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EXTREME VALUE ANALYSIS AND JOINT DENSITY OF METOCEAN LOADS FOR MALAYSIAN WATER

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Abstract: Environmental load is the main key to designing the coastal structure which consist of wind speed, wave height and wave current. These environmental loads strongly affect all kinds of maritime activities especially the platform stability, and their worst effect is typically caused by the maximum wave height. In order to avoid the platform subjected by extreme loadings, the design crest elevation should be above the extreme flood level, which is usually composed of tides and storm surges along with tsunami, el Niño, and other climate and geological effects. The extreme wave height may be determined with the annual maxima or joint density distribution. Platforms are usually designed based on the parameter of 100-year return period. The 100-year return period is for the wind speed design, wave height design and also for the current design. The data is collected either by in-situ measurement or by Hindcast analysis which has been practiced by the operation for better research and findings. For this research, the Gumbel distribution is used to forecast the 100-year event, while the correlation of joint density and environmental loads is achieved by Weibull distribution. These methods are applied in order to provide the correlation of wind and wave as well as wave and current. In addition, the benchmark can be set up for the operational region of the operation. The interim guidelines will be useful to expect the joint densities in this region and it will benefit the operation on optimization the current design cost and time completion with lighter platform design. Based on the study conducted, it is proposed that for a wave load mean return interval (MRI) is 100 years while for wind load design and the current load design is 10 years for 6 platforms which are the study parameter.

Keywords: *Joint Densities; Wave Height; Wind Speed; Wave Current; Return Period; and Extreme Values*

1.0 Introduction

Wind speed, wave height and wave current are the dominants factor in designing offshore structures and have been traditionally considered as a combination of environmental loads during the design phase. In one of the article by (Nerzic, R., 2006), the climate of offshore West Africa suggests that wind, wave and current are generated by different directions and uncorrelated sources and therefore may have different directions and intensities. This means that a 100-year current is not likely to be observed at the same time as the 100-year wave and wind as well and vice versa. Again, according to him, the design periods are varied between 50 and 100 years, however they are not being considered for their joint effects, but more so as a combination or additional factors. However, there is an article regarding the joint density effect adoption to their own local water region. The West African water have adopted the joint distribution where the results is based on the 100-year condition for a given element is associated to 1 or 10 years of value (Colwell, S., and Basil B., 2006).

Sea waves are caused by wind blowing for a sufficiently long time, the state of the sea is related to wind parameters and the possibility of correlating wind and wave loading conditions on structure exist. However, according to Joan C. Liu 2010, estimating extreme sea conditions requires an understanding of oceanographic science and coastal engineering. By determining the local oceanographic environment and employing coastal engineering knowledge, the process of predicting extreme sea value conditions can be determined. Thus as such, a separate joint density study has to be conducted for local application in South China Sea waters for operation in this region.

To study the data, B., A., and Rober D, suggest that Weibull distribution is the best method. It have been utilized in order to get a better analysis and to use the data with full benefit. The primary advantage of Weibull analysis is the ability to provide reasonably accurate exceedance analysis and forecasting. This will give a better view on analysing the raw data. Furthermore, Agarwal, P. and Manuel, L. have also included the extreme value method whereby the prediction of extreme loads associated with a target return period required statistical extrapolation from available loads data. This will forecast the extreme loads from the data given of any targeted return period. The extreme value distribution is the limiting distribution for the minimum or the maximum of a very large collection of random observation from the same obituary distribution (Filiben, James J. and Guthrie, William ., 2000)

This research summarized the results of the joint densities study as to assess the joint effects of different environmental loads and its associated return periods for 6 different platforms located throughout Peninsular Malaysia, Sabah and Sarawak. The analysis uses joint probabilities to assess the effects of 50 years wave mean return intervals on the associated wind and current return periods. This methodology sets itself apart from existing forecasting methods that utilize combined effects of various environmental loadings which may result in overdesign of structures. This study is expected to provide the valuable insight into the optimization of current practices which will ultimately result in major structural cost savings for the operations. The objective of this research is to obtain joint densities characteristics of the measured metocean data related to wind, wave and current in Malaysian water using Weibull distribution and probability density function. This method helps to provide the correlation of wind, wave and current. In addition, the benchmark can be set up for the operational region of the operation. The interim guidelines will be useful to expect the joint densities in this area and it will benefit operation on optimization of current design cost and time completion with lighter platforms design. In completion, forecasting the return period design of correlated wind, wave and current based on measured data will be performed.

2.0 Data Descreption and Analayis

Data were analyzed for their correlation separately. The first set of data is for wave height over wind speed correlation.

Table 1: Table of probability for 0.99 probability correlation

Wave Height	Wind Speed																	
	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	62-62.9	63-63.9	64-64.9	65-65.9	69-69.9	
0-0.5	0.00439	0.0153	0.01766	0.01643	0.01661	0.01559	0.01176	0.00848	0.00668	0.00385	0.00222	0.00122	0	0	0	0	0	0.12197698
0.6-1	0.01237	0.0529	0.05832	0.05716	0.06271	0.06505	0.05913	0.0486	0.04503	0.03361	0.02798	0.022	0	0	0	0	0	0.598221108
1.1-1.5	0.01568	0.07212	0.07645	0.07059	0.07641	0.07999	0.07497	0.06369	0.05998	0.04665	0.0398	0.03173	0	0	0	0	0	0.808281516
1.6-2	0.01642	0.08076	0.08624	0.07746	0.08255	0.08605	0.08103	0.06974	0.06696	0.05333	0.04603	0.03725	0	0	0	0	0	0.908332595
2.1-2.5	0.01702	0.08558	0.09557	0.08352	0.08709	0.0895	0.08393	0.07231	0.06995	0.05615	0.04882	0.03962	0	0	0	0	0	0.963544107
2.6-3	0.01727	0.08649	0.09886	0.08698	0.08934	0.09127	0.08533	0.07337	0.07109	0.05719	0.0498	0.04065	0	0	0	0	0	0.988036591
3.1-3.5	0.01727	0.08656	0.09933	0.08756	0.09013	0.09195	0.08594	0.0739	0.07154	0.05763	0.05017	0.04112	0	0	0	0	0	0.996209195
3.6-4	0.01727	0.08656	0.09934	0.0878	0.09046	0.09225	0.08618	0.07404	0.07166	0.05772	0.05028	0.04119	0	0	0	0	0	0.99890244
4.1-4.5	0.01727	0.08656	0.09934	0.0879	0.09058	0.09237	0.08623	0.07406	0.07167	0.05775	0.0503	0.04122	0	0	0	0	0	0.999822702
4.6-5	0.01727	0.08656	0.09934	0.08793	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999974672
5.1-5.5	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999987336
5.6-6	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999991557
6.1-6.5	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999991557
6.6-7	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999991557
7.1-7.5	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999995779
7.6-8	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999995779
8.1-8.5	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	0.999995779
8.6-9	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	1
9.1-9.5	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	1
9.6-10	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	1
10.1-10.5	0.01727	0.08656	0.09934	0.08794	0.09061	0.09238	0.08623	0.07406	0.07167	0.05775	0.0503	0.04123	0	0	0	0	0	1

While the second set analyzed data is for wave height over wave current. All of the data is based on 3 different regions of 6 different platforms; Platform A, Platform B, Platform C, Platform D, Platform E and Platform F. The data consist of wind speed (knots), wave height (m) and current (cm/s). The data is first filtered for wave height and wind speed which is prepared for the first correlation and will be resuming with wave height and wave current for the second correlation. All the data will be compiled and corrected through the SPSS PASW and Easyfit software. This is to ensure that there is no error in the data collection that consists of 5 consecutive years of raw data. The data will be then used for the joint density and forecasting analysis. There are two steps needed in order to find the correlation and forecast of the mean return interval (MRI). The first step is by using the Weibull distribution (probability theory). For this step, the total of 250,000 data will be filtered and calculated through the probability of exceedance (Table 1). This data is then further elaborated with the cumulative density function which will give a better view on the data correlation.

Figure 1 is a typical plot frequency of wind speed over wave height at platform A while Figure 2 is a typical plot of cumulative density function of wind speed over wave height at platform A. The data trend for wave height over wave current is an identical trend with the wave height over wind speed correlation.

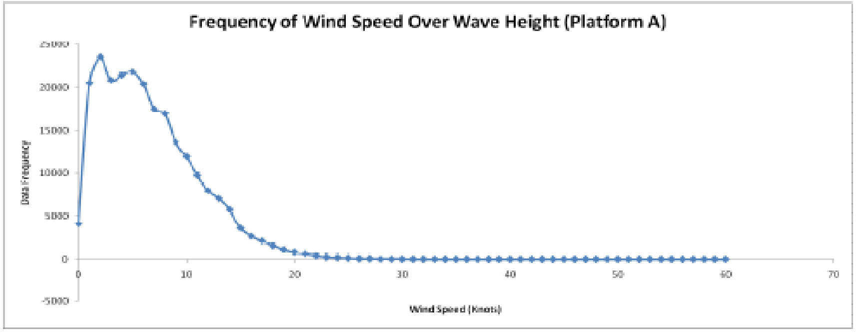

Figure 1 : Frequency of wind speed over wave height

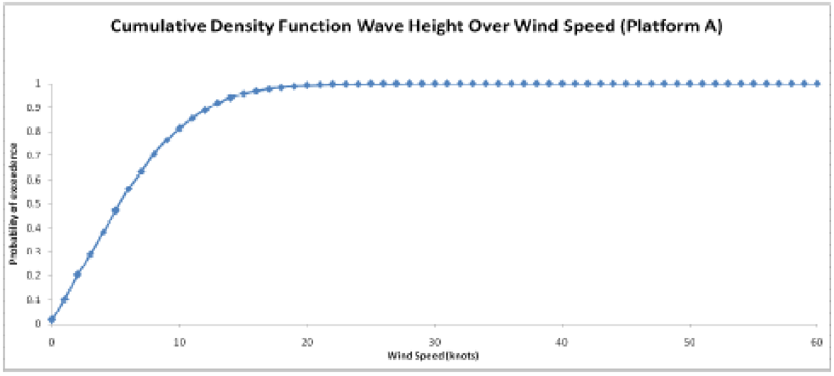

Figure 2 : Cumulative density function of wave height over wind speed

Next, all the data is utilized into the Gumbel method for the forecasting which is based on extreme value. Gumbel method will sort the extreme value monthly from the lowest to the highest value with a set of rank. A graph is plotted based on the ranked probability to the wind speed or wave height value. The graph will provide the value of R square, intercept and slope. This will further help the calculation of the predicted mean return interval and its predicted extreme value. This will be presented through the logarithmic scale graph of monthly return period to predicted max wind speed or wave height.

3.0 Results and Discussions

The methodology and results in this paper will demonstrate the wave height over wind speed design. This is sufficient to show the entire process since the same processes were applied for the wave height over wave current correlations.

3.1 The Correlation of Wind Speed and Wave Height

Table 1 shows the joint density by using the probability density function that provides the correlation between the wind speed and the wave height. The highlight shows the correlation for the 0.99 probability of exceedance. The horizontal value is the wind speed while the vertical value is the wave height. For example, the forecasting value of 50 years wind speed will give the result of 64.6 knots (refer Table 1), based on 0.99 probability of exceedance. The table will then display the correlated value of the wave height of 4m (max horizontal value) based on the 64.6 knots wind speed (vertical value). All the steps taken in order to find the correlation of wind speed over wave height is also applied for the correlation of wave height over wave current.

3.2 Forecasting using the Gumbel Distribution

Table 2 is the summary of the Gumbel method result for the predictive wind speed based on given return period while Table 3 shows the predictive value of wave height. From the Gumbel method which is based on ranking probability, the slope and the intercept of the forecasting graph (Figure 3) can be obtained. Also provided will be the wind speed, Vr values and its' associated return period. For example, a 50 year (600 months) return period for wind speed will give the forecasted wind speed, Vr at 62.24 knots. This can also help to identify the other return period such as 10 years, 20 years or 100 years.

Table 2: Table of forecasting wind speed return period (Gumbel distribution)

Return Period, R	Intercept ,u	Slope, 1/a	(-ln(-ln(1-(1/R))))	1-(1/R)	Vr Knots)
12	29.12	5.18	2.44	0.92	41.77
24	29.12	5.18	3.16	0.96	45.47
50	29.12	5.18	3.90	0.98	49.33
120	29.12	5.18	4.78	0.99	53.89
300	29.12	5.18	5.70	1.00	58.65
600	29.12	5.18	6.40	1.00	62.24
1200	29.12	5.18	7.09	1.00	65.84
2400	29.12	5.18	7.78	1.00	69.43
5000	29.12	5.18	8.52	1.00	73.23
10000	29.12	5.18	9.21	1.00	76.82
20000	29.12	5.18	9.90	1.00	80.41
50000	29.12	5.18	10.82	1.00	85.15
100000	29.12	5.18	11.51	1.00	88.74

Table 3: Table of forecasting wave height return period (Gumbel distribution)

Return Period, R	Intercept ,u	Slope, 1/a	(-ln(-ln(1-(1/R))))	1-(1/R)	Vr (m)
12	1.71	0.44	2.44	0.92	2.78
24	1.71	0.44	3.16	0.96	3.09
50	1.71	0.44	3.90	0.98	3.42
120	1.71	0.44	4.78	0.99	3.81
300	1.71	0.44	5.70	1.00	4.21
600	1.71	0.44	6.40	1.00	4.52
1200	1.71	0.44	7.09	1.00	4.82
2400	1.71	0.44	7.78	1.00	5.13
5000	1.71	0.44	8.52	1.00	5.45
10000	1.71	0.44	9.21	1.00	5.76
20000	1.71	0.44	9.90	1.00	6.06
50000	1.71	0.44	10.82	1.00	6.46
100000	1.71	0.44	11.51	1.00	6.77

Figure 3 is an excerpt of Platform A to show the forecasted return period of the wind speed. The X axis shows the month of the return period in logarithmic terms and the Y axis shows the forecast wind speed value. The result can be based on the return period for the predicted wind speed, or the wind speed for the predicted return period.

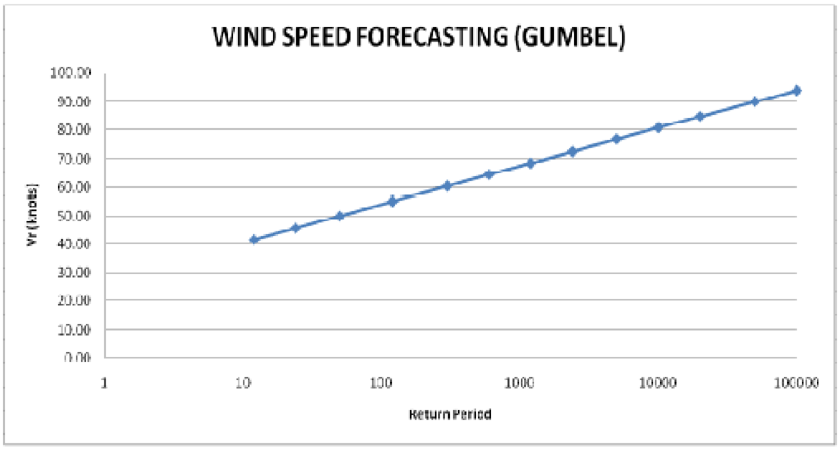

Figure 3 : Wind speed forecasting on logarithmic scale graph

3.3 *Correlation of wind, wave and current and 100-year return period*

Table 4 shows the standards that commonly be used as the benchmark. The standards has been used for the Malaysian water and always be the reference for any research regarding the metocean data.

Table 4: Technical standards references

PTS	Wave (m)	Wind (m/s) 3 sec gust	Current (cm/s)
PMO	5.77	33	167
SKO	5.1	42	180
SBO I	5.7	50	230
SBO II	5.6	40	130

From this benchmark standards, then comes a research for the extreme value analysis and the joint density associates number. Table 5 and 6 show the summary of correlation values between wind and wave and for all 6 platforms of concerned. Table 5 and table 6 shows the different results due to its data source. This paper have gone through the measured data source. The measured data has the limitation of 5 years of data. Due to that, this paper has advanced its research into the hindcast data due to it data access of 50 years. Due to that, the 50 years of data has been adjusted based on the 'Mayeetae Z., 2012' study that has included the correlation factor between the hindcast and the measured data. Table 5 shows the result associated wind and current return periods based on 100 year wind of MRI. The result shown below were based on the 5 years of measured data compared to the Table 6 which were based on the 5 years of hindcast data. Table 6 shows the forecasted 100-year wave height value and its associated wave current for all 6 platforms as well.

Table 5: extreme value analysis and the associated joint density (measured)

	Wave (m)	Associated Wind (m/s)	MRI for Wind (years)	Associated Wave Current (cm/s)	MRI for Wave Current (years)
Platform A	7.5	17.7	10	68	10
Platform B	8.5	19.1	10	69	10
Platform C	5.3	18.4	10	57	10
Platform D	6.3	19.1	10	79	10
Platform E	5.1	19.9	10	66	10
Platform F	4.7	21.3	10	71	10

Table 6 : Extreme value analysis and the associated joint density (hindcast)

	Wave (m)	Associated Wind (m/s)	MRI for Wind (years)	Associated Wave Current (cm/s)	MRI for Wave Current (years)
Platform A	6.6	19.9	10	68	10
Platform B	7.9	19.9	10	69	10
Platform C	4.0	17.6	10	57	10
Platform D	5.2	19.9	10	79	10
Platform E	3.7	19.9	10	66	10
Platform F	5.3	20.6	10	71	10

Table 7 shows the full summary of the final result based on 100 year MRI of wave which concluded the return period and the associated value of the wind speed and the wave height. Table 7 were based on 50 years adjusted data of hindcast which is the most precise result that this paper could produce. The first column is the 100-year wave extreme value analysis. The second and third column is the associated joint density value based on the 100-year wave extremes and the return period, while the 4th column is the associated current speed and its return period.

Table 7 : Extreme value analysis and the joint density (50 years data of hindcast)

	100-Year Wave (m)	Associated Wind 3sec. Gust (m/s)	MRI for Wind (years)	Associated Wave Current (cm/s)	MRI for Wave Current (years)
Platform A	5.7	18.4	10	68	10
Platform B	5.7	19.9	10	69	10
Platform C	3.9	16.8	10	57	10
Platform D	5.8	18.4	10	79	10
Platform E	4.9	19.9	10	66	10
Platform F	5.6	18.4	10	71	10

3.4 Percentage Differences Between 50 and 100 Years for Wind and Wave

Table 8 shows the percentage differences, we can concluded that there is a marginal increase in design parameters between 50 and 100 year MRI and therefore suggested that 100 years wave MRI and 10 years associated wind MRI is sufficient for design purposes.

Table 8: Percentage differences between 100 and 50 years MRI

% Difference more rec. 100 years compared to rec. 50 yrs MRI		
	Wind	Wave
Platform A	+6.2%	0.0%
Platform B	+5.8%	0.0%
Platform C	+5.0%	0.0%
Platform D	+5.9%	0.0%
Platform E	+6.4%	0.0%
Platform F	+5.8%	0.0%

3.5 Comparative study with the PTS

Based on the comparison below, it is observed that while there is marginal increase of PTS values in terms of wave height extremes, the difference of the associated wind speeds are very large with almost 151.26% increase in the Platform E compared to our joint density analysis results. This indicates a possibility that PTS values for wind speeds may have been overestimated and that the joint density analysis has provided a method to optimize these results.

Table 9 : Results Differences Against PTS

	100 Years Wave			Associated Wind		
	MRI	PTS	Differences, %	MRI	PTS	Differences, %
Platform E	4.9	5.7	16.33	19.9	50	151.26
Platform F	5.6	5.6	0.00	18.4	40	117.39

In order to support these recommended associated wind speed values, a background study is made based on the regional wind speeds for Sabah and Sarawak regions.

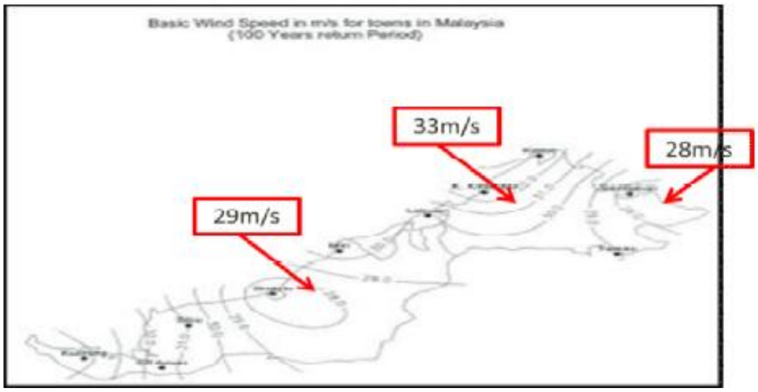

Figure 4: Wind speed value of the Sarawak and Sabah region

The above figure indicates that the average wind speed values of the Sarawak and Sabah region vary around 30m/s and thus as such, it closely follows the values of the 50 year wind MRI based on joint density analysis. The PTS values of 40m/s and 50m/s for Platform E and F can be rated as to have been overestimated compared to actual measure values. There is a concern about the effects of typhoons that pass through the region. The following figure shows the history of category 5 typhoons that have passed through the region from 1995 to present day.

Figure 5 : Megi (2010), 64 m/s

Figure 6 : Songda (2011), 52 m/s

Figure 7: Sepat (2007), 57 m/s

Figure 8 : Angela (1995), 60 m/s

Looking into regional extreme values (typhoon incidents), although the values surpassed the design values, the typhoons have never breached Malaysian waters due to the combination buffering effect by Philippines as well as the coreolis effect of typhoons during their travel path.

There have however been cases whereby typhoons on a smaller scale have breached into Sabah waters such as Tropical Storm Greg. While it has crossed over into Sabah waters, it only presence at a sustained 1-min wind speed of 21m/s which is far lower than ordinary wind speed values as prescribed by MMS.

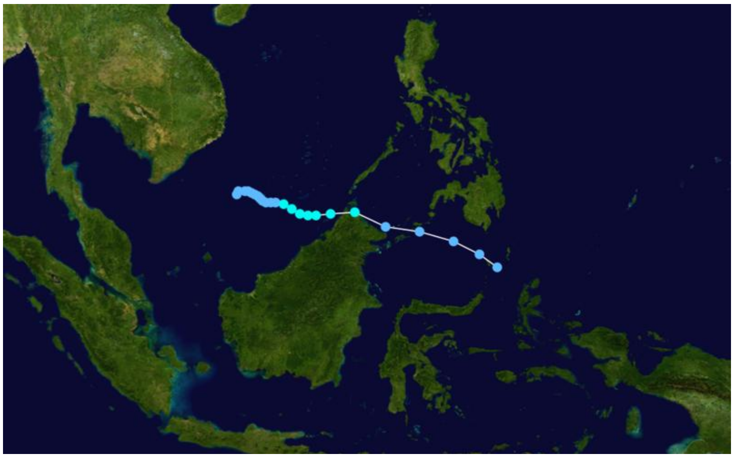
Figure 9: Path of tropical storm Greg in 1996

4.0 Conclusion

In conclusion, this research has indicated that joint density analysis has provided a key contribution in optimizing current practices and design values. The correlation has clearly demonstrated the relation of the wind speed and the wave height in producing results that vary significantly in combination of environmental loads (traditional practice). The current data analyses are based on 5 years of past data. The forecast can be more accurate if a longer period of data can be provided.

Based on the forecast of associated wind and current MRI based on 50 year wave MRI and vice versa, it is recommended to refer the following parameters.

Table 10: Design MRI for Wind and Wave and its' Associated

Design MRI	Associated MRI
Wave : 100 Years	Wind : 10 years
	Current : 10 Years

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