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Metocean Loads in Malaysian Waters

Extreme Value Analysis and Joint Probability

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Abstract— **Most offshore structures in the South China Sea (SCS) region are designed according to the American Petroleum Institute (API) standards which are based on harsher sea conditions. As the SCS sea-state conditions are calmer compared to those of the Gulf of Mexico and the North Sea, the use of API standards will overdesign the structures. Wind speed, wave height and current speed are among the metocean conditions that are considered in the design of offshore structures. Current practices treat the three types of metocean conditions independently of one another. This paper will employ extreme value analysis (EVA) and joint probability (JP) method to analyze measured metocean data and to determine the associated wind speed and current speed given the 100-year extreme wave height. The results show that the design loads can be reduced by 30% for design of offshore structures in the SCS region.**

Keywords— **Metocean, Extreme Values, Joint Probability, Mean Return Period.**

I. Introduction

The Malaysian oil-and-gas (O&G) industry has expanded since its early days of the 1900's. According to the Halliburton report [1], there are over 200 platforms installed through the SCS region, covering 30% of the 615,100 square kilometers of acreage available for oil-and-gas exploration. Most offshore platforms are installed according to the API standards which were developed based on harsher and rougher sea state conditions, such as those in the Gulf of Mexico and the North Sea [2][3]. As metocean conditions in the SCS region are generally calmer, the use of the API standards in structural design for the SCS region will overdesign the structures. Such design will result in heavier and larger structures, as well as incurring higher materials and fabrication costs. In Malaysia, most of the installed offshore structures have exceeded 20 years, and 51% of them have exceeded their designed 25-year life span [4], confirming that most of the structures were designed too conservatively.

To optimize the design of offshore structures for the SCS region, particularly for offshore Peninsular Malaysia, Sabah and Sarawak, the sea state parameters employed in the design should reflect those of actual SCS conditions.

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Current practices employ the 100-year wind speed, wave height and current speed in structural design. However, the probability that the 100-year wind, wave and current conditions occur simultaneously is infinitesimal. Therefore, the authors of this paper will employ the Gumbel method and joint probability methods to obtain the associated wind speed and wave height (and their corresponding return periods) given the 100-year extreme wave height. To prevent offshore structures from being subjected to extreme loads, the design crest elevation should be above the extreme water level, which is usually composed of tides and storm surges but could also include tsunamis, El Nino effects, and other climatological and geological effects. The extreme wave height is determined by the annual maxima or through the joint distribution.

In this paper, measured metocean data are analyzed through joint probability. Given the 100-year MRI extreme wave height, the associated wind speed and current speed, as well as their respective associated MRI, can be determined. These associated values provide optimal design parameters that the oil-and-gas industry can adopt for structural design in the SCS region.

II. Methodology

A. *Measured Data and Statistical Analysis*

Metocean data containing wind speed, wave height and current speed were analyzed jointly – the first involved joint density analysis of wave height and wind speed while the second involved the same analysis of wave height and current speed. Data were measured and recorded from a total of six platforms covering three distinct regions. Platforms A and B are located offshore Peninsular Malaysia; platforms C and D are located offshore Sabah; and platforms E and F are located offshore Sarawak. All data were compiled and statistically analyzed using the SPSS PASW Statistics and Easyfit software.

Figure 1 shows the histogram of wave height recorded at Platform A. The probability distribution function (PDF) of the wave height can be obtained from the histogram. By plotting the histograms and the PDF for the other platforms, it is observed that the distribution fits that of a lognormal distribution. Figure 2 shows a plot of the cumulative distribution function (CDF) of wave height recorded at Platform A.

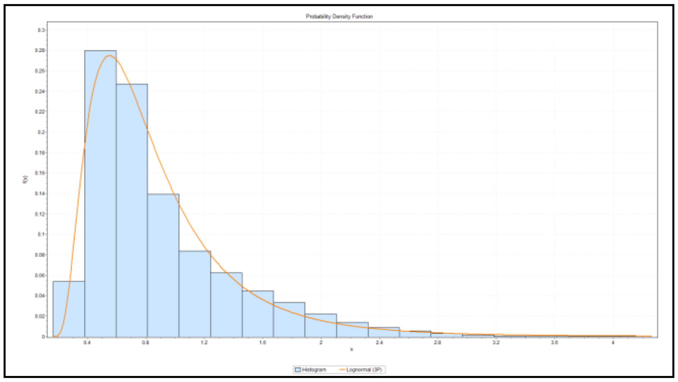


Figure 1: Histogram of wave height (Platform A)

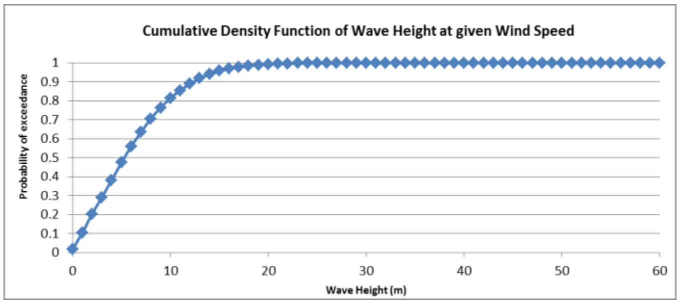
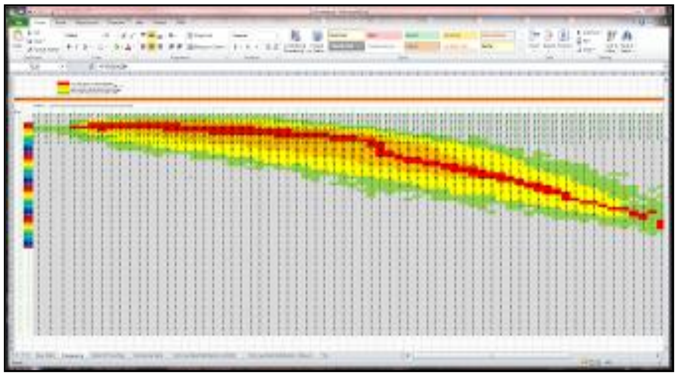


Figure 2 : Cumulative density function of wave height at given wind speed (Platform A)

Table 1 illustrates how frequent a particular wave height and wind speed will occur together at the same time for Platform A. The horizontal axis indicates the wind speed and the vertical axis indicates the wave height. A parametric study can then be conducted and a data trend is obtained by highlighting the highest occurrences (shown in red).

TABLE I : JOINT DENSITY TABLE OF WIND SPEED AND WAVE HEIGHT (PLATFORM A)



B. *Extreme Value Analysis*

Extreme value analysis (EVA) is a branch of statistics dealing with the extreme deviations from the median of probability distributions. It seeks to assess, from a given ordered sample of a given random variable, the probability of events that are more extreme than any of those observed prior to that. In this paper, the Gumbel method is employed for EVA.

In probability theory and statistics, the Gumbel method is used to model the distribution of the maximum (or the minimum) of a number of samples of various distributions. Such a distribution might be used to represent the distribution of the maximum wave height, wind speed or current speed in a particular year if there was a list of maximum values for the past years.

Table II shows a list of wind speed values determined using the modified Gumbel method given a specified return period while Figure 3 is a graphical representation of Table II. The horizontal axis represents the return period while the vertical axis represents the wind speed. The extreme values are obtained using the following mathematical expression:

$$z = -\ln(-\ln(F)), \qquad 0 \leq F \leq 1 \tag{1}$$

Where z is the predicted value of the forecasted return period and F is the probability of exceedance for the return period chosen. From equation (1) and Figure 3, the extreme values for any return period can be quantified.

TABLE II : EXTREME VALUE ANALYSIS (PLATFORM A)

Return Period, R	Intercept ,u	Slope, 1/a	(-ln(-ln(1-(1/R)))	1-(1/R)	Vr (m)
12	1.930155	0.837296	2.441716	0.916667	3.974595
24	1.930155	0.837296	3.156849	0.958333	4.573373
50	1.930155	0.837296	3.901939	0.98	5.197233
120	1.930155	0.837296	4.783311	0.991667	5.935202
300	1.930155	0.837296	5.702113	0.996667	6.704513
600	1.930155	0.837296	6.396096	0.998333	7.285581
1200	1.930155	0.837296	7.08966	0.999167	7.8663
2400	1.930155	0.837296	7.783016	0.999583	8.446844
5000	1.930155	0.837296	8.517093	0.9998	9.061484
10000	1.930155	0.837296	9.21029	0.9999	9.641896
20000	1.930155	0.837296	9.903463	0.99995	10.22229
50000	1.930155	0.837296	10.81977	0.99998	10.98951
100000	1.930155	0.837296	11.51292	0.99999	11.56988

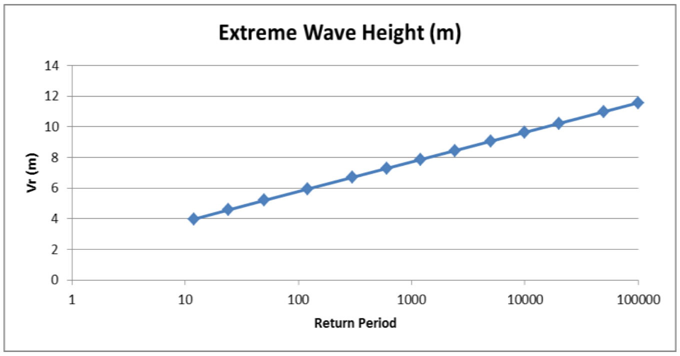


Figure 3: Extreme Wave Height (Platform A)

C. *Joint Densities*

Joint densities involve analyzing probabilistic and statistical characteristics of two or more sets of data that occur simultaneously. It basically answers the question on quantifying the probability that event X will occur given that event Y occurs as well. In this paper, the joint densities for wave height and wind speed, and those for wave height and current speed, will be outlined.

Table III shows the joint probability distribution for wave height and wind speed recorded at Platform A. The vertical axis represents the wave height range and the horizontal axis represents the wind speed range. By knowing the total number of observations, each joint occurrence can be represented in terms of probability. By summing the probabilities in each row or each column, the summation of all those probabilities should yield unity, as illustrated in the bottom-right cell of Table III.

To find the associated value, the EVA from section B will provide the extreme wave height as the first metocean loads of the joint density. The associated wind speed/current speed or the second variables will be based of the 0.99 of cumulative joint probability. This will results the value of 0.99 of the second variable and lead to a joint probability up to 99% from the whole joint data sets. The results will be discussed in the 'resuts and discussions'.

TABLE III : JOINT DISTRIBUTION (PLATFORM A)

WH\WS	0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-11.9	12.0-12.9	Total
0-0.5	0.0044	0.0153	0.0177	0.0164	0.0166	0.0156	0.0118	0.0085	0.0067	0.0038	0.0022	0.0012	0.0007	0.12198
0.6-1	0.0080	0.0376	0.0407	0.0407	0.0461	0.0495	0.0474	0.0401	0.0383	0.0298	0.0258	0.0208	0.0163	0.47624
1.1-1.5	0.0033	0.0192	0.0181	0.0134	0.0137	0.0149	0.0158	0.0151	0.0150	0.0130	0.0118	0.0097	0.0088	0.21006
1.6-2	0.0007	0.0086	0.0098	0.0069	0.0061	0.0061	0.0061	0.0060	0.0070	0.0067	0.0062	0.0055	0.0042	0.10005
2.1-2.5	0.0006	0.0048	0.0093	0.0061	0.0045	0.0034	0.0029	0.0026	0.0030	0.0028	0.0028	0.0024	0.0018	0.05521
2.6-3	0.0003	0.0009	0.0033	0.0035	0.0023	0.0018	0.0014	0.0011	0.0011	0.0010	0.0010	0.0010	0.0011	0.02449
3.1-3.5	0.0000	0.0001	0.0005	0.0006	0.0008	0.0007	0.0006	0.0005	0.0005	0.0004	0.0004	0.0005	0.0004	0.00817
3.6-4	0.0000	0.0000	0.0000	0.0002	0.0003	0.0003	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00269
4.1-4.5	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00092
4.6-5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00015
5.1-5.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00001
5.6-6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
6.1-6.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
6.6-7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
7.1-7.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
7.6-8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
8.1-8.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
8.6-9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
9.1-9.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
9.6-10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
10.1-10.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000
	0.0173	0.0866	0.0993	0.0879	0.0906	0.0924	0.0862	0.0741	0.0717	0.0578	0.0503	0.0412	0.0335	1

III. Results & Discussions

Table IV lists the associated values of wind speed and current speed given the 100-year extreme wave height. The table provides the results for all the six platforms covering offshore Peninsular Malaysia, Sabah and Sarawak regions obtained using the methods as outlined in Section II.

The results obtained through EVA and joint densities were found to be up to 50% lower than the metocean design values used in current practice. Given the 100-year wave extreme wave height, it was found that associated wind speed and current speed correspond to a 10-year return period. This indicates that the current practice, which employs the 100-year wind, wave and current design values, leads to overdesign of the offshore structures.

TABLE IV : EVA AND JP SUMMARY RESULTS

		100 Years MRI of Wave				
		Wave (m)	Associated Wind, m/s (3 sec gust)	MRI for Wind (years)	Associated Wave Current (cm/s)	MRI for Wave Current (years)
Offshore Peninsular Malaysia	Platform A	5.7	18.4	10	68	10
	Platform B	5.7	19.9	10	69	10
Offshore Sarawak	Platform C	3.9	16.8	10	57	10
	Platform D	5.8	18.4	10	79	10
Offshore Sabah	Platform E	4.9	19.9	10	66	10
	Platform F	5.6	18.4	10	71	10

IV. Conclusion

Offshore structures in the SCS region are designed too conservatively because the current design practice employs the 100-year wind, wave and current. This paper has shown that given the 100-year extreme wave height, the associated wind speed and current speed correspond to a 10-year return period. The results obtained through EVA and joint densities can be recommended to be used for optimal design of offshore structures in the SCS region.

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