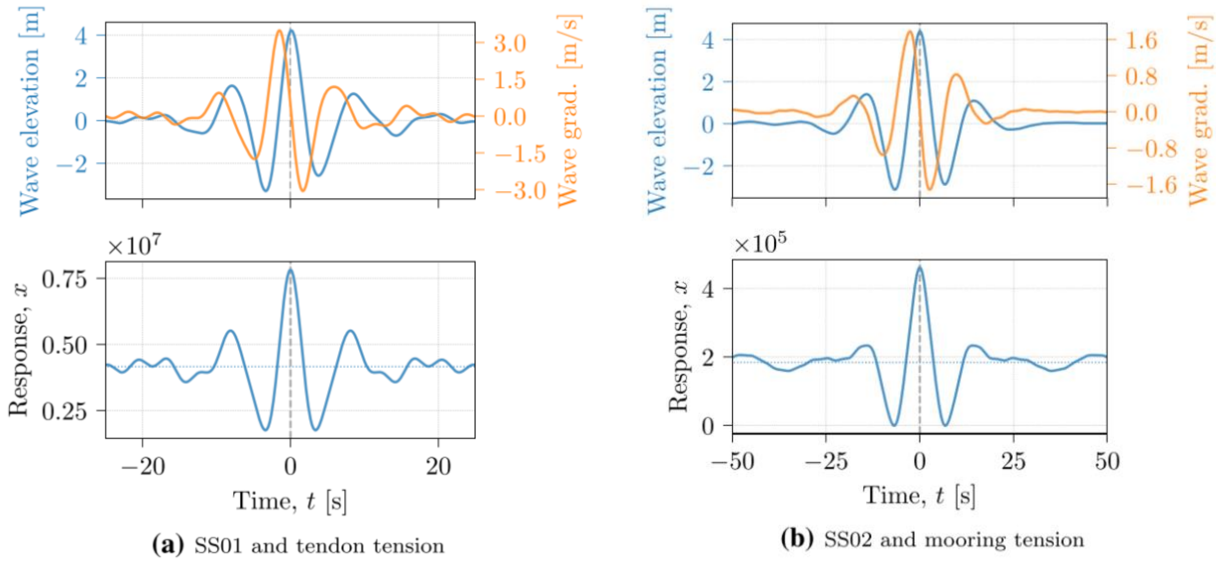



**Figure 3: Example of a focused wave and expected response for tendon tension**

## Phase II - Tasks 1~3: Set-up & Validate CFD Models of DLCs, Run CFD Models & Process Results

Sandia developed the CFD models in STAR-CCM+ of the Triton WEC with the support of NREL team. Figure 4 shows the boundary condition settings and the rendering of a selected case. To better investigate behavior in the tail region, we thus consider the complementary cumulative distribution functions (CCDF). The tendon tension responses are shown in Figure 5, and more details of the study are presented in [2].

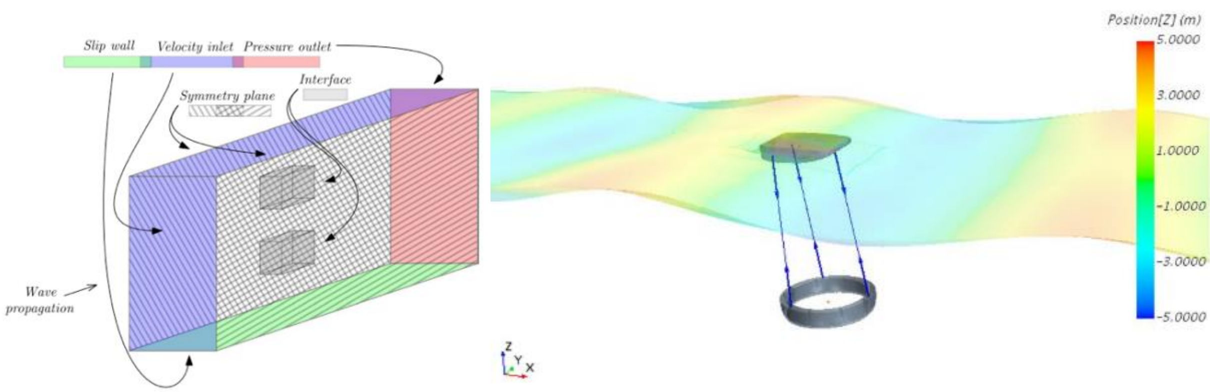



**Figure 4. Dimensions of computational domain for CFD simulation of Triton WEC Inlets (left) and rendering of StarCCM+ simulation (right)**

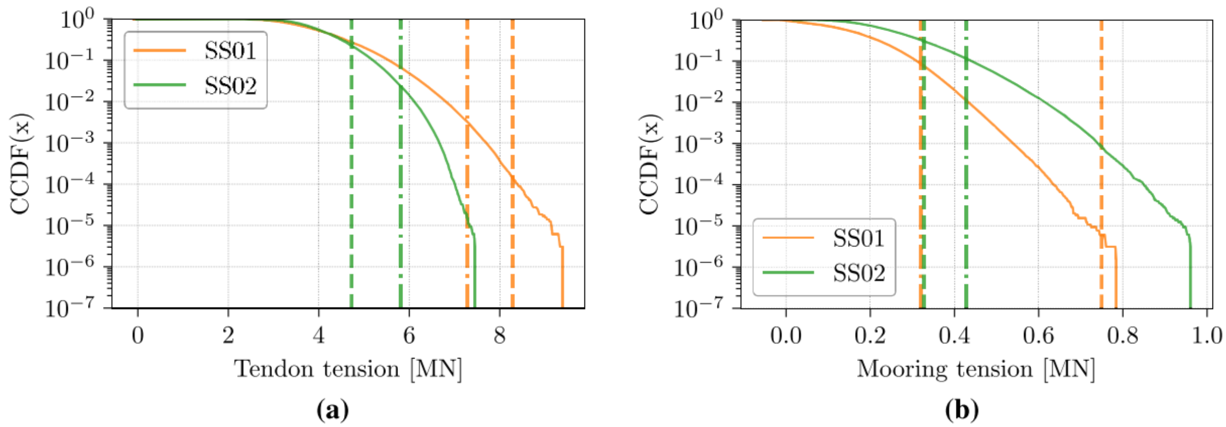



**Figure 5. Complementary cumulative distribution functions (CCDFs) along with the results from CFD simulations shown by vertical lines. Regular-wave results are shown by dashed lines (- - -); focused-wave results are shown by dash-dot lines (- · -)**

Finally, a comparison was presented between the design loads predicted by the mid- fidelity model, the CFD model and the physical model tests, and based on this comparison. Figure 6 shows a comparison the physical model and CFD data for two regular wave case. In general, the results suggest reasonable agreement between the physical model and CFD.

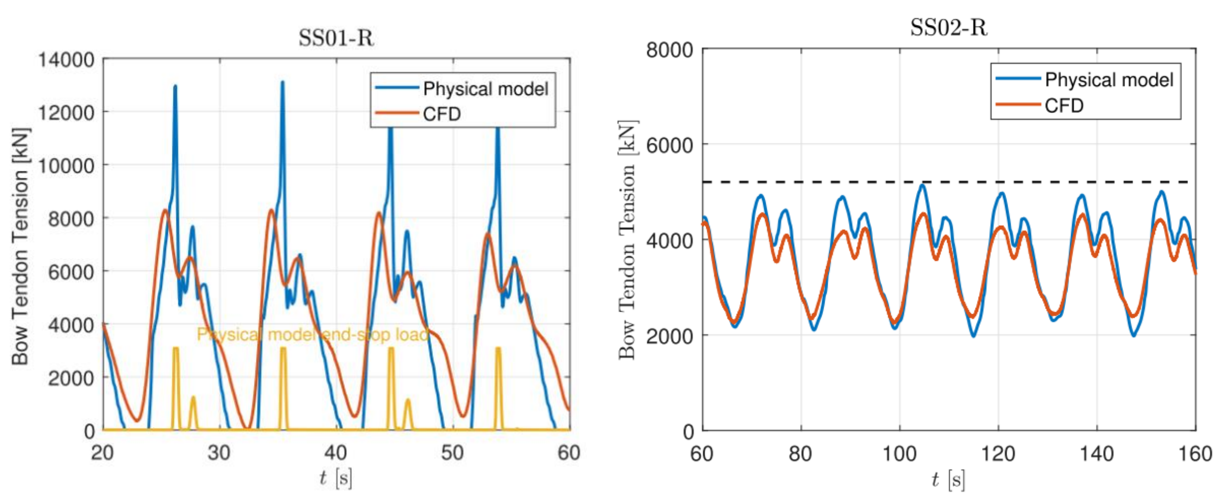



**Figure 6. Comparison between experiments and CFD for two regular wave cases**

Figure 6 summarizes the maximum bow tendon load produced by all experimental and numerical approaches. Percent differences for each method are compared to the equivalent long-duration irregular physical model test, which is taken here to be the benchmark. The varying levels of accuracy between the design loads produced by CFD and the long-duration irregular physical model tests could be attributed to two explanations: inaccuracies in the CFD calculation, or inability of the simplified design waves to reliably predict the maximum loads in the corresponding irregular sea state. The results from this study also indicate that the CFD model compares fairly well against the physical model tests in several cases, suggesting that the simplified wave approaches may have some shortcomings, where long-duration irregular wave tests are required. A complete comparison of numerical and experimental approaches was presented in [3].

**Phase III - Task 1: Prepare Final Report**

As agree by all three participants (i.e., NREL Sandia and OPI), to better report and disseminate the outcome of the project, all the technical results/accomplishments and findings that will benefit the WEC community are documented in the three conference and journal papers [1-3], listed in the References.

**Reference**


[1] Mundon, T. R., Rosenberg, B. J., & van Rij, J. (2017). Reaction Body Hydrodynamics for a Multi-DoF Point-Absorbing WEC. *12th European Wave and Tidal Energy Conference (EWTEC), Cork*, 1–10. Available for purchase at https://proceedings.ewtec.org/product/ewtec2017-cork-ireland/

[2] Coe, R. G., Rosenberg, B. J., Quon, E. W., Chartrand, C. C., Yu, Y.-H., van Rij, J., & Mundon, T. R. (2019). CFD design-load analysis of a two-body wave energy converter. *Journal of Ocean Engineering and Marine Energy*, *5*(2), 99–117.

[3] Rosenberg, B. J., Mundon, T. R., Coe, R. G., Quon, E. W., Chartrand, C. C., Yu, Y., & Rij, J. Van. (2019). Development of WEC design loads: A comparison of numerical and experimental approaches. *13th European Wave and Tidal Energy Conference*.


**Subject Inventions Listing:**

None

**ROI #:**

None

**Responsible Technical Contact at Alliance/NREL:**


Yi-Hsiang Yu, yi-hsiang.yu@nrel.gov
Jennifer van Rij, Jennifer.VanRij@nrel.gov
(for Al LiVecchi and Arielle Cardinal on the agreement)


**Name and Email Address of POC at Company:**


Brian J. Rosenberg, rosenberg@oscillapower.com
Tim Mundon, mundon@oscillapower.com


**DOE Program Office:**

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