Correlation of Metocean Parameters for Malaysian Waters

Othman, N.A.; Liew, M.S.

Abstract— **Numerous time series analysis method has been introduced. Metocean forces are known as the most challenging factors in designing stage of offshore structure. Environmental loads are also known as the basic design of any primary structure of offshore platforms. Cross-spectral analysis enables two parameters to be analyzed simultaneously. In this research, a cross-spectral analysis of two environmental loads which are; wind speed and wave height, will be analyzed simultaneously. Cross-spectral density is defined as the Fourier Transform of the corresponding cross-correlation function. Cross-correlation is a measure of similarity of these two waveforms as a function of a time-lag applied to one of them. In time series analysis, the cross-spectrum is used as part of frequency domain analysis of the cross-correlation between two time series. Cross-spectral analysis is also known as an extension of spectral analysis. Spectral analysis is described as a representation of a time series or mathematical functions in the frequency domain. Spectral and cross-spectral analysis has a number of applications in electronics and mechanical engineering such as a measure of magnitude of a harmonic distortion, a measure of extra signals (inter-modulation distortion), a measure of harmonic content of a signal, extraction of signals from noise may require knowledge of the cross-spectrum of the signal noise, it is useful to see the spectrum diagram for modulation and other waveforms manipulations. Thus, this research will bring valuable information about the environmental loads acting on offshore structures. The cross-spectrum which will be generated throughout this research will also help to acquire knowledge of the spectrum of the signal and the noise. The objectives of this paper are (i) To develop cross-spectral analysis of two parameters; wind and waves, in the frequency domain. (ii) To study the frequency range of the peak energy content of the generated cross-spectrum. Findings from this research have distinguish resemblance among the frequency peaks range that is significant for understanding the environment of offshore structures.**

Keywords—metocean, cross-spectral, spectral, offshore structures, coherence

I. Metocean

Ever-expanding development of oil and gas exploration has grown its interest in metocean studies due to the significant costs of oil and gas industry. Mushrooming market of metocean research projects has enforced many oil and gas companies to revise the design standard of offshore structures in Malaysian waters which they are currently based on. Metocean data have been used to develop new design standards of offshore structures in Malaysian waters which is more reliable for the South China Sea region.

As an initiative towards achieving the objectives, many metocean studies has been done for Malaysian waters [1-4]. As stated of realistic description of wind generated sea state; Pierson-Moskowitz (P-M) and JONSWAP spectrums, ZLLC spectrum was generated for Malaysian waters, [2] of the South China Sea region. The frequency peaks range between P-M and JONSWAP, have proven that province of offshore structure's location creates an aim of this research. This study intended to determine the frequency peaks of significance metocean load energy distribution. As a result of being the important loadings acted on offshore structures, wind and wave are seen as the essential environmental loadings that need to be studied for a better understanding of the offshore platform surroundings.

II. Wind and Wave

A. *Dynamic loads*

Wind and wave are considered as dynamic loads of which its magnitude, direction and position varies with time [5]. Wind and wave records are considered as stochastic loads as every unique record does not resemble one another. Wind and wave are treated as random data which varies over time or frequency. To represent wind climates, wind speed have been seen as the significant metocean parameters to be analyzed whilst for studying the behavior of waves, crucial parameter of wave height is chosen to be examined [6].

By reason of wave and wind is a random physical process which is a function of time, it can be described as time histories. In general, time histories are superlative to be analyzed using statistical analysis [1, 7]. Time-series records in many application fields have undergone statistical analysis processes that allow interpretation of time-series data.

Metocean data treatment has implemented statistical analysis in order to provide a derivation of environmental statistics. Different province of the same region is included in this study intent to characterize each specified area of offshore platforms. Propped up with the aim of studying the characteristics of wind speed and wave height data for Malaysian waters, measured metocean data consisted of three different regions for Malaysian waters; Peninsular Malaysia Operations (PMO), Sabah Operations (SBO) and Sarawak Operation (SKO), will be analyzed.

Convolution of wind and wave data treatment is resolved through the existence of time-series analysis by its capability

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of dissecting random data. Methods of time-series studies comprised of statistical analysis to study the nature occurrence of metocean loads acting on offshore platforms in a specified region. Forecasting of environmental loadings acting on offshore structures is rationally imposed by the nature phenomenon of significant metocean loadings; wind and wave.

B. *Time-Series Forecasting*

Time history is the past observations of phenomena that will aid in predicting the upcoming event of the same phenomena[8]. Prior to experimental results, future measurement of a certain observation can be predicted with acceptable accuracy. However most of the data of engineering applications are random which means each of the observations is unique. Unique time history records do not contain any data that is similar to each other, every data produce its own value[5].

Time series forecasting is the analysis of history to make current decisions and plans for the future. Long-term prediction from the past observations of wind and wave observations will facilitate design of offshore structures in a particular province. Measured data over a period of time is successively important to allocate sufficient time for procurement in order to build up an offshore platform. Hence time-series forecasting of environmental loads is practically dictated by the nature occurrence of wind and wave. Long-term forecast of approximately 5 years of measured metocean data on a monthly basis were recorded and analyzed.

The underlying confidence of using time series analysis is to extract meaningful statistics and significant characteristics of the data. Time domain of time series analysis is used to illustrate how a signal changes over time. Quantization of the signals lies within a frequency band is determined using frequency domain analysis. The significant challenge of time domain analysis is that it requires a lot of time as it entail more tedious work in comparison with frequency domain analysis. This has created an attention to attain statistical information of wind and wave data.

III. Ergodicity

Quantum of physics is a branch of science that deals with discrete units of energy. The idea of quantum physics was that particles of light is not a continuous wave but exists with a random amount of energy. Idea of locality was stipulated from quantum theory; nonlocality describes the apparent ability of an entity to instantaneously know about each other's state in anticipation for prediction of future events.

sErgodicity is a significant measure of invariant and other related problems of any dynamical system. Development of ergodic theory was motivated by statistical physics that uses probability and statistical analysis to describe a wide variety of fields with an inherent stochastic nature. Ergodic is a statistical ensemble which is "equally-likely" among facsimile of a system [9, 10]. Statistical ensemble speculates that the possible states of a system can be determined by considering a large number of essential resemblance in a system. Ensembles of copies may be used to characterize each of the states that might appear in the real system . To study the dependence of resemblance among a system, ergodicity allows the application of suitable generalizations so that inference becomes possible.

Locality and ergodicity realism holds the theory of quantum averages which are well-approximated by ensemble averages. This is the logical behind two concepts of ergodicity and locality which the first and latter are well-approximated by time and ensemble averages [5]. Nonlocality is an action at a distance; a direct interaction of two objects that are separated in space with no intermediate mechanism. The principle suggested that non-local correlations may be significant within the nature and thus is essential for the quantum description of nature [11]. In this research, such principle has been considered to emphasize seasonal component and location of platforms as the non-local correlations.

Hence, from data it is possible to infer some significant characteristics of the entire ensembles. To provide sufficient ergodicity of wind wave correlation, cross-spectral analysis is done to study the behavior of the data for every specified region in Malaysian waters.

A. *Cross-Spectral*

Cross-spectral analysis enables two parameters to be analyzed simultaneously to facilitate the identification of variations that which encompass comparable spectral properties. Identical spectral peaks properties in term of spectral frequency bands will be distinguished if the variability of two dissimilar time-series is interrelated in the frequency domain.

The measured data are obtained from different platform of three regions. Monthly data set of recorded wind speed and wave height time-series, was analyzed using cross-spectral analysis to identify frequency peaks of two analyzed metocean data. The findings from cross-spectral analysis is presented herein :

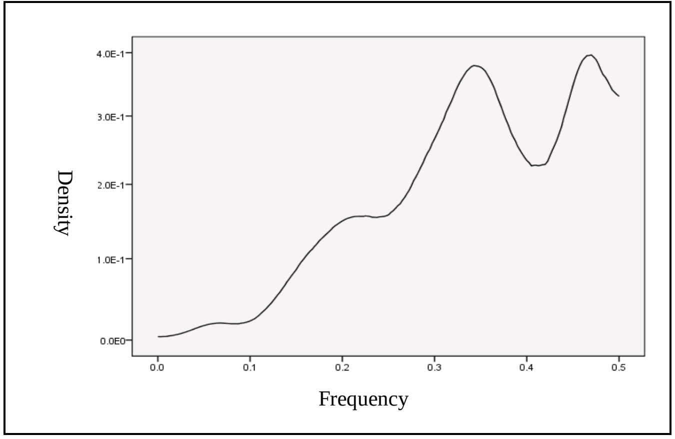


Figure 1. *Cross-spectral density of wind speed and wave height for Platform-A in the month of August 1999*

From the figure presented above, significant frequency ranges were distinguished and resemblance of frequency peaks was found in 75% and above of overall analyzed monthly data for six platforms. Spectral peaks in the cross - spectral density of wind speed and wave height is between the frequency range of 0.25 Hz to 0.5 Hz. Most of the cross-spectral densities which were investigated have two spectral peaks. At frequency range of 0.25 Hz to 0.35 Hz, the first spectral peaks plot at the maximum amplitude and from frequency range of 0.35 Hz to 0.5 Hz, the second spectral peaks plot at higher magnitude of amplitude. As a result of corresponding spectral properties of frequency peaks for analyzing cross-spectral densities of wind speed and wave height, both time-series is believed to be interrelated in the frequency domain. Wind speed and wave height is then prevail to be proved that there is a correlation between these two metocean parameters

B. *Coherence*

The degree of correlation between two time-series shall be assessed by the computation of magnitude-squared coherence. Coherency between two parameters is a measure of values between zero to one as one to be its high correlated values and zero is to be uncorrelated signals. Thus wind speed and wave height data is analyzed to find the maximum coherence frequency ranges. Coherence spectrum of wind speed and wave height for monthly data of Platform-A in August 1999:

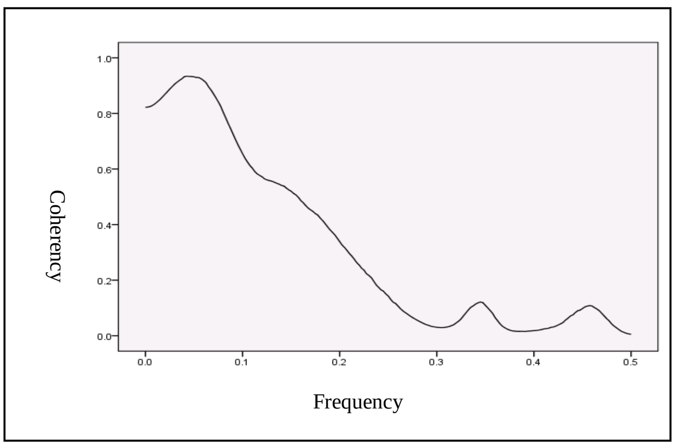


Figure 2. *Coherence spectrum of wind speed and wave height for Platform-A in the month of August 1999*

From the generated coherence spectrum for wind speed and wave height, it is found that both metocean parameters have a higher degree of correlation of at lower frequency; ranges from 0 Hz to 0.25 Hz and lower degree of correlation at high frequency; frequency ranges between 0.25 Hz to 0.5 Hz. Interpretation of coherence spectrum of metocean inputs as the environmental loadings acting on an offshore platform shall contribute in the development of the transfer function of significant applications in offshore structures research.

C. *Phase*

Phase is the time delay between two time-series which enables researcher to ascertain the coherence spectrum generated as well as to depict the significance frequency ranges of two measured variables. Wind speed data and wave height data were then processed to develop the phase spectrum. Monthly data in August 1999 of Platform-A was analyzed and the phase spectrum is shown below :

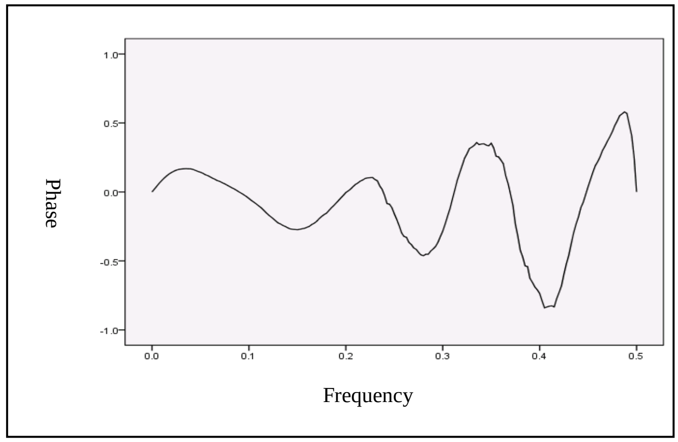


Figure 3. *Phase spectrum of wind speed and wave height for Platform-A in the month of August 1999*

To evaluate the delay of time series between wind speed and wave height, phase spectrum is presented above. From the phase spectrum, we can see that the values at low frequency is approaching zero and continue to decrease and increase towards both negative and positive values. High coherency of wind speed and wave height at low frequency prevailed to be ascertained as zero phase value at low frequency is portrayed above. Both wind speed and wave height is highly correlated at low frequency which means there is no time delay between these two time-series as they are moving at the same time.

D. *Seasonal patterns*

The behaviour of the data has been examined in turn of distinguishing significant traits of the time-series. For this reason, cross-spectral densities for three platforms from different provinces of the South China Sea region have been analyzed. The findings of the analysis have contributed in attaining monsoon seasonal features of three different areas of study for wind speed and wave height data. The monsoon season for the South China Sea region is divided into two main seasons which are; North East monsoon (NEM), and South West monsoon (SWM). Monsoon season of NE takes place in the month of November until March whilst SW monsoon starts from May to August [12, 13]. Based on the two dominant monsoon season for the South China Sea region of Malaysian waters, seasonal patterns of cross-spectral densities have been categorized. Findings from the analysis is presented below.

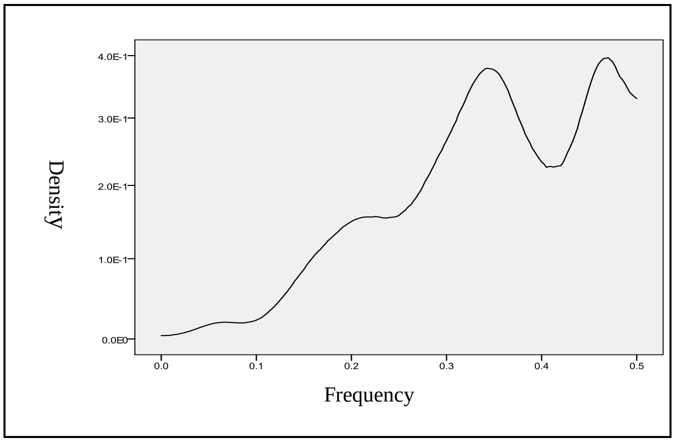


Figure 4. *Cross-spectral density of wind speed and wave height for Platform-A during Southwest Monsoon*

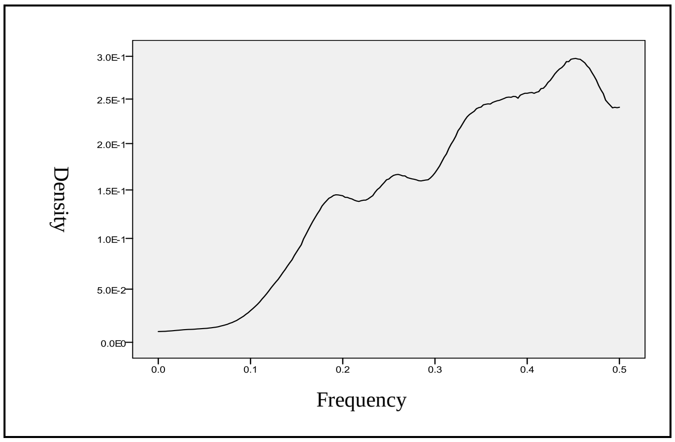


Figure 5. *Cross-spectral density of wind speed and wave height for Platform-C during Southwest Monsoon*

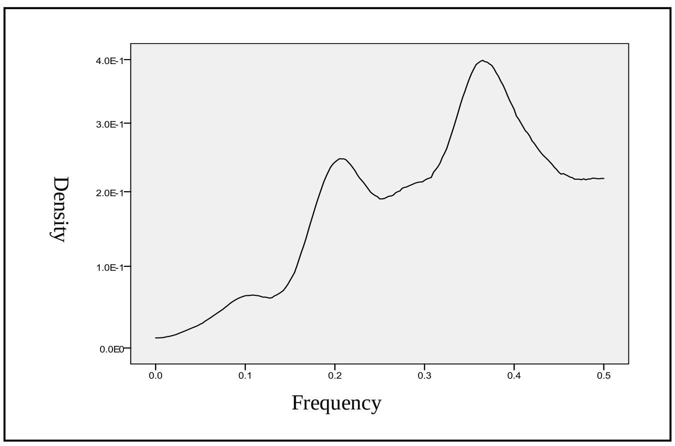


Figure 6. *Cross-spectral density of wind speed and wave height for Platform-F during Southwest Monsoon*

From the figures shown below, there are seasonal patterns found throughout the analysis of cross-spectral for wind speed and wave height. Distribution of frequency ranges from the cross-spectral peaks varies with the influence of two monsoon seasons. During SWM, there are mostly two peaks of cross-spectral densities with frequency ranges from 0.2 Hz to 0.3 Hz for the first peak and 0.4 Hz to 0.5 Hz. The resemblance of the frequency ranges of cross-spectral peaks among different platforms have satisfied the seasonal patterns of two main monsoon seasons.

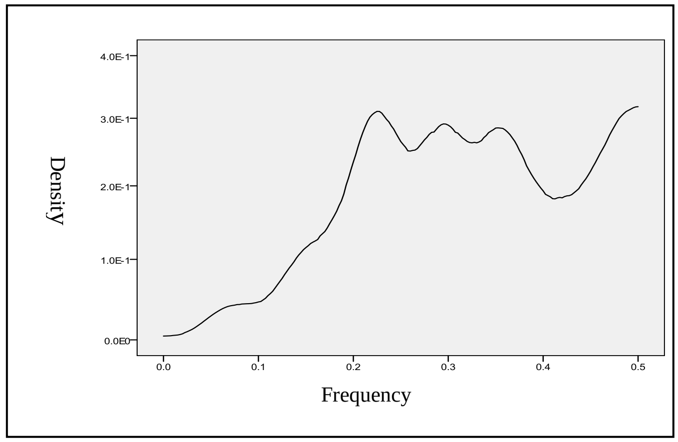


Figure 7. *Cross-spectral density of wind speed and wave height for Platform-A during Northeast Monsoon*

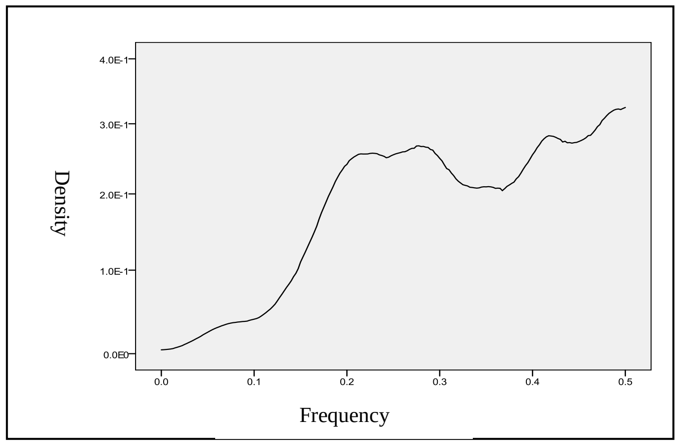
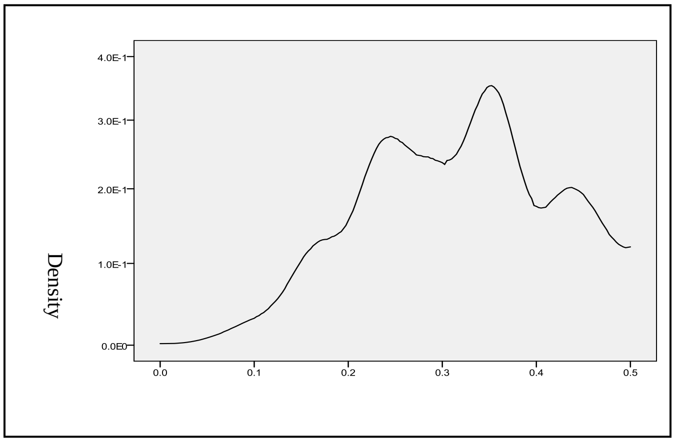


Figure 8. *Cross-spectral density of wind speed and wave height for Platform-C during Northeast Monsoon*



Frequency

Figure 9. *Cross-spectral density of wind speed and wave height for Platform-F during Northeast Monsoon*

Figures of cross-spectral densities during NEM are shown above. From the presented results, it is found that the frequency ranges of cross-spectral peaks differ from SWM. Cross-spectral densities during SWM are consisted of two or more peaks, varying from 0.1 Hz to 0.5 Hz. In the months of NEM, most of the peaks fluctuates from 0.2 Hz to 0.5 Hz. From the findings, we can conclude that there is other correlations and considerations that can be depicted from the results. Considerations of different provinces of SKO, PMO and SBO shall be analyzed to infer essential attributes of platforms' location.

IV. Potential contributions

This paper proposed a statistical analysis of cross-spectral for the applications in studying the frequency peaks of metocean data. The findings of the generated result had somehow contributed to the identification of significant traits as well as the frequency peaks range of wind speed and wave height correlations. This research will be able to aid the process of understanding environmental loads acting on the offshore structures in the studied research area of Malaysian waters.

Acknowledgment

I would like to express my deepest gratitude to Universiti Teknologi Petronas for supporting this on-going research and I would like to acknowledge with high appreciation to Civil Engineering Department, UTP and Offshore Engineering Centre UTP (OECU) for their crucial role in contributing and assisting offshore research in UTP.

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