ON THE SHORT-TERM UNCERTAINTY IN PERFORMANCE OF A POINT ABSORBER WAVE ENERGY CONVERTER

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INTRODUCTION

Of interest, in this study, is the quantification of uncertainty in the performance of a two-body wave point absorber (Reference Model 3 or RM3), which serves as a wave energy converter (WEC). We demonstrate how simulation tools may be used to establish short-term relationships between any performance parameter of the WEC device and wave height in individual sea states. We demonstrate this methodology for two sea states. Efficient structural reliability methods, validated using more expensive Monte Carlo sampling, allow the estimation of uncertainty in performance of the device. Such methods, when combined with metocean data quantifying the likelihood of different sea states, can be useful in long-term studies and in reliability-based design.

BACKGROUND

The Reference Model 3 (or RM3) WEC is free to move in all six degrees of freedom in response to ocean waves; however, power is captured only from the device's heave motion [1]. This device follows a relatively simple operating principle and is quite representative of some designs that the WEC industry is actively pursuing. The device is a simple two-body point absorber, consisting of a float and a reaction plate. The full-scale dimensions of the RM3 and its mass properties are shown in Figure 1.

Although the device will likely be deployed as part of an array or farm, we consider in this study the performance in irregular waves of an isolated single unit. Stochastic simulation of the waves and device performance are carried out using the open-source software, WEC-Sim [2]. In particular, we consider the PTO (Power Take-Off) extension of the device in two representative sea states. PTO extension is considered to be an important design parameter as it can affect sizing of various mechanisms. For this study, we consider a resistive control strategy on the PTO.

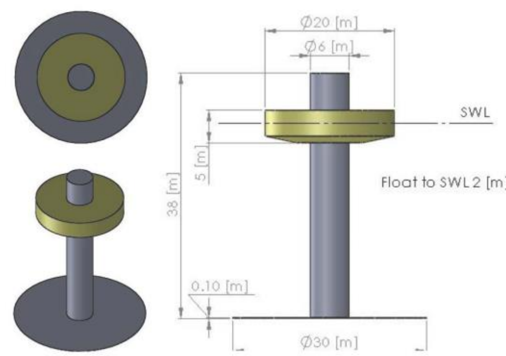


FIGURE 1. Schematic representation of the RM3 two-body point absorber [1].

NUMERICAL STUDIES

We consider two sea states. These are selected because they lie on the 100-year contour for the NDBC 46022 site [3]. Figure 2 shows time traces of 100-sec segments showing the sea surface elevation (wave) process as well as the contemporaneous PTO extension for both sea states.

When a regression of the maximum PTO extension during each wave in a 1-hour simulation is carried out against wave height, a relationship results that relates the two. This relationship is as follows:

$$d(h,\epsilon) = (ah^2 + bh + c) + \epsilon \qquad (1)$$

where a, b and c are parameters estimated based on the WEC-Sim simulations. The variable, ϵ, is included in order to represent the uncertainty in the prediction of the PTO extension, d, from each wave of height, h, in the simulations. The heights of individual waves, H, in each simulation for a sea state with specified significant wave height, H_s, are represented by a Rayleigh distribution as follows:

$$F_H(h) = 1 - \exp\left[-\frac{1}{2}\left(\frac{h}{\alpha}\right)^2\right] \qquad (2)$$

where α is chosen such that the mean of the largest one-third of all wave heights is H_s. Also, the variable, ϵ, is modeled as a normal random variable with zero mean and with standard deviation, σ_ε, found following regression of d vs. h. Table 1 summarizes the results from the regression as well as the relevant parameters for the distributions of the wave height and of ϵ.

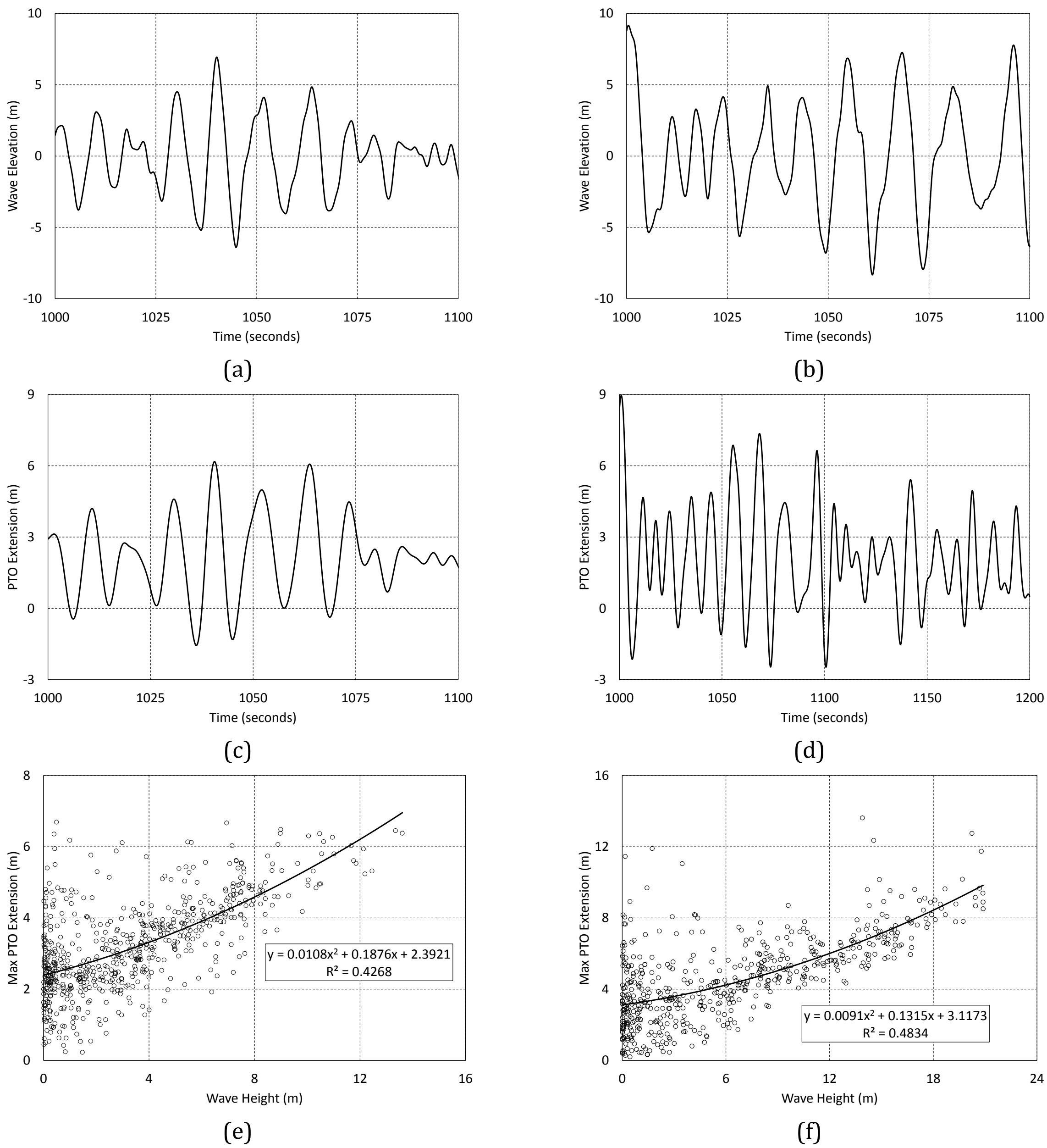


FIGURE 2. Representative 100-sec segments from 1-hr simulations of the wave elevation process and the RM3 PTO extension for two sea states and established statistical relationship between maximum PTO extension and wave height. Plots (a), (c), and (e) are for the sea state with H_s = 8.2 m, T_p = 11.0 s; plots (b), (d), and (f) are for H_s = 16.0 m, T_p = 13.3 s.

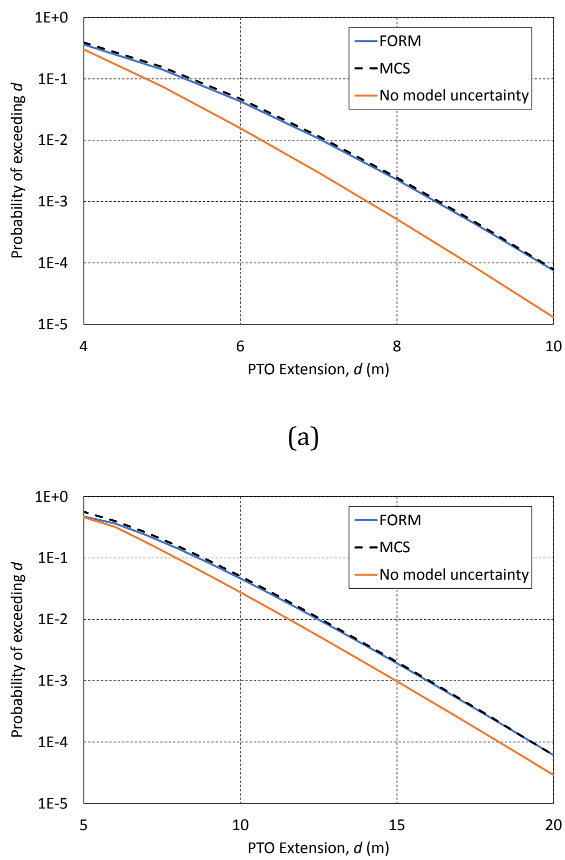
Table 1. Parameters describing wave height, *h*, PTO extension, *d*, and model uncertainty variable, ε.

H_s (m)		8.2	16.0
h (m)	α (m)	4.0955	7.9915
d (m)	a (1/m)	0.0108	0.0091
	b (-)	0.1876	0.1315
	c (m)	2.3921	3.1173
σ_ε (m)		0.9788	1.7051

On the basis of the established distributions of the various random variables that are needed to define the performance in terms of PTO extension for each sea state, a limit state function $g(\boldsymbol{X})$ is defined as follows:

$$g(\boldsymbol{X}) = d_{allowable} - d(h, \epsilon) \qquad (3).$$

Using first-order reliability methods (FORM) [4] and Monte Carlo simulation (MCS), it is possible to estimate the probability that the demand, $d(h, \epsilon)$, will exceed any specified levels of allowable PTO extension, $d_{allowable}$.



(b)

FIGURE 3. Probability of exceeding specified PTO extension levels computed using FORM and MCS for two states: (a) H_s = 8.2 m; (b) H_s =16.0 m.

On the basis of the simulations carried out and the various probability distributions estimated, Figs. 3(a) and 3(b) summarize the performance of the RM3 wave point absorber by quantifying the probability of exceeding various specified PTO extension levels for the two sea states analyzed.

Comparing Figs. 3(a) and 3(b), it is seen that, as expected, larger amounts of PTO extension are more likely in the more severe sea state. For instance, a PTO extension of about 16 m is exceeded with a 10^{-3} probability in a 1-hour long simulation for H_s =16.0 m versus an extension of about 8.5 m for H_s = 8.2 m. The figures also indicate that the two methods, MCS and FORM, yield results that are very similar. For the MCS computations, 1,000,000 simulations were carried out; this is very computationally expensive compared to FORM.

It is interesting to see, in Figs. 3(a) and 3(b) that when the model uncertainty in relating PTO extension to wave height in the sea state (see Figs. 2(e) and 2(f)) is ignored, the probability of any specified level of PTO extension in both sea states is reduced. This is an expected effect; it highlights the importance of collecting data or of running additional simulations to reduce model uncertainty. At the 10^{-3} exceedance probability level, the estimated PTO extensions reduce from 8.5 m to 7.5 m for the H_s = 8.2 m sea state and from 16.0 to 15.0 m for the H_s = 16.0 m sea state.

The methods demonstrated here for two sea states are easily extended to assess all sea states of interest in long-term reliability analysis of a WEC device. Metocean data need to be used to weight short-term probability distributions of the device response (as in Figs. 3(a) and 3(b)) to yield long-term probability distributions. The procedure for establishing the computational effort required to analyze each sea state is similar to that described for wind turbine load simulation in different wind speed bins [5]. While FORM was employed here to *analyze* two sea states, Inverse FORM (or IFORM) may also be employed and is useful in a *design* framework; this has been demonstrated for wind turbines [6, 7] and can readily be employed for WEC devices in a similar manner.

CONCLUSIONS

Based on stochastic simulation of the RM3 wave energy converted in two sea states, we have demonstrated a procedure for evaluating the uncertainty in its performance using the efficient First-Order Reliability Method (FORM) that is validated against Monte Carlo sampling. Such a procedure may be readily incorporated in the systematic evaluation of all sea states likely to be encountered where the device may be deployed. Then, metocean data can be combined with the short-term performance variability assessments of the kind demonstrated here in order to develop a probabilistic basis for design. The role of model uncertainty in predicting PTO extension levels in each sea state using WEC-Sim was also evaluated.

ACKNOWLEDGMENTS

This work was partially funded by the U.S. Department of Energy's Wind and Water Power Technologies Office. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Additional support from the University of Texas' Department of Civil, Architectural and Environmental Engineering Legacy Campaign is acknowledged.

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