Development of a Survival Configuration for the Triton Wave Energy Converter

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1. INTRODUCTION

This paper details the development of a survival strategy for the Oscilla Power Triton Wave Energy Converter. This work was completed as part of a DoE project to reduce the costs of wave energy. We investigated a number of different approaches to managing the extreme loads in the Triton system which are described herein. A primarily numerical approach was taken to evaluate the relative performance of these strategies against the baseline system, while CFD and small scale physical model testing are currently being pursued to validate the performance of the leading approach.

Characteristics of the baseline system are discussed that were leveraged to identify suitable strategies. Mid-fidelity numerical modeling was used to evaluate performance and a key interest of this work is the suitability of this numerical approach in the highly non-linear nature of extreme waves. In addition to a highly instrumented physical model, a number of different, high fidelity CFD approaches are used to determine extreme loads within the system.

2. APPROACH

Ocean waves demonstrate an extremely large peak to average power content which is especially evident if we consider the extreme conditions that may be experienced over the course of a commercial deployment. A commercial device cannot expect to be removed from the environment in the case of a storm and therefore must incorporate some mechanism of managing the infrequent peak loads that may be generated. At one extreme this mechanism can simply be a substantial mechanical over-design or locating the device in an area where the incident energy is reduced. In either of these approaches the cost of energy will be impacted by either increased system cost or reduced incident energy.

The ideal circumstance is to design the device to avoid the large extremes that occur, either through an inherent design choice, or through a mechanism that allows the device to reconfigure in the case of an impending storm. In either case, the hydrodynamic efficiency of the system must reduce as the wave height increases. A number of different survival mechanisms have been developed and these tend to be somewhat specific to the WEC in question.

Design Conditions

The selection of a return period for determination of extreme wave conditions can be an area of debate with regard to wave energy devices. It is often argued that the typical offshore oil and gas standards should not apply as, amongst other reasons, typical design lifetimes may be shorter and there will be no risk to human life [1]. For the purpose of this work, a 1:50 year return period was selected. An IFORM [2] contour method was used to identify a number of different Hs/Tp pairs with equal probability for a hypothetical deployment location off the coast of California (DoE Humbolt Bay reference location). Figure 1 shows the extreme contours at this location and Table 1 indicates the conditions chosen from the 1:50 year contour [3].

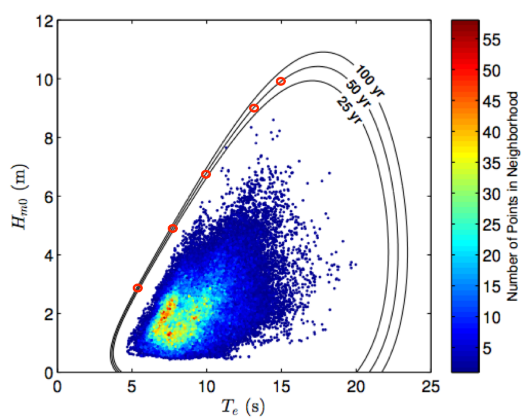

Figure 1: Extreme wave contours for CDIP128/NDBC 46212 (2004-2012). Test conditions indicated with red circles. Reproduced from [3].

Table 1: 1:50 year extreme events selected for evaluation.

Label	EC1	EC2	EC3	EC4	EC5
Te [s]	5.5	7.6	10.1	13.0	15.1
Hs [m]	2.9	4.9	6.8	8.7	9.6

3. BASELINE DESIGN

This work focusses on the OPI Triton WEC shown in Figure 2. This is a two-body multi-mode WEC system that has been studied in detail [4] and was evaluated as part of the DoE Wave Energy Prize competition. The baseline system has been developed to withstand the extreme event without a specific survival mechanism through a combination of tailored reaction ring hydrodynamics (see subsequent section), and additional line compliance. However, the introduction of a survival strategy has the advantage of reducing the loads on the system and allowing for reduced mass and stiffer connecting tendons, resulting in increased AEP and reduced CAPEX.

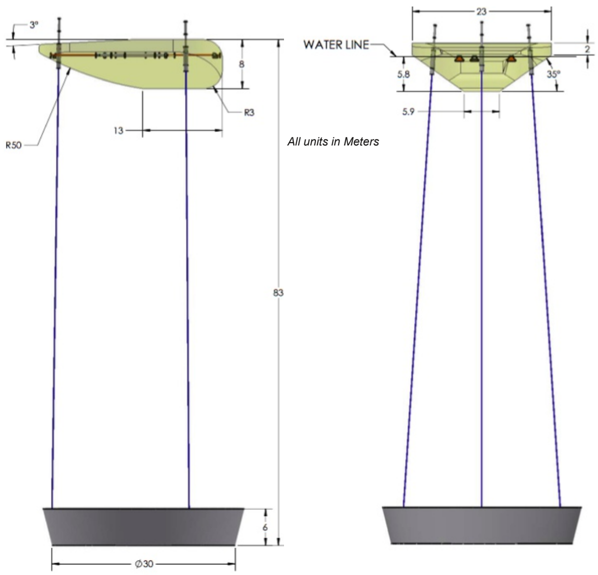

Figure 2: Triton WEC.

Reaction structure

The Triton WEC features a ring shaped reaction structure with a elliptical cross sectional profile that is designed to maximize the survival performance of the system in large waves. However, its unusual profile means that the hydrodynamic performance of this structure is not easy to predict or model. Extensive work has been completed to characterize the performance of this structure [5, 6] and identify how the added mass and drag will vary in different regimes. Figure 4 shows an example of how the drag and added mass varies with the vertical oscillation amplitude of the reaction structure (KC). The color of each circle identifies the particular value of R_e that was achieved in each test. The stars indicate results achieved with equivalent CFD analysis, more thorough analysis is provided in [5]. This work was used to inform the time-domain numerical models of the forces imparted by the reaction structure.

Figure 3: Simplified sketch of the reaction structure for the Triton WEC

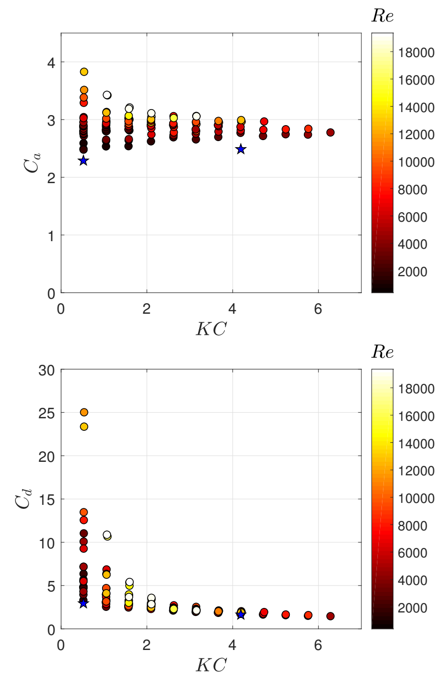

Figure 4: Variation in Drag (C_d) and Added Mass (C_a) with relative motion of the structure (KC).

4. SURVIVAL STRATEGIES

Additional Lines

In addition to the three operational tendons that connect to the PTO, six auxiliary tendons of moderate elasticity are used to connect the reaction ring to the surface float structure, as shown in Figure 5. These lines are tensioned with a simple mechanism only in the event of a storm, allowing nine lines to share the loads between the surface float and reaction ring. This will significantly reduce the load in the main tendons and distribute the reaction ring load evenly amongst all the lines. With this arrangement, it is appreciated that slack events on the tendons are likely to increase. Ordinarily, slack tendon events are to be avoided as they typically result in unpredictable snap loading. The consequence is that this unpredictability results in a structural design with substantial safety factors, driving the cost and risk up significantly. However, this unpredictability is inversely proportional to the number of lines supporting the mass. In this design, by using 9 lines, the aim is to increase the predictability and make snap loads of a much lower and more manageable magnitude. Further, we can distribute these loads across more lines and thus tendon end-connection loads and reaction ring bending moments also become more manageable.

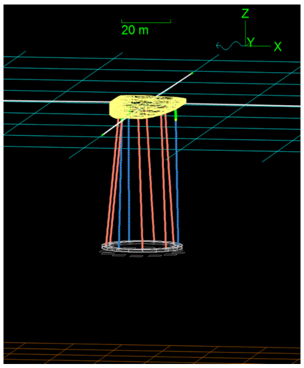

Figure 5: Orcaflex diagram showing the configuration with additional support lines

Increased Mooring Stiffness

For operational waves, Triton's three-point mooring system is designed to have large horizontal compliance, thus allowing for power capture from the relative surging motion between the surface float and the (less mobile) reaction ring. Analysis of the baseline system suggests that the dangerous tendon slack/snap events are introduced primarily during large surge excursions of the surface float, which occur during high, long period (and hence long wavelength) waves. By increasing the mooring stiffness significantly in extreme waves until the float surge motion is substantially reduced, we might be able to eliminate slack events in the tendons. This is shown in Figure 6

Submerged system

The third survival concept is to decrease the wave excitation forces on the surface float by sinking it below the surface. Moving below the surface will significantly reduce the dynamic loads on the float and hence the tendons and drivetrain. This strategy can be implemented with ballasting, giving the entire system a few 10's of tonnes of negative buoyancy and a rough position of 10m below the water surface. Oversized mooring floats are used to maintain the submerged depth. Figure 7 illustrates this strategy.

5. RESULTS

The Orcina Orcaflex software package was used to build numerical models of each of the survival strategies.

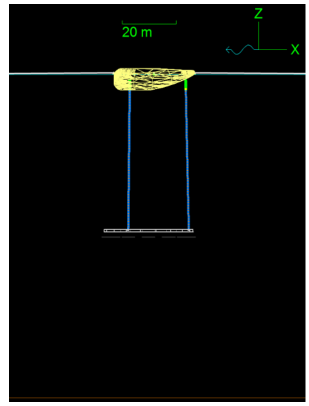

Figure 6: Orcaflex diagram showing the taut moored survival configuration

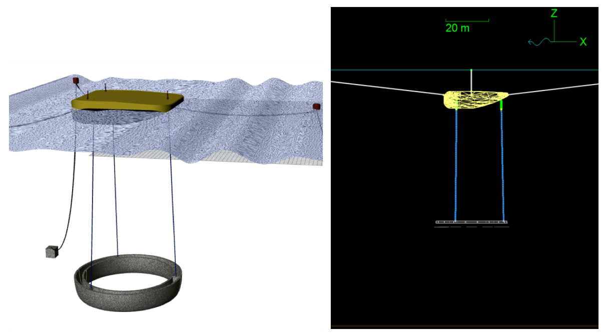

Figure 7: (Left) Operational configuration with three-point mooring. (Right) Orcaflex diagram showing the submerged configuration, supported by the mooring floats.

This is a time-domain mid-fidelity simulation package that primarily relies on linear assumptions, although it has the ability to include some non-linear components. NEMOH was used to generate hydrodynamic coefficients for the hull for both the surface and submerged cases. Physical model experimentation of the reaction ring was also used to determine coefficients. The baseline model was validated against the Wave Energy Prize 1:20 scale physical model tests, then modified for each of the different strategies.

Selection of comparative metrics

We identified four relevant metrics that allow a generalized comparison between the survival strategies with specific focus on system reliability and structural loads (note that for the moment, the simulations are currently only in 0 degree long crested waves, so the front tendon will be representative of the worst case):

1. Frequency of slack events: i.e. slack events/hour, using the front tendon as a proxy (which is typically most severely affected).

2. Representative maximum tendon load: the average of the 20 largest tension peaks in the front tendon (in a 1 hour simulation).

3. Maximum drivetrain travel: the peak-to-peak stroke of the front tendon.

4. Representative maximum mooring load: the average of the 20 largest tension peaks in the front mooring line.

Numerical analysis

An extract of the results is shown in Figure 8. This shows how the max tendon load, one of the selection metrics identified above, varies across the different strategies for different wave heights.

As expected, it was found that using auxiliary tendons encourages significantly more slack events (due to the reduced mean static load on each line). However, the additional lines result in lower peak loads and also allow management of the drivetrain stroke, thus preventing end-stop impacts. A less obvious result was seen for the increased mooring stiffness, and so three different stiffnesses were evaluated, low (L), medium (M) and high (H) which identified that while increasing the mooring stiffness does indeed reduce slack event frequency, it appears that an extremely stiff mooring (20x baseline) with impractical mooring loads may be required to completely eliminate them. Further, although slack events can be mitigated using this strategy, end-stop impacts appear more difficult to manage (as the mooring does not restrict heave motion of the float). The submerged strategy was evaluated for a 10m float submergence depth with 20Te of net negative buoyancy supported by the mooring floats. This configuration results in zero hard end-stop impacts and nearly zero slack events (limited events during EC5 only). Furthermore, the characteristic peak tendon load does not exceed 1.5x the mean load.

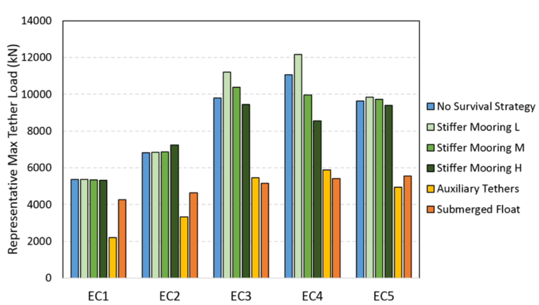

Figure 8: Tendon max load for each of the different strategies for each of the selected extreme wave states

6. DISCUSSION

Down-Selection

The submerged survival strategy clearly demonstrates the best load mitigation in the extreme cases. It can also be seen that submerging the float requires significantly less adaptive hardware than the other two strategies and has the potential to be the simplest and lowest cost option. Sealing the float from water ingress would be somewhat straightforward using bulkheads and common marine engineering techniques. The structural design of the system then becomes limited by the hydrostatic loads from the submergence depth selected, and therefore the maximum design loads now become defined by the threshold conditions for entering the survival strategy. The design challenge is then balancing the threshold conditions to maximize AEP with the maximum submergence depth.

Experimental Validation

Given that we are using a simplified mid fidelity modeling approach, we intend to compare and validate these results against a series of physical model tests. Both the baseline and submerged strategy will be replicated in a series of 1:30 physical model tests at Oregon State University in February 2018 and reported on here. The paper will discuss the experimental validation against the numerical results and explore the discrepancies. This work is expected to inform and explore the limits of validity of mid fidelity modeling to predict behavior in extreme waves. We intend to also add some recent CFD results as additional comparison points to this work.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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