International Journal of Civil & Structural Engineering – IJCSE
Volume 1 : Issue 1 *[ISSN 2372 – 3971]*
Publication Date : 09 January 2014

Analyses and Validation of Measured Metocean Data in Time and Frequency Domains for Malaysian Basins and Operations

Duong Vannak
Civil Engineering Department
UNIVERSITI TEKNOLOGI PETRONAS
Perak, Malaysia
duongvannak@gmail.com

Mohd Shahir Liew
Civil Engineering Department
UNIVERSITI TEKNOLOGI PETRONAS
Perak, Malaysia
shahir_liew@petronas.com.my

Abstract—**In this research, the data of wave height and wind speed are collected from metocean data of the three existing oil fields in South China Sea – Terengganu, Sarawak and Sabah regions by getting their extreme values and significant data for analysis. The data consists of actual data which were recorded from year 1999 until 2008. From observation, the offshore structures are particularly at risk with any unacceptable motions initiated by wind and waves, which can lead to impact and capsize events, whereas the worst impact comes from the extreme wave height. To prevent the offshore structure from any damage, there is a need to study their descriptive statistics and spectra envelope of wind speed and wave height, and to ascertain the frequency content of each spectrum for offshore structures in the South China Sea shallow waters from actual time series. The results indicate that the data process is non-stationary process; it is transferred to stationary process by first difference method for developing the normalized power spectral density envelope. For descriptive statistics analysis, it illustrates that both wind speed and wave height have significant influence to the offshore structure during northeast monsoon with the high mean wind speed of 13.5195 knots (σ = 6.3566 knots) and the high mean wave height of 2.3597 m (σ = 0.8690 m). For spectral density analysis, it shows that there is no clearly dominant peak and the peaks seem to fluctuate at random. Each wind speed spectrum and wave height spectrum has its own individual identifiable pattern. The wind speed spectrum tends to grow gradually at lower frequency range and increasing significantly, double at the higher frequency range with the mean peak frequency range of 0.4104Hz - 0.4721Hz, while the wave height tends to grow dramatically at low frequency range, and fluctuate and decrease slightly at the high frequency range with the mean peak frequency range of 0.2911Hz - 0.3425Hz.**

Keywords— Metocean, Offshore Engineering, Time Series, Autocorrelation, Noise, Descriptive Statistics, Spectral Analysis, Environmental load, Wind, Wave, Normalized Spectra, Envelope.

I. Introduction

At present, there are more than 10,000 offshore production structures worldwide and more than 250 fixed platforms in South China Sea – Terengganu, Sarawak and Sabah regions. The numbers will keep increasing as the world energy demand increases. The platform design life is 25 years; the majority of the structures are going to exceed design life. With increasing energy demand, the companies are eager to find other frontier areas to provide new source of hydrocarbon. Therefore to determine the sites for exploratory drilling, regional sea state condition surveys are undertaken to ensure that the operations will be conducted without disruption from any extreme event and the design of offshore platform will be scrutinized on its deign efficiency and economics due to escalating material cost.

In deep water areas, the offshore structures are often exposed to critical states due to severe meteorological conditions such as wave, wind and current. In fact, a lot of damage has been reported on offshore drilling platforms, which is due to periodic wave forces. The periodicity of load has two phases on structural damage, one is the dynamic resonance of the structure and the other is the fatigue failure of the material [1]. In general, the overall design of the offshore structure depends on the environmental loads, with the most critical ones being wind speed and wave height, which are applied to the structure in various directions. These environmental loads data information can be obtained from a hindcast database which provides significant wave heights, wave directions and spectral information, current amplitude and direction, and wind speed and direction over a long time period. Hindcast data is a far more comprehensive data set than any measured time series [2]. If there is insufficient or inappropriate measured data for the location, it is standard practice to use hindcast data to derive metocean design criteria [3].

II. Metocean

Metocean could monitor the responses of selected offshore structures in real-time and full scale, which could provide essential information and knowledge for the design of offshore installation, for example to assess workability conditions. It could also produce customized domains to get high resolution prediction of the ocean and coastal conditions, and also can be configured to whatever scale required – for instance resolving the wave energy gradients behind an island, throughout an oil field or along a shipping channel and into a harbour entrance [4]. Good high-quality metocean data helps to reduce construction costs with accurate and non-conservative design conditions and also to avoid high costs during installation and operation with accurate operational conditions. It is necessary to support offshore operational planning for the optimal design of offshore installations and to ensure offshore safety and environmental protection as there is no wave spectral model which may be applicable to all storm situations in all parts of the world. The environmental study of the area where the installation may be exposed is essential and is required for all stages of offshore oil and gas exploration and production [5]. However, at some locations and for specific types of operations, other parameters may be important such as air and sea temperatures, visibility and ice conditions [6]. The response or resistance of offshore structural facilities to environmental loads is usually dependent on the load application and it is critical to the reliability of offshore structures for the loads and responses induced by extreme storms. The use of wind and wave statistics in the design and operation of offshore facilities provides the engineer with one sources of information on output or response statistics for key design parameters, rather than only single-value input statistics. Although it is not practical to analyze each and every facility exposure event during its lifetime, simplified statistical models can account for the environmental exposure and its effect on response parameters [7].

III. Power Spectral Density

In metocean analyses, the random sea state on a short term basis maintains certain identifiable statistical properties [8]. The intensity of the sea is characterized by its total energy which is distributed according to the frequencies of the various wave components - length, period or frequency [9]. The energy of the sea is normally expressed as power spectral density or power spectrum; it is given as local energy spectrum, and it describes the energy distribution over different wave frequencies at a fixed point [10], providing a more comprehensive description of the environmental load conditions normally defined for a single position, with surface characteristics (height, period, direction, etc.) specified [5].

A. Fourier Transform and Autocorrelation

The most common way of generating a power spectrum is by using a Fourier transform of the autocorrelation function R(τ) for wide sense stationary random processes as shown in Figure 1 [11]. This transfer function will be transformed from time domain into the frequency domain to ascertain the frequency response function unique to the structure [4]. The autocorrelation is the correlation of functions with a shifted version of itself. It is an even function and has its maximum magnitude at zero time delay [12] and the autocorrelation function tells us something about how rapidly the time series can be expected to change as a function of time. If the autocorrelation function decays rapidly (or slowly), it indicates that the process can be expected to change rapidly (or slowly). The autocorrelation function also contains information about the expected frequency content of the time series. If the autocorrelation function has periodic components, then the corresponding process also will have periodic components. [13]. Informally, autocorrelation is a mathematical tool for finding repeating patterns, such as the presence of a periodic data which has been buried under noise, or identifying the missing fundamental frequency in a signal implied by its harmonic frequencies [14]. The time series values should be considered stationary if the sample autocorrelation function of the times series values either cuts off fairly quickly or dies down fairly quickly, but if it dies down extremely slowly, then the time series values should be considered nonstationary and it must be transformed into a series of stationary time series values [15].

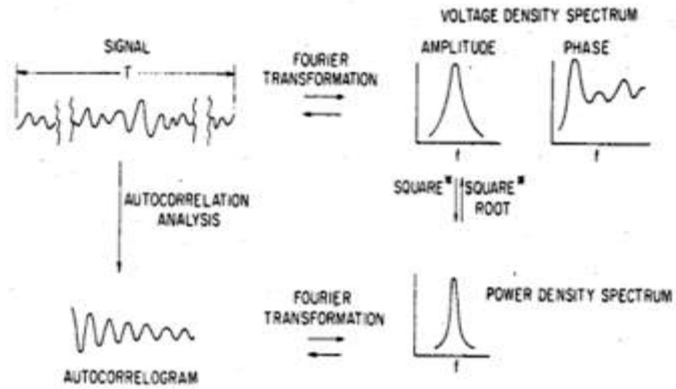

Figure 1: Relationships between a signal and its analyses.

B. Spectral Analysis

Spectral analysis at present is the most important technique in time series analysis, as it will produce the density distribution of wave periods which is far more representative of the actual conditions [16] and it is the best means to describe a random sea state. From the resulting response spectrum, the significant and the maximum expected response in a given time interval can be easily deduced [17]. It is a technique applied to real wave measurements to estimate the amplitude of each oscillatory component from the first low frequency wave to high frequency components [5]. If the signal varies slowly, then its power will be concentrated at low frequencies; if the signal tends to be rhythmic, then its power will be concentrated at the fundamental frequency of the rhythm, perhaps at its harmonic frequencies; if the signal lacks rhythmicity, then its power will be distributed over a broad range of frequencies. It is important that aliasing errors be avoided in order to obtain an accurate estimate of the power spectrum [16]. The frequencies carried most energy in the sea during the time interval of the measurement. It can be seen that in any particular sea, there is very little energy associated with low-frequency waves and also little energy associated with high-frequency waves. Most of the energy is concentrated in the middle band of frequency; i.e. PM Spectrum (describes ‘fully developed’ sea states at Gulf of Mexico) and JONSWAP spectrum (describes ‘fetch-limited’ sea states at North Sea) [18].

For a real valued random process, the autocorrelation function is even, thus the power spectral density function

$$S(f) = \int_{-\infty}^{\infty} R(\tau)\cos(2\pi f\tau)d\tau \qquad (1)$$

This implies that *S(f)* is wave energy density spectrum or the wave spectrum. It is a real and even function of frequency *f*, $S(f) \geq 0$, $S(f)=S(-f)$ and the power spectral density yields no phase information [11].

Since the data, *x(t)*, is non-stationary based on the results of the autocorrelation results, the first difference method, as in (2), is used to transfer data to stationary process for calculating the power spectral density together with Tukey smoothing window, *w(k)*, for removing white noise. *k* is time lag. M ≤ N-1and it usually restricted to M ≤ N/10 [11].

$$z_t = x_t - x_{t-1} \text{ where } t = 2, \ldots, N \quad (2)$$

$$S(f) = \sum_{k=-M}^{M} w(k)R(k)e^{-j2\pi fk} \quad (3)$$

There are two types of power spectrum

1. A low-frequency spectrum: If the spectrum (variance) tends to be higher at the low frequency than at the high frequencies
2. A high-frequency spectrum: If the spectrum (variance) tends to be higher at the high frequency than at the low frequencies.

C. Normalized Power Spectral Density

Normalization is the process of regularizing data with respect to variations in sample preparation, sample thickness, absorber concentration, detector and amplifier settings, and any other aspects of the measurement; and also tends to produce values that are more exchangeable across different laboratories, research studies, and spectral analysis algorithms [19][20]. Normalization of spectra is application of similarity analysis to correlate spectra with generation factors. The analysis establishes the dependence between various normalized nondimensional parameters and thereby leads to a possible universal function [18].

Normalized power spectral density compensates for large values in the spectrum that may have been brought about not by an increase in the coupling between the processes at frequency, *f*, but by an inherently large concentration of power at that frequency in the process [16].

There are two commonly used methods to normalize spectral data: the dot product normalization, which essentially normalizes the spectrum based on the total area under the curve and the scaling normalization, which normalizes the spectrum based on the height of the strongest peak [21]. One of many schemes used effectively in studying the similarity characteristics of wind wave spectra obtained from a wide variety of sea conditions is the dot product normalization and the results can be described by a universal spectral form [18].

$$\frac{S(f)f}{\sigma^2} = F(f) \quad (4)$$

where *S(f)* is a frequency spectrum of the water surface displacements at a fixed location with respect to the frequency, *f*. *F(f)* is a dimensionless function that is universal for the spectrum of energy. σ^2 is the variance of the water surface displacements which is related to the spectrum function by

$$\sigma^2 = \int_0^\infty S(f)df \quad (5)$$

IV. Environmental Loads

A. Significant Wave Height

The surface characteristics of the real sea are extremely complex and variable [5]. In the design of offshore structure, the main target is to attain a maximum of safety and reliability at an acceptable cost for both extreme loads as well as fatigue loads [22]. The forces on the structure are caused by the motion of the water due to the waves generated by the action of the wind on the surface of the sea. In most aspects of offshore engineering design, the wave loading on the structure is usually the most important of all environmental loadings and has substantial forces much higher than the other environmental factors (wind, current etc.) [17].

Waves are characterized by wave height, wavelength, period and wave direction (with respect to north) [3], passed through the structure with discrete time lags [22]. Wave height is measured as the elevation of the water level at a point close to the platform [17] and generally quoted as the significant wave height parameter, Hs, which is equal to the average of the largest one-third of all waves in a particular sea state [9].

The concept of significant wave height was first introduced by Sverdrup and Munk, 1947.

$$H_s = \frac{1}{N/3}\sum_{i=1}^{N/3} H_i \quad (6)$$

where N is the number of individual wave height; H_i is a record ranked highest to lowest.

In spectral analysis, the significant wave height is related to the total energy content of the wave spectrum.

$$H_s = 4\sqrt{m_o} \quad (7)$$

where $m_o = \int_0^\infty S(f)df$ is the total area under the wave energy spectrum or wave spectrum [9].

B. Wind Speed

As wind passes over the water's surface, small ripples are formed. These ripples grow exponentially and form fully developed waves [17]. Wind is caused by differences in atmospheric pressure because air moves from the higher to the lower pressure area, resulting in winds of various speeds [23].

Wind is an important process in most aspects of metocean engineering as well as representing a major structural load and also a common factor in the design of structures. It acts on the portion of a platform above the water level as well as on any equipment, housing, derrick, etc. located on the deck and has a very direct influence on sea state and current circulation, and also drives a significant element of non-tidal surge elevation. The other consideration of wind conditions is important for design (orientation and strength of facilities such as flare booms), offshore operational planning (crane and helicopter operation etc.) and in process engineering related to the offshore industry (e.g. dispersion of airborne pollutants) [5] [17].

An important parameter pertaining to wind data is the time interval over which wind speeds are averaged. For averaging intervals less than one minute, wind speeds are classified as gusts. For averaging intervals of one minute or longer they are classified as sustained wind speeds [17].

C. Wave and Wind Statistics

For a given location and period, wind records are segmented by speed and direction, and expressed as percentage occurrences within a given speed/direction category [5]. Using such trace records, two types of analysis may be performed: the time domain analysis and the frequency domain analysis. Both methods assume a state of stationarity (i.e. the sea state does not vary with time). The time domain is the analysis of mathematical functions, physical signals or time series of environmental data with respect to time while the frequency domain is the domain for analysis of mathematical functions or signals with respect to frequency [3]. For wave records, there are two assumptions made. First, the wave field can be described as the summation of sine waves of varying frequency, amplitude and direction. Second is the assumption that the field is statistically stationary – which means that the statistical description of the waves at a given time is essentially the same description that would be obtained at a slightly different time [24].

In the South China Sea, waves are primarily wind driven by the monsoons, with the roughest weather arriving from the North-Northeast during the Northeast monsoon. In addition, tropical storms and typhoons can also produce severe weather, although much less predictable. Typhoons are rare in Sabah waters and are relatively mild in strength, but still strong enough to skew the long-term wind and wave distributions, but less likely to control extremes in current speed. Operational statistics are required for many offshore activities i.e. monthly, seasonal and directional statistics (maximum, mean and standard deviation).

There are four seasons of the year as follows:

- Northeast Monsoon (November to March) characterized by predominantly northeast winds, increased cloudiness and the heaviest rainfall of the year. Regular 'Surges' in the Monsoon winds increase the wind speeds and raise the wave heights.
- Transition (April and May) is the time when the winds are light (except during occasional squalls) and variable in direction.
- Southwest Monsoon (June to September) is dominated by southwest winds, which occasionally increase due to approaching typhoons east of Philippines, thus raising the waves. Nonetheless, the duration, wind speed and wave heights are lower than those experienced during the Northeast Monsoon.
- Transition (October and November) sees changeable wind direction with an increase in wind speed and frequency squalls. It is also the time of the year when the risk of typhoons affecting the area is the greatest [3].

V. METHODOLOGY

This study is conducted by analyzing the measured data of wave height and wind speed in South China Sea.

- Dulang – Malay Basin (offshore Terengganu),
- Baronia – Sarawak Basin and
- Erb West – Sabah Basin.

The interval between each consecutive measurement was ten minutes. It is possible that there may have been an error in recording the measured data. First of all, bad data points are marked and thrown out. Each bad value is filled by interpolation of adjacent data points. Hence, the calculation of mean and standard deviation are not corrupted by the removed bad data. If more than 20 % of the data has to be thrown out in this manner, the entire time series is marked bad [24].

For descriptive statistics analysis, the calculation of mean and standard derivation for all data in the above three locations is based on monthly, seasonally and yearly basis, respectively. For power spectral analysis, it focuses on different months in each year; each month in different years; and northeast and southwest monsoons, respectively, by calculating the normalized power spectral density envelope.

VI. RESULTS AND DISCUSSION

A. Descriptive Statistics Analsyis Results

The figures below show the average and standard deviation of Wind Speed and Wave Height in South China Sea – Terengganu, Sarawak and Sabah regions.

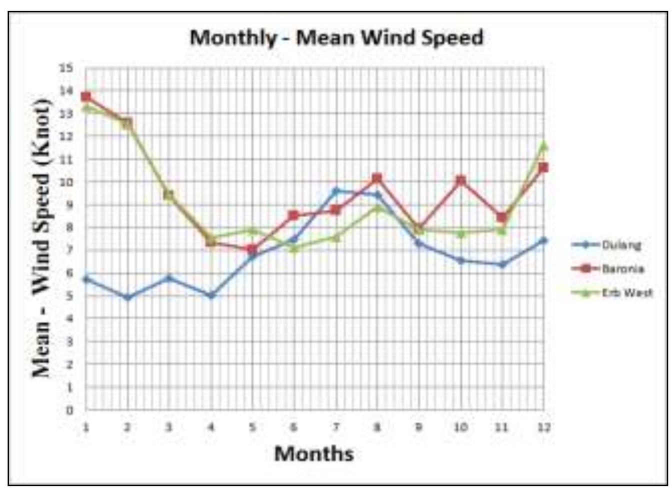

Figure 2: Monthly – Mean Wind Speed
for Dulang, Baronia and Erb West.

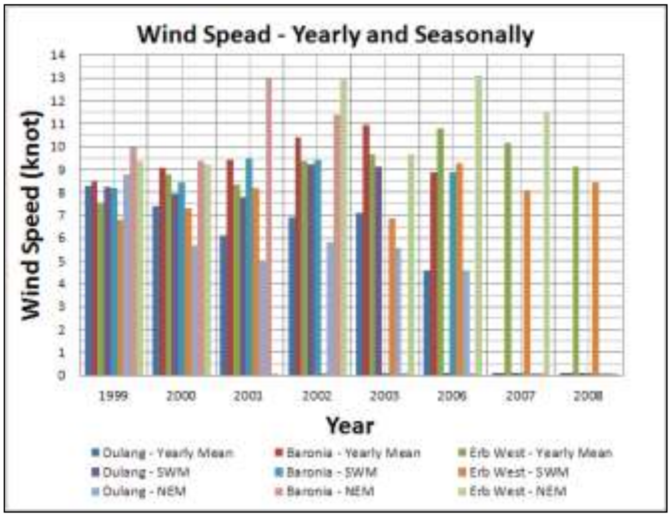

Figure 3: Wind Speed – Yearly and Seasonally for Dulang, Baronia and Erb West.

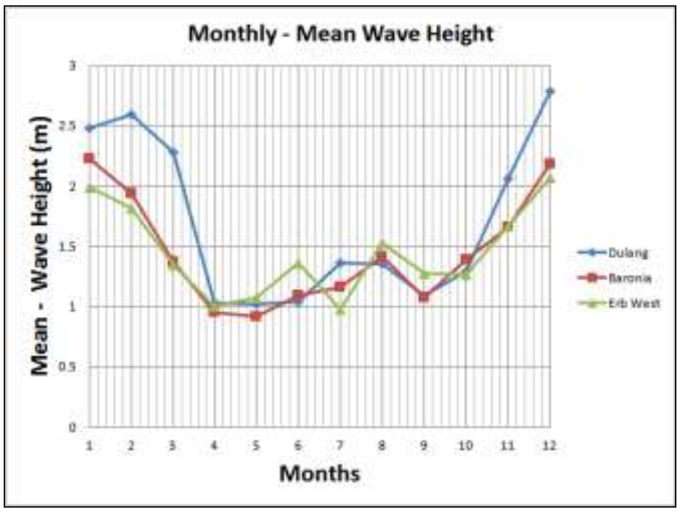

Figure 4: Monthly – Mean Wave Height for Dulang, Baronia and Erb West.

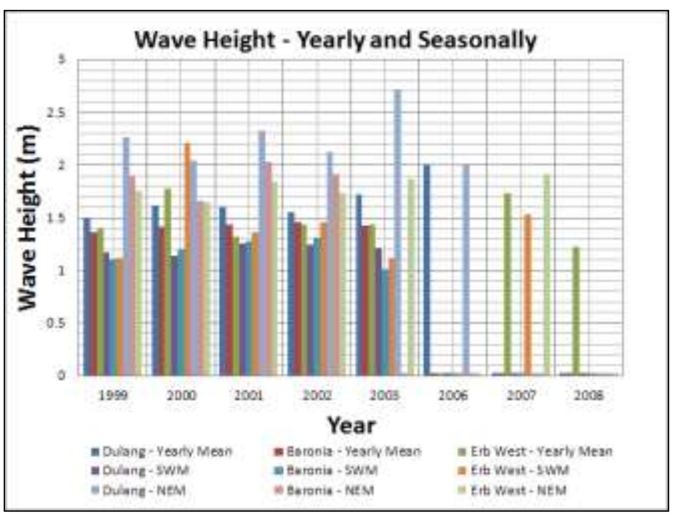

Figure 5: Wave Height – Yearly and Seasonally for Dulang, Baronia and Erb West.

The results indicate that the process is non-stationary which is transferred to stationary process by first difference method and the white noise presented in the data is removed through the Tukey smoothing window for developing power spectral density.

For wind speed, it shows that the maximum wind speed occurs in Southwest monsoon for Dulang field, Northeast monsoon for both Baronia and Erb West fields with maximum mean of ($\bar{x}$ =9.2406 knots, σ =4.7506 knots), ($\bar{x}$=12.9636 knots, σ =6.1407 knots) and ($\bar{x}$ =13.1300 knots, σ =6.3346 knots), respectively. Those three fields have high mean wind speed ($\bar{x}$ =13.5195 knots, σ =6.3566 knots).

For wave height, it shows that the maximum wind speed occurs in Northeast monsoon for all the three locations - Dulang, Baronia and Erb West fields with maximum mean of ($\bar{x}$ =2.7163 m, σ =1.1108 m), ($\bar{x}$ =2.0316 m, σ =0.8135 m) and ($\bar{x}$ =1.9100 m, σ =0.6868 m), respectively. Those three fields have high mean wave height ($\bar{x}$ =2.3597 m, σ =0.8690 m).

B. Spectral Density Analysis Results

The figures below show the normalized power spectral density envelope of wind speed and wave height in South China Sea – Terengganu, Sarawak and Sabah regions.

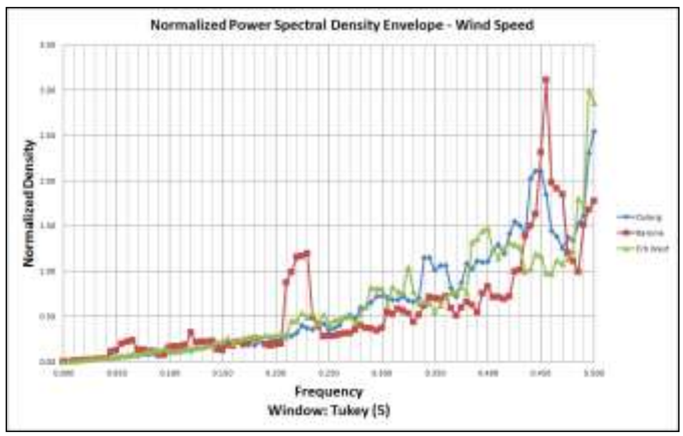

Figure 6: Normalized Power Spectral Density Envelope – Wind Speed for Dulang, Baronia and Erb West

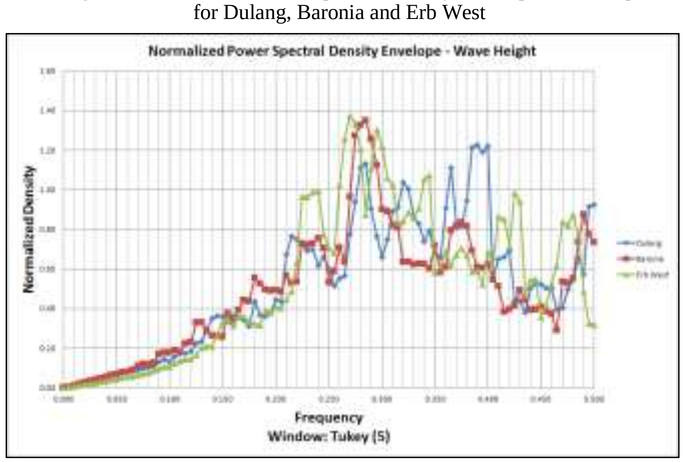

Figure 7: Normalized Power Spectral Density Envelope – Wave Height for Dulang, Baronia and Erb West

From the results, it can be seen that although there is no clear dominant peaks and they seem to fluctuate at random, there are two different identifiable patterns for wind speed spectrum and wave height spectrum in shallow waters, respectively.

For wind speed spectrum, the appearance of the spectral plot indicates that it tends to grow gradually at lower frequency range and increasing significantly, double at higher frequency range with the significant peak frequency range: 0.455Hz-0.5Hz and has the overall peak frequency range: 0.23Hz-0.5Hz and the mean peak frequency range: 0.4104Hz-0.4721Hz.

For wave height spectrum, the appearance of the spectral plot indicates that it tends to grow dramatically at low frequency range, and fluctuates and decreases slightly at high frequency range with the significant peak frequency range: 0.27Hz-0.295Hz and has the overall peak frequency range: 0.235Hz-0.49Hz with the mean peak frequency range: 0.2911Hz-0.3425Hz.

VII. Conclusion

In conclusion, the both wind speed and wave height have significant influence to the offshore structures during northeast monsoon with the high mean of 13.5195 knots (σ = 6.3566 knots) and 2.3597 m (σ = 0.8690 m), respectively. There is an individual identifiable pattern for wind speed spectrum and wave height spectrum with the mean peak frequency range of 0.4104Hz-0.4721Hz and 0.2911Hz-0.3425Hz, respectively.

Acknowledgment

The authors would like to thank UNIVERSITI TEKNOLOGI PETRONAS for the support throughout this research work.

References

[1] Toshio Atsut, Shoji Toma and Kawasaki, 1976, "Fatigue Design of an Offshore Structure", Offshore Technology Conference, Houston, Texas, 3-6 May 1976.

[2] Peter S. Tromans and Luc Vanderschuren, “Response based design of floaters”.

[3] Rizwan Sheikh, “Kebabangan Northern Hub - Metocean Design and Operation Criteria”, 2010.

[4] Datta, Bisuddhan, “Design lower shallow – water offshore platform cost”, Vol.87, No.22, 1989, pp: 85-88.

[5] Institute of Marine Engineering, Science & Technology, “METOCEAN Awareness Course”. 2011.

[6] Metocean, “The International Association of Oil & Gas producers (OGP)”

[7] Haring, J.B. Bole and R.A. Stacy, “Application of directional wind and wave statistics”.Techinp, “Wave and Wind Directionality – Applications to the design of structures”, 1982, pp.545-573.

[8] Chakrabati, S.K., “Hydrodynamics of Offshore Structures” Computational Mechanics Publications, Southampton, Boston. 2011, pp.86-90, 105-127.

[9] Walter H.Michel, “Sea Spectra Revisited” Marine Technology, vol.36, No.4, winter. “Applied Mechanics and Materials”, 1999, pp. 211-227.

[10] Georg Lindgren and Igor Rychlik, 1997, “The Relation Between Wave Length and Wave Period Distributions in Random Gaussian Waves”. Proc. of the Seventh International Offshore and Polar Engineering Conference, Honolulu, USA, May 25-30, 1970.

[11] Donald G., “Childers, Probability and Random Processs using MATLAB with application to continuous and Discrete Time Systems”, 1997, pp. 208-218, 300-303, 236-237.

[12] M.J. Robets, “Correlation, Energy Spectral Density and Power Spectral Density”, Chapter 8, 2005.

[13] T. Veerarajan, “Probability, Statistics and Random Processes”, 2nd Edition, 2003, pp. 372-375.

[14] Patrick F. Dunn, “Autocorrelation”, 2005.

[15] Bowerman B.L., O’Connell R. “Forecasting and Time Series – an applied approach”, 3rd Edition, 1993, pp.436-450.

[16] Edmund M. Glaser and Daniel S. Ruchkin, “Power Spectra and Covariance Function”, Principle of Neurobiological Signal Analysis. Chp.3. 1976, pp. 113-176.

[17] N. Yahaya, “Offshore Structures: General Introduction”

[18] Paul C. Liu, “Normalized and Equilibrium Spectra of Wind Wave in Lake Michigan”, 1971.

[19] Bruce Ravel, “Normalization”, Center for Advanced Radiation Sources, 2008.

[20] Robert L. Burr, “Interpretation of Normalized Spectral Heart Rate Variability Indices in Sleep”, 2007.

[21] Bio-Rad Laboratories, Inc. Philadelphia, USA, “Search Strategies for IR Spectra – Normalization and Euclidean Distance vs. First Derivative Algoritm”, 2008.

[22] O.P. Torset and O.A. Olsen, “The need of direction for structure design”, Techinp “Wave and Wind Directionality – Applications to the design of structures”, 1982, pp.365-377.

[23] JetStream, "Origin of Wind", 2008.

[24] Teledyne RD Instruments, “Waves Primer: Wave Measurements and the RDI ADCP Waves Array Technique”.