Measurement-Based Estimates of Extreme Wave Conditions for the Gulf of Mexico

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Abstract - **During 2004 and 2005, four severe hurricanes - Ivan, Dennis, Katrina, and Rita – occurred in the Gulf of Mexico. These hurricanes created winds and waves that were close to or exceeded the calculated 100 years return period conditions. As a result, new estimates of extreme metocean conditions are needed for many offshore engineering applications. Recently, such estimates have been derived by Berek et al. (2007) using hindcast (modeled) data. In some regions of the Gulf, these new (proposed) estimates suggest a substantial increase, relative to the American Petroleum Institute's current estimates of the 100-year design conditions, the maximum wave heights increasing by as much as 6.4 m and the wind speeds by 5 m/s. We have therefore reexamined the problem and obtained additional estimates in the Gulf of Mexico using other methods. To overcome difficulties associated with synthetic data which can generally subject to modeling related errors, we use buoy data. At several locations, nearly 32 years of data are available. (According to a rule of thumb, extrapolations to three or four times the data length are appropriate). In the context of statistical modeling of extremes, the basic problem is ill-posed. Various difficulties and the need for multiple or even non-standard tools have been noted in the literature. Instead of the traditional methodology of using one or more distribution (e.g. Gumbel, Weibull, Frechet, etc.), we used the Generalized Extreme Value distribution, which eliminates the need for identifying the most appropriate distribution. Also, to increase the utility and value of possibly short datasets, we use the *r*-largest order statistic (instead of the annual maximum traditionally used). This approach is intended to make more efficient use of the data and to mitigate concerns about small dataset length. Using these methods, estimates of the significant wave heights and wind-speeds are derived for the Gulf of Mexico and compared with the estimates of Berek et al. (2007). Besides traditional statistical aspects, factors such as long-term trends in wave height changes must also be considered. In the literature, such trends have been noted off both US coasts. We estimate an average increase of 3.5 cm/year in the annual maximum significant wave heights; Komar and Allan (2007) give an estimate of 1.7 cm/year for the location of a buoy in the mid-Atlantic. Based on these our study has made initial attempts to include an appropriate "trend parameter" in the n-year return period calculation.**

I. INTRODUCTION

The Gulf of Mexico region experienced hurricanes of unusual strength in the last few years. During Hurricane Ivan in 2004, "maximum" wave heights as high as 27.9m were recorded, and Wang et al. (2005) suggest that even larger waves may have occurred. During Hurricane Ivan, "significant" wave heights (SWH's) as large as 15.96 m were recorded by NDBC buoys. These wave heights are well in excess of the 100-year return period estimate (Panchang and Li 2006). Comparably large (and at some locations, larger) wave heights were recorded again during Hurricane Katrina in 2005, as noted later. The extreme storm surge, wind, and wave conditions, which have been documented and analyzed in part by Hovis (2005) and Panchang and Li (2006), wrought havoc on the extensive oil and gas facilities in the Gulf of Mexico. Approximately 190 production platforms were destroyed or severely damaged, disrupting the nation's energy supplies for months to the tune of hundreds of millions of dollars (Clayton 4/29/07, *"Gearing up for Gulf Hurricanes",* Houston Chronicle). Significant storms during this season were primarily Hurricanes Ivan (September 2004), Dennis (July 2005), Katrina (August 2005), and Rita (September 2005); see Fig. 1.

As a result, the American Petroleum Institute has started efforts to reexamine the specification of design conditions for offshore structures in this area. Berek et al. (2007) have used a combination of synthetic hindcast (modeled) wind and wave information (including the most recent period) and the Weibull distribution to estimate the n-year return period wind and wave conditions. In some regions of the Gulf, these new estimates suggest a substantial increase, relative to API's current estimates of the 100-year design conditions, the maximum wave heights increasing by as much as 6.4 m and the wind speeds by 5 m/s.

Because such estimates can be sensitive to the data as well as the statistical method used to generate them, we have tried to provide additional estimates by using other data and statistical tools. This helps the engineer make informed decisions and assess the uncertainty that surrounds the results.

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