ON THE IMPORTANCE OF CONSIDERING MULTIPLE SEASTATE REALIZATIONS WHEN ESTIMATING DESIGN LOADS IN MULTI-DIRECTIONAL SHALLOW-WATER WAVES

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INTRODUCTION

Practitioners tasked with designing new offshore structures or upgrading older structures located in shallow waters and exposed to energetic multi-directional waves generated by passing hurricanes or cyclones must first estimate the maximum wave heights and crest elevations at the site, and then estimate the corresponding extreme pressures and loads exerted on the structure. However, due to the complexity and nonlinearity of the processes involved, and a current deficit of knowledge concerning both near-breaking multi-directional shallow-water wave conditions and the effect of such waves on structures, these design tasks are quite challenging (Taylor *et al.*, 2020). In such situations designers often resort to scale model tests and/or computational fluid dynamics simulations to investigate both the wave conditions and the wave-structure interactions and develop pressure and load estimates for use in design (Cornett *et al.*, 2013). However, because neither of these approaches is exact, the resulting pressure and load estimates must be associated with a considerable degree of uncertainty which introduces considerable risk to the design process (Huang *et al.*, 2017).

OBJECTIVES AND METHODOLOGY

The objectives of this work are to close some of the knowledge gaps responsible for the aforementioned uncertainty and risk. This will be accomplished by first investigating and characterizing the natural variability of the maximum wave heights and crest elevations found in multiple 2-hour long realizations of several short-crested shallow-water near-breaking seastates. Following this, the variability in the distributions of peak pressures and peak local and global loads exerted on a gravity-based offshore structure will be explored. The analysis will focus on establishing extreme value distributions for each realization, quantifying their variability, and exploring how the variability is diminished when results from multiple seastate realizations and repeated tests are combined. The importance of considering multiple realizations of a design spectrum when estimating peak values for use in design will be investigated and highlighted.

SCALE MODEL EXPERIMENTS

Short-crested storm wave conditions were generated in a 50 m x 30 m directional wave basin and measured after first propagating across a broad section of shallow horizontal (level) bathymetry where the local water depth was ~13m at full scale (Fig. 1). Several different pseudo-random realizations of each multi-directional seastate were generated and measured. Multiple repetitions of several realizations were also generated and measured. Pressure and load data were measured in a set of 1/35 scale physical model experiments (Fig. 2) conducted to determine extreme wave pressures and loads on the sub-structure and super-structure of a gravity-based structure located in ~15 m water depth (Baker *et al.*, 2019). The structure is part of an offshore marine terminal used to load product from a mine onto bulk carriers. Pressures, loads and moments were measured in several locations for multiple realizations of each design seastate, and also for multiple repetitions of several wave trains.

Figure 1 - Overview of experiments in the 50 m x 30 m directional wave basin.

Figure 2 - Wave loads and pressures were measured on a 1/35 scale model of a gravity-based structure.

RESULTS AND DISCUSSION

The wave data measured in these experiments has been analyzed to identify H_{max}/H_{m0} ratios for design wave conditions at the site and characterize the considerable natural variability in maximum wave heights and crest elevations that occur within multiple realizations of short-crested shallow-water design wave conditions. Fig. 3 illustrates the repeatability and variability of wave statistics measured in three different 2-hour long realizations (Seed 1, 2 and 3) of a design seastate with

6.5 m significant wave height and 10 s peak period, where each test was repeated twice (Trial 1 and 2). In this figure, "H_1%" denotes the 1% exceedance wave height, "H_max" denotes the maximum down-crossing wave height and "eta_max" denotes the maximum crest elevation. This data illustrates that more extreme wave statistics, such as H_max and eta_max, are more variable than less extreme statistics, as expected; and that the variability across different realizations significantly exceeds the repeatability encountered when duplicating tests with the same realization.

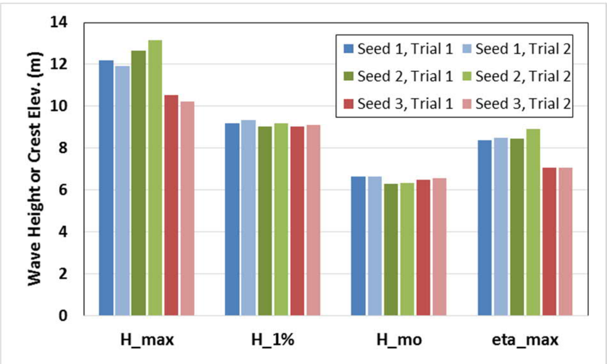

Figure 3 - Repeatability and variability of wave statistics.

The pressure, load and moment data has been analyzed to identify extreme value distributions for each realization, quantify the variability of extreme values, and investigate how the variability (or uncertainty) can be reduced by combining results from tests with multiple realizations and from repeated tests. Fig. 4 illustrates the repeatability and variability of global peak horizontal loads measured on a gravity-based caisson structure in the same six tests considered in Fig. 3. In this figure, "Top_5" denotes a statistic obtained by averaging the five largest independent force peaks in the 2-hour long record, while "Top_10" denotes the average of the 10 largest independent force maximums. Similarly, Fig. 5 summarizes peak overturning moments measured on the same structure in the same six tests. In these figures forces and moments have been presented in a normalized form to maintain client confidentiality. The peak forces (Fig. 4) tend to be considerably more variable and somewhat less repeatable than the peak wave statistics (Fig. 3). Moreover, the peak moments in Fig. 5, and particularly the maximum moments, are even more variable than the peak forces. Much of the added variability can be attributed to the complex non-linear relationships between wave height, crest elevation and global load and moment for this structure, where a small difference in wave height or crest elevation can lead to large differences in the resulting force and moment. The data in Fig. 4 and Fig. 5 also provide an example of how considering results for a single realization of a design sea state can lead to serious under- or over-prediction of extreme loads.

These results illustrate the degree of repeatability to be expected when conducting scale model tests to establish wave loads on complex structures in energetic shallow-water wave conditions. They also highlight the importance of considering results from multiple realizations of a design wave condition in order to obtain more reliable estimates of extreme loads for use in design.

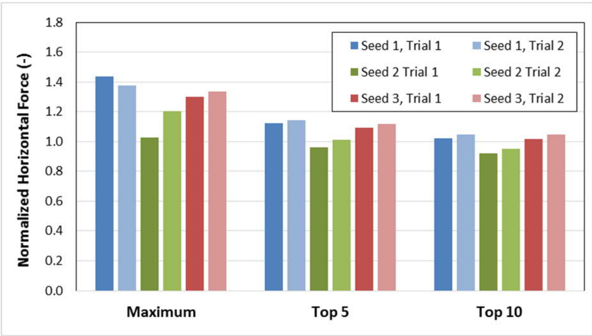

Figure 4 - Repeatability and variability of global horizontal load.

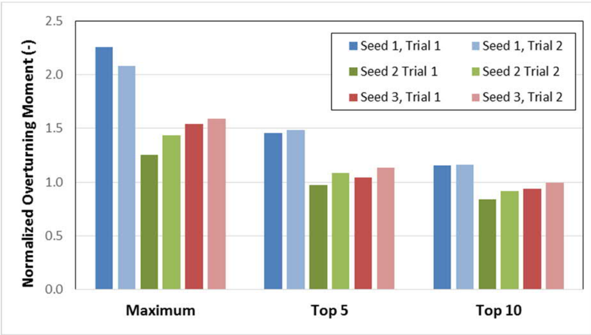

Figure 5 - Repeatability and variability of global overturning moment.

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