ON THE SELECTION OF SEA STATES IN ASSESSING EXTREME LOADS ON A WAVE ENERGY CONVERTER

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INTRODUCTION

This study is concerned with the extreme response of a two-body wave point absorber (Reference Model 3 or RM3) [1]. This device, which serves as a wave energy converter (WEC), is a simple two-body point absorber consisting of a float and a reaction plate. Power generation results from heave motion induced by waves. We use the open-source simulation tool (Wave Energy Converter Simulator or WEC-Sim) to carry out simulations of the device. We are interested in site-specific design loads associated with a 50-year return period. Accordingly, we use the Inverse FORM approach in this study [2, 3]. The deployment site of interest for this device is near National Data Buoy Center Site 46022. We are most interested in discussing how the availability of metocean data from such sites may be used to define "environmental contours" that help to derive design loads. We show how, given the same metocean data, we can either estimate joint distributions or marginal distributions of the underlying variables together with different correlation measures. These two different approaches, both consistent with the data, lead to somewhat different environmental contours used for design.

Environmental Contour Method

Inverse FORM (I-FORM) is an efficient procedure employed when probabilistic design requires establishment of "characteristic" loads associated with specified return periods. An especially tractable version of this method, termed the environmental contour (EC) method, uncouples the "environment" from the system "response" and examines only certain combinations of the environmental variables that are, by some measure, rare or unlikely enough to be of concern at the return period levels of interest. The method is approximate in that it neglects uncertainty in the response given environmental conditions. Improvements in the accuracy are possible. At any rate, the EC method has been widely used in the design of offshore oil and gas platforms, of land-based and offshore wind turbines, etc. Its use in problems associated with the offshore/ocean environment relies on joint probabilistic information commonly of wave heights, wave periods, etc. This is also the case for WEC devices.

The preferred way to provide distribution information on two variables such as the significant wave height, H_s, and spectral peak period, T_p, is to have the joint distribution available for the two variables—this means, that one needs to have established the joint probability density function, $f_{H_s,T_p}(h,t)$, or the marginal density function, $f_{H_s}(h)$, and the conditional density function, $f_{T_p|H_s}(t|h)$. Often, as a site is being considered for the deployment of a device, sufficient information is not available to define the joint probability distribution. Uncertainty is especially large in predictions (from data) of $f_{H_s,T_p}(h,t)$ for the rarest H_s and T_p values; these are often the values that define the environmental contour of interest. With limited data, it is often easier to predict marginal distributions of both variables; simpler dependence statistics between the two variables such as the Pearson's correlation coefficient or Kendall's rank correlation coefficients can also be used [6], [7].

The EC method can be used with Rosenblatt transformations when full joint distributions are available; in the case where Pearson's correlation coefficients are available along with marginal distributions, a Nataf transformation can be used and if Kendall's rank coefficients are available, a copula-based transformation can be used. A comparison of the environmental contours is presented with the three approaches; subsequently, load simulations using tools such as WEC-Sim [4] may be employed to yield time-domain simulations of the response of the device for various sea states that lie on the respective contour depending on which approach is used to define the dependence structure among the random variables. Figure 1 shows a flow chart for how environmental contours may be constructed with all three approaches.

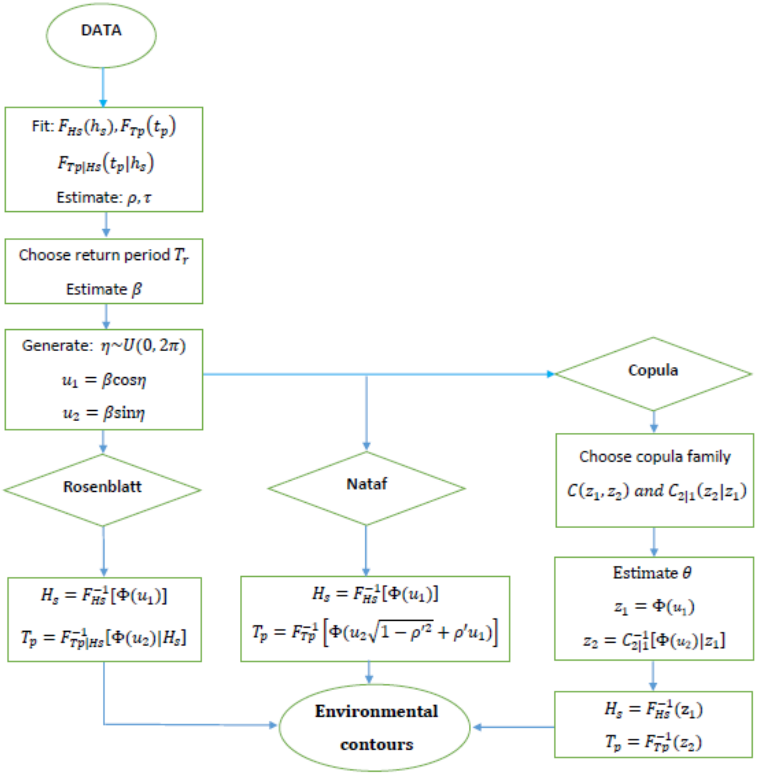

FIGURE 1. A FLOWCHART DESCRIBING PROCEDURES FOR CONSTRUCTING ENVIRONMENTAL CONTOURS USING ROSENBLATT, NATAF, AND COPULA-BASED TRANSFORMATIONS

DERIVED STATISTICS AND DISTRIBUTIONS

The data from the NDBC 46022 site are presented in Fig. 2 [5]. For the two variables of interest, H_s and T_p, various derived statistical parameters and distributions are summarized here. Both parametric and non-parametric distributions can be used to fit data. For the marginal distribution of H_s, a Weibull model is used with scale factor equal to 2.75 m and shape factor equal to 2.26. For T_p, a lognormal marginal distribution is fit to the data; the resulting parameters are 2.37 and 0.22, respectively, for the mean and standard deviation of $ln(T_p)$.

For the Rosenblatt transformation, along with the marginal distribution for H_s, a lognormal conditional distribution for T_p given H_s is fit to the data such that the mean and standard deviation of $ln(T_p)$ are now functions of H_s.

Non-parametric marginal distributions of H_s and T_p are considered next. For each H_s bin, the conditional distribution of $T_p|H_s$ is derived. Estimated Pearson's and Kendall's correlation coefficients are 0.446 and 0.270, respectively.

DERIVED ENVIRONMENTAL CONTOURS

Figure 3 shows 50-year return period contours based on (i) a Rosenblatt transformation that uses the joint distribution of H_s and T_p; (ii) a Nataf transformation that uses marginal distributions for H_s and T_p along with Pearson's correlation coefficient; and (iii) two different copula-based transformations that use the same marginal distributions but with Kendall's rank correlation coefficient. Both parametric and non-parametric models are used. Clearly, different sea states are identified on each of these contours that are all consistent with the same site data. As expected, distribution-free contours envelope all the data, as they should, compared to contours based on parametric models.

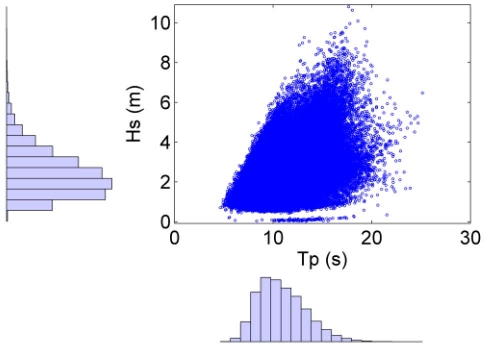

FIGURE 2. WAVE HEIGHT AND PERIOD DATA FOR THE NDBC 46022 SITE [5]

CONCLUSIONS

When site data are limited, it might not be possible to derive complete joint distribution on the metocean variables of interest in WEC device design for extreme loads. We show how the same data set produces quite different environmental contours when different dependence structure assumptions are made. We add that it is also possible to construct distribution-free non-parametric environmental contours which may have the advantage of not requiring fits to the data, although extrapolation may be needed in many situations where data are sparse.

The contours produced in this study are often used in the design load prediction process. Further work should consider more closely the impact that these differences in environmental contour definition may have on the design loads obtained via modeling.

ACKNOWLEDGEMENTS

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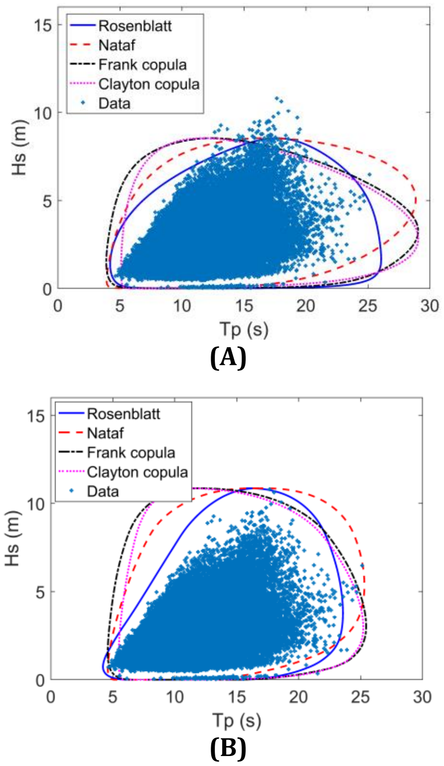

FIGURE 3. FIFTY-YEAR RETURN PERIOD ENVIRONMENTAL CONTOURS BASED ON ROSENBLATT, NATAF, AND TWO COPULA-BASED TRANSFORMATIONS: (A) PARAMETRIC METHOD; (B) NON-PARAMETRIC METHOD

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