Evaluation of Seakeeping Analysis of a Fishing Vessel using a Wave Buoy and Onboard Motions Monitoring Device

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Abstract: Seakeeping analysis is important in assessing the performance of floating structure in waves. To perform Seakeeping calculations, the wave characteristics as well as the response of the vessel are needed. The analysis normally requires reliable computer programs to calculate response amplitude operator (RAO) and accurate seaway representation. For seaway representation theoretical spectra can be used but it is always preferable to use the measured spectra which can be obtained through full scale measurement. On the other hand theoretical spectra can be used for comparison. This paper presents the results of a full-scale measurement of wave and vessel motions taken from a Malaysian fishing vessel. The vessel operates off the East Coast of Peninsular Malaysia. Wave buoy was used to measure wave data and Vessel Motion Monitoring System (VMMS) was used to measure the vessel motions. They are basically composed of a set of accelerometers gyroscopes and wind sensors. The data processing and analyzing is done using *LabVIEW* software. Finally, the main analysis of the results obtained is in the form of spectral analysis of wave and vessel motions. From them the RAO can be obtained, which is the key to all Seakeeping analysis.
Key Words: Seakeeping, RAO, VMMS, Wave Spectra

INTRODUCTION

Fishing vessel is one of the most ancient vessels in Malaysia. Most of them are built traditionally. During their operation they have to work in rough weather. It is always a question of safety of these vessels in the hostile seaway as these are traditional and usually they were not built according to the proper seaway. To build them according to the proper seaway it first necessary to analyze the motion of these vessels in that seaway where it is designed to operate. This shows importance of the analysis of motion of these fishing vessels. The motion analysis (Seakeeping) means finding the motion and related factors of a vessel subjected to a certain sea-state. It also refers to the analyzing the behavior of a vessel in a seaway.

The study of Seakeeping has been started in early 1950's. The study was initiated by the application of hydrodynamic theory, in the use of experimental model technique and in the collection of full-scale empirical data. The papers by St. Denis and Pierson [1] are of particularly important. Those papers showed that the ship motion in random waves could be calculated using the technique of spectral analysis borrowed from the field of electromagnetic communications. The paper of Ursell [2], which indicate how the flow around a circular cylinder oscillating in a free surface could be theoretically calculated, also important. These works opened the way to predict the ship behavior in regular and irregular waves.

The importance of simulating the operation of crane vessel in realistic waves was emphasized by Hoffman and Fitzgerald [3]. Their earlier work has shown that error up to 100% of motion may occur arising from the use of inadequate data. Soares and Trovao [4] investigated the sensitivity of Seakeeping prediction to spectral models and concluded that short-term responses are sensitive to the type of spectral model used while for long-term predictions only Pierson-Moskowitz model could be used.

The regular waves are rarely found in nature. The natural seaway in which a ship operates can only be described by means of statistical method. The spectrum or the spectral density function is the primary parameter used for representing the seaway and the oscillatory response of the vessel to the seaway.

Since there is no standard spectrum exists for local wave condition, few studies were carried out to measure the wave data at different locations of Malaysian water. One of the measurements was carried out in Malacca Straits near

Kukup using the Shipboard wave radar and another was carried out near Pulau Sibu in South China Sea using CMST wave recorder. The measurement results were reported by Yaakob and Maimun [5]. From the result it has been shown that standard spectra could not match the measured spectra fully. So there is a need to find the local spectra for Malaysian water.

METHODOLOGY OF SEAKEEPING ASSESSMENT

The first step in the assessment of Seakeeping performance is usually to determine the wave spectrum for a seaway [6]. Wave spectrum is the spectral representation of wave elevation. The wave elevation which is based on time is converted so that it can be represented as function of frequency by using FFT integration technique.

The overall principle to convert time series wave data to frequency domain spectral representation can be described by the following figure-

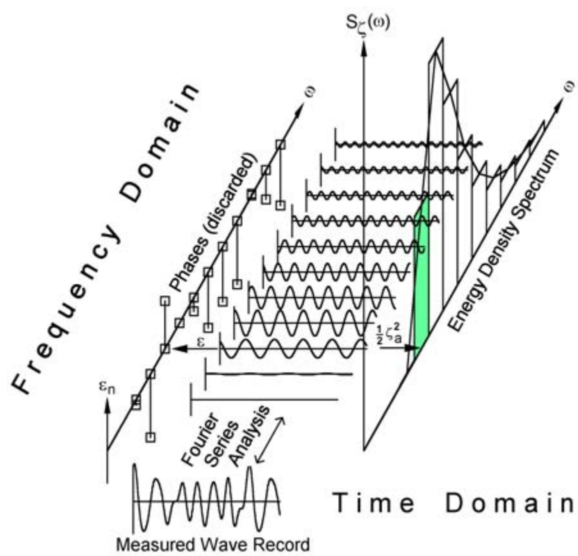


Figure 1: Principle of Conversion from time domain to frequency domain

The wave assumed to be long crested that incident on the vessel. The way in which the energy of the sea distributed at various encounter frequencies is given by the wave spectrum $S\zeta(\omega e)$. By the principle of linear superposition, the sea spectrum can be related to the motion spectrum through the response amplitude operator (RAO). Response amplitude operators (RAO) are then computed for each critical mode of motion. The RAO defines the amplitude of response due to unit wave excitation. These RAO are the heart to all Seakeeping assessment. If the transfer function at various encounter frequencies are designated RAO, the response spectra is $Sr(\omega e)$ then the response spectra of the vessel in that particular seaway is given by-

$$S_r(\omega e) = S_\zeta(\omega e) \times |RAO|^2 \qquad (1)$$

FULL SCALE MEASUREMENT

The aim of full-scale sea trial is to give a better understanding of the real situation that the ship encounters. It also helpful to investigate the correlation between analytical calculation and model test results with the actual behavior of the vessel to determine whether the vessel fulfills the design specifications.

The field measurement was carried out on the 18 September 2005 using a Malaysia fishing vessel belonging to Universiti Teknologi Malaysia. The main particulars of the boat are shown in the table bellow. Total 5 runs were carried out and the detail of the location with various conditions is shown in the table bellow. Run1 was carried out in Head sea, run 2 in Following Sea, run 3 in Bow quartering, run 4 in Beam Sea and run 5 in Stern quartering sea.

Table: 1 Principal particulars of the fishing vessel TRF 1010

Length overall (LOA)	25.97m
Length Between Perpendicular (LBP)	23.38m
Breadth Moulded (B)	6.24m
Depth Moulded (D)	3.21m
Draft at Midship (T)	2.02 m
Block Coefficient C_B	0.4501
Prismatic coefficient C_P	0.6109
Volume Displacement	115.52 m^3
Midship Section Coefficient	0.7367
Designed Speed (V)	10 knots

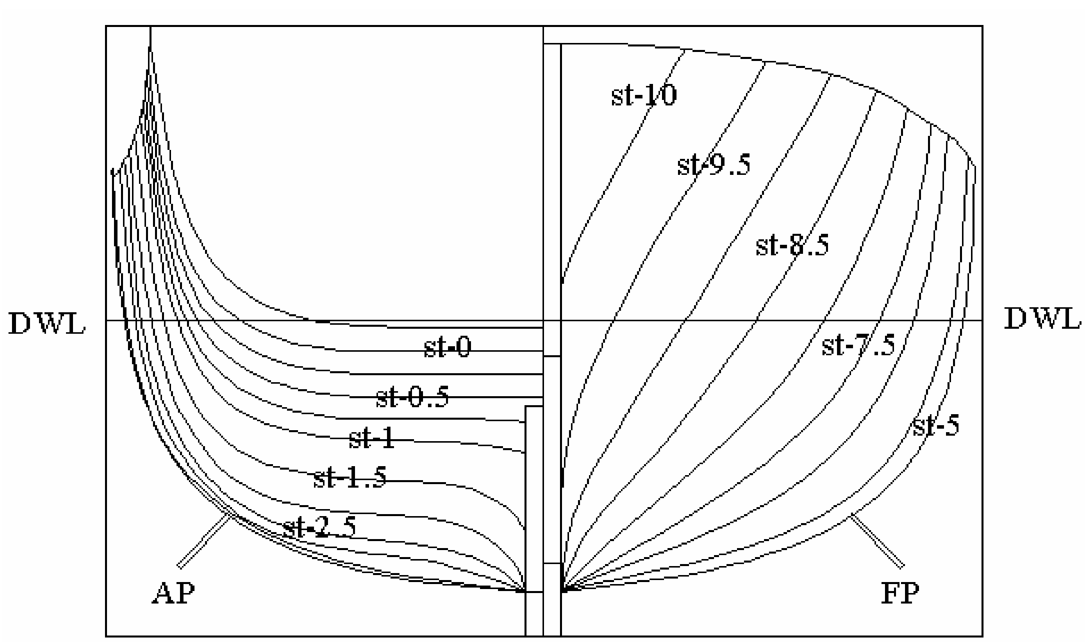


Figure 2: Body Plan of TRF 1010

This fishing vessel is provided with a pair of bilge keel whose dimension is provided bellow-

Bilge keel specification

Length = 7.11 m
Breadth = 0.457 m
Starting Point of Bilge keel (from AP) = 6.52 m
End point of bilge keel (from AP) = 13.63 m
Thickness = .03 m

Table: 2 Conditions during test

Conditions	**RUN 1**	**RUN 2**	**RUN 3**	**RUN 4**	**RUN 5**
Start					
Latitude	$05^0$14’	$05^0$13’	$05^0$16’	$05^0$17’	$05^0$16’
Longitude	$103^0$32’	$103^0$32’	$103^0$31’	$103^0$30’	$103^0$28’
Ship Speed (Knots)	4.2	5.7	5.1	3.7	3.5
End					
Latitude	$05^0$13’	$05^0$13’	$05^0$17’	$05^0$17’	$05^0$16’
Longitude	$103^0$32’	$103^0$32’	$103^0$30’	$103^0$28’	$103^0$27’
Ship Speed (Knots)	4.3	5.9	5.3	3.9	3.7

INSTRUMENTATION AND DATA ANALYZING SYSTEM

For the measurement of wave the wave buoy and for the motion of the vessel the Vessel motion monitoring system (VMMS) was used. From the spectral distribution of wave and vessel motion the RAO was calculated. The details of the instumentation are described bellow-

a) VESSEL MOTION MONITORING SYSTEM (VMMS)

The VMMS is a modular system that has been developed to monitor the motion of floating structures in waves [7]. The intended application for the VMMS is installation on smaller vessel such as fishing vessel for the measurement of Pitch Roll Yaw and Heave motions under various wave conditions. The system is designed to run under the software called LabVIEW. The VMMS is comprised of a microwave wave height sensor, set of accelerometers, a connection box and a processing unit is shown in Figure 3. The processing system and data analysis of VMMS is shown in Figure 4.

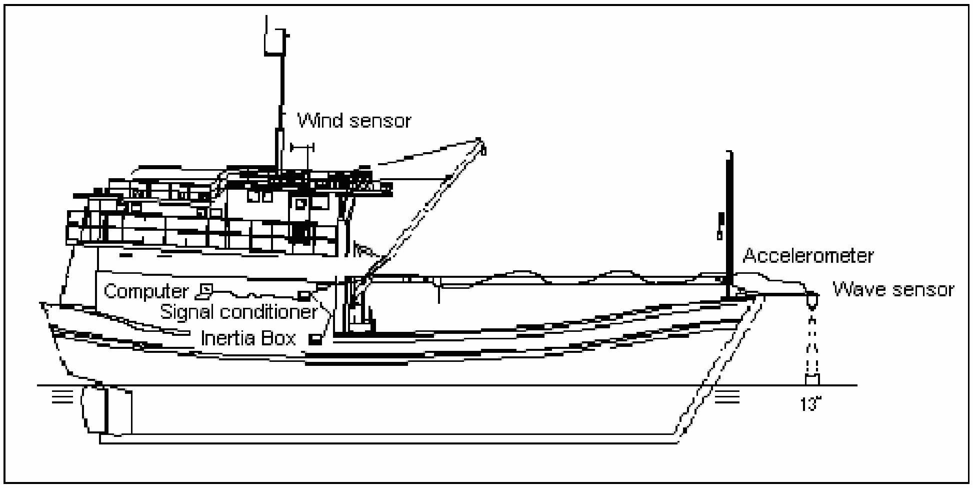


Figure 3: Typical Installation of VMMS

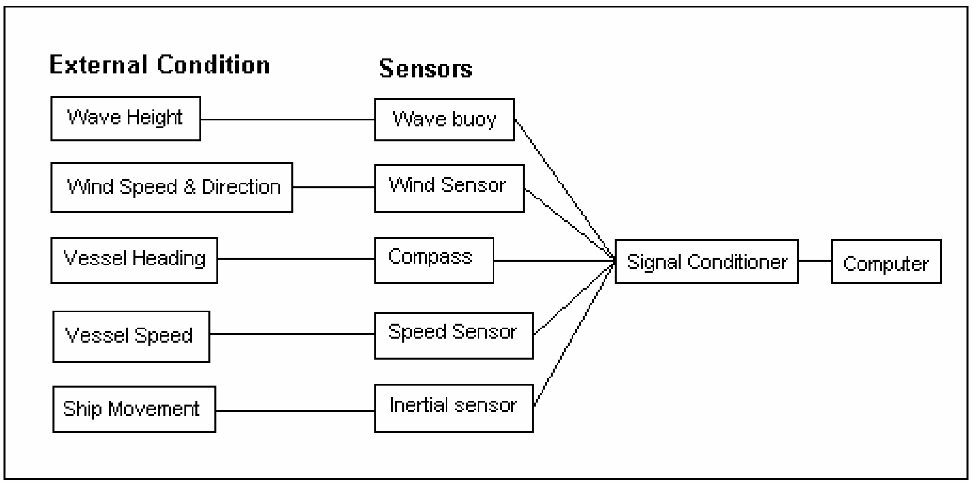
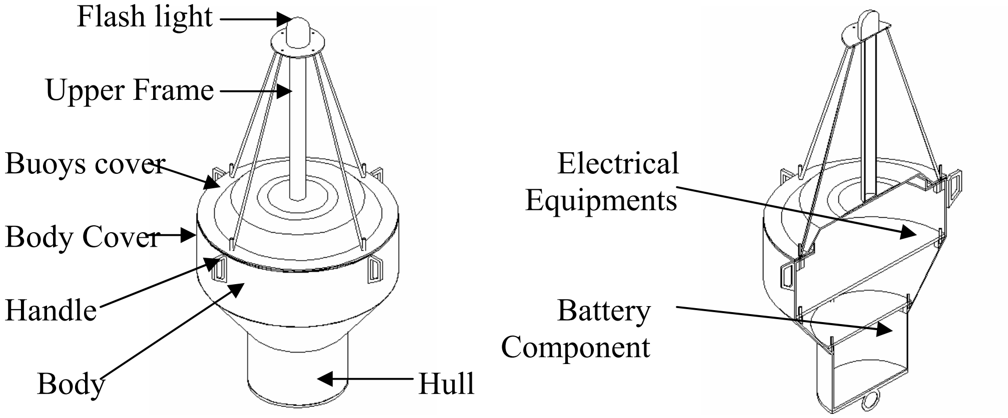


Figure 4: Flow of Data Processing and Analyzing

b) WAVE BUOY

The wave buoy has been used to measure the wave data at sea. It has been used while the VMMS operation at South China Sea. The wave buoy is equipped with an accelerometer, Data acquisition, GPS, battery, and a flashing light. The buoy floated up and down along the surface of the sea, and the accelerometer inside the buoy has measured the acceleration. The acceleration then converted to displacement by double integration using LabVIEW. Using this displacement the spectra has been achieved by spectral analysis using LabVIEW. The mooring system will constrain the area to some area centered about the anchoring system.



3D view **Slice View**

Figure 5: Wave Buoy

Wave Buoy Specifications:

Diameter (Max) = 0.6 m
Height = 0 .6 m
Displacement = 48.44 kg
Heave Natural Period = 1.1004 sec
Roll Natural Period = 0.8941 sec

RESULTS

The results regarding the wave and motion measurement will be presented in this paper. The results obtained from the measurement are plotted in the form of wave spectra. These wave spectra are compared with some standard spectra. Also the heave, pitch, and roll motions are plotted in the form of spectra called response spectra. From them the RAO was calculated.

Bretschneider spectrum is based on the following formula [8]

$$S(\omega) = 0.1687 H_{1/3}^2 \frac{\omega_s^4}{a^5} \exp^{-0.675(\omega_s / \omega)^4} \quad (2)$$

The theoretical formulations for the Pierson-Moskowitz spectra are based on Gran [9]. The formulation used the significant wave height and peak period of the measured spectra and since wind speed is not included, uncertainties in wind speed measurement are eliminated. The Pierson-Moskowitz spectra can be represented as-

$$S(\omega) = \frac{5}{16} \frac{H_S^2}{\Omega} (\frac{\omega}{\Omega})^{-5} e^{-\frac{5}{4}(\frac{\omega}{\Omega})^{-4}} \quad (3)$$

The JONSWAP spectra which is a peak enhanced Pierson-Moskowitz spectra given in the form [9]

$$S(\omega)=\frac{\alpha g^2}{\omega^5}\exp\left\{-\frac{5}{4}(\frac{\omega}{\Omega})^{-4}+e^{-\frac{1}{2}\frac{(\omega-\Omega)^2}{(\sigma\Omega)^2}}\ln\gamma\right\} \qquad (4)$$

Where: $\Omega=\left(\frac{4}{5\pi}\right)^{\frac{1}{4}}\frac{2\pi}{T_Z}$ is peak frequency, and $\gamma = 7(1-2.18\times10^{-5}\frac{g^2T_z}{H_2^2})$

Usually γ is in the range $1<\gamma<5$

$\alpha=\frac{4\pi^3}{g^2}\frac{H_S^2}{T_Z^4}$ is the Philips constant.

g = Acceleration due to gravity in m/sec^2

Usually the value for γ is taken as 2.5

$\omega_s = 2\pi/T_{1/3}$

σ = Relative measure of the width of the peak.

σ= 0.07 for $\omega<\omega_p$
σ= 0.09 for $\omega>\omega_p$

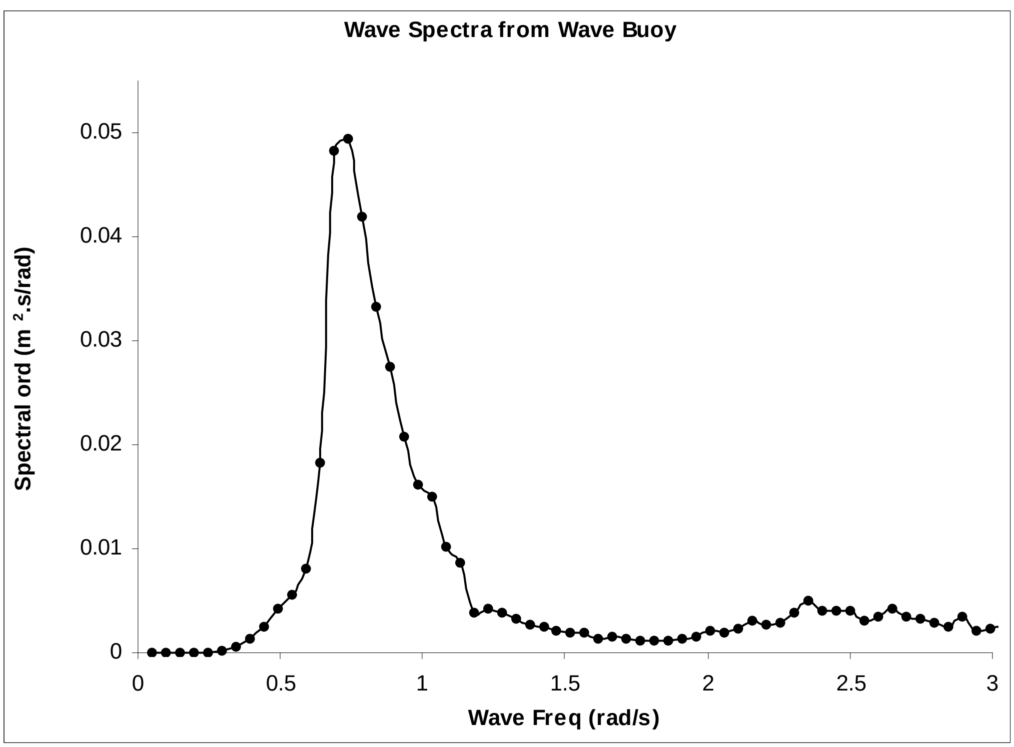


Figure 6: Wave Spectrum from the Wave Buoy Data

Table 3: The RMS values and Hs as calculated from the wave spectra

	Measured	P-M	JONSWAP	Bretschneider
RMS	0.1437	0.1496	0.1675	0.1498
Hs	0.5749	0.5987	0.6702	0.5990

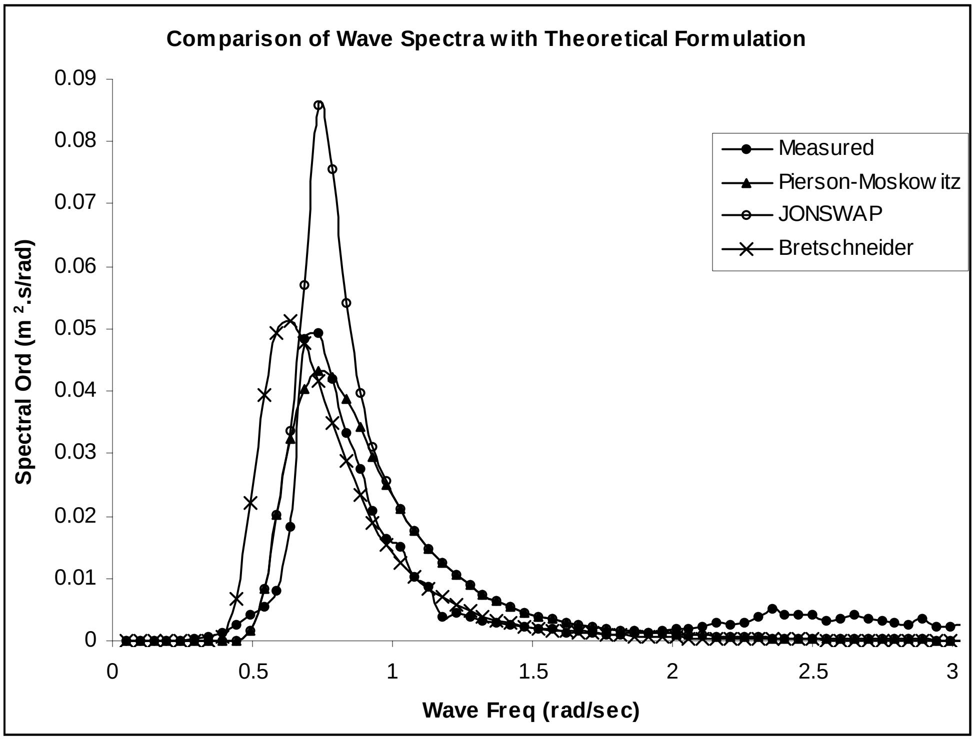


Figure 7: Comparison of wave spectra with theoretical formulation

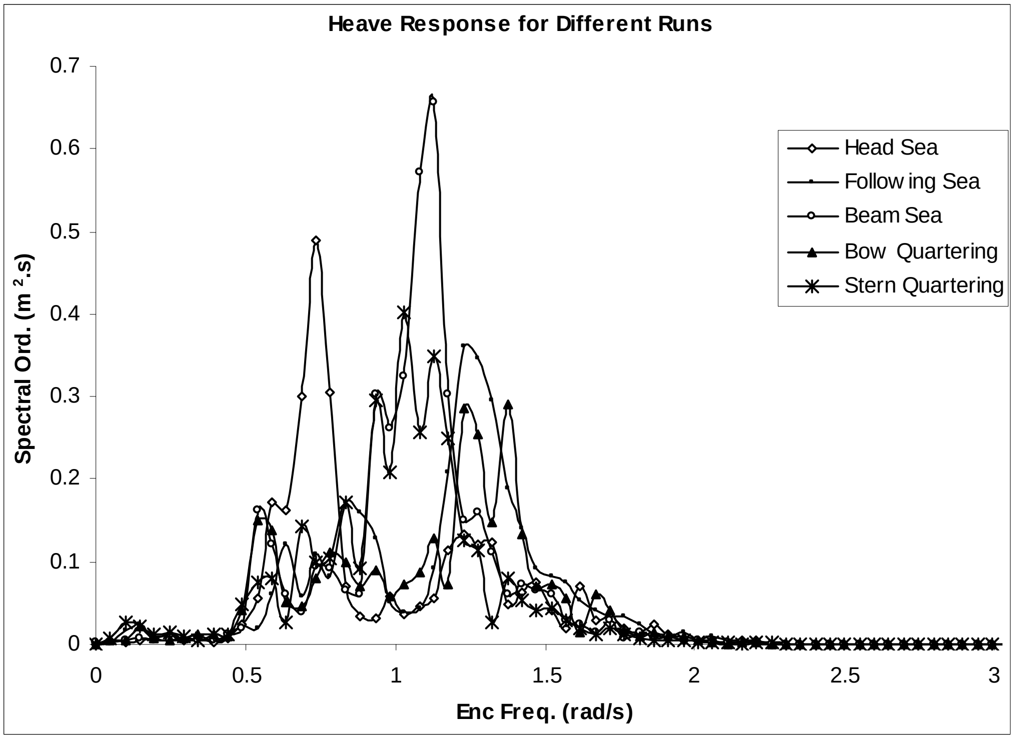


Figure 8: Heave spectra for different runs

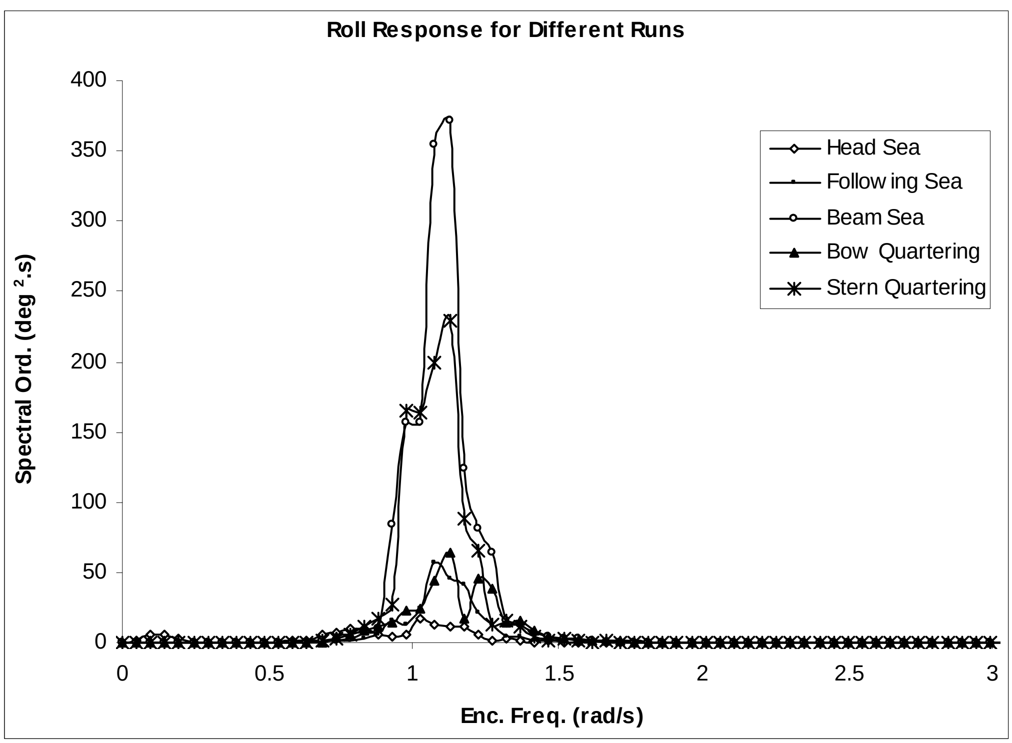


Figure 9: Roll spectra for different runs

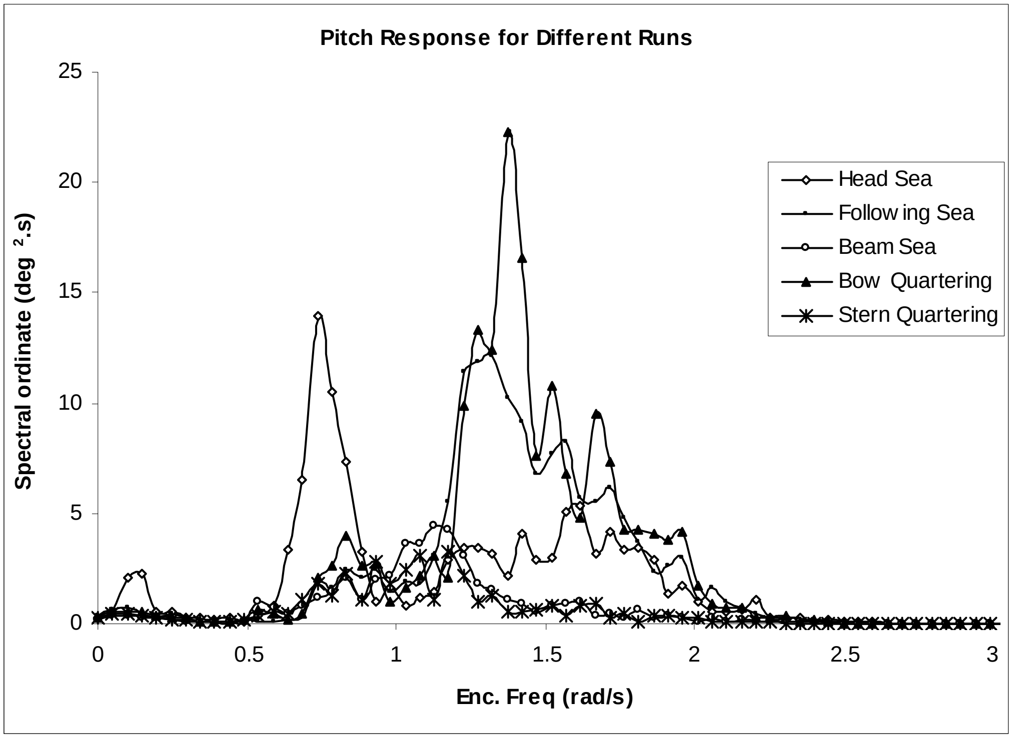


Figure 10: Pitch spectra for different runs

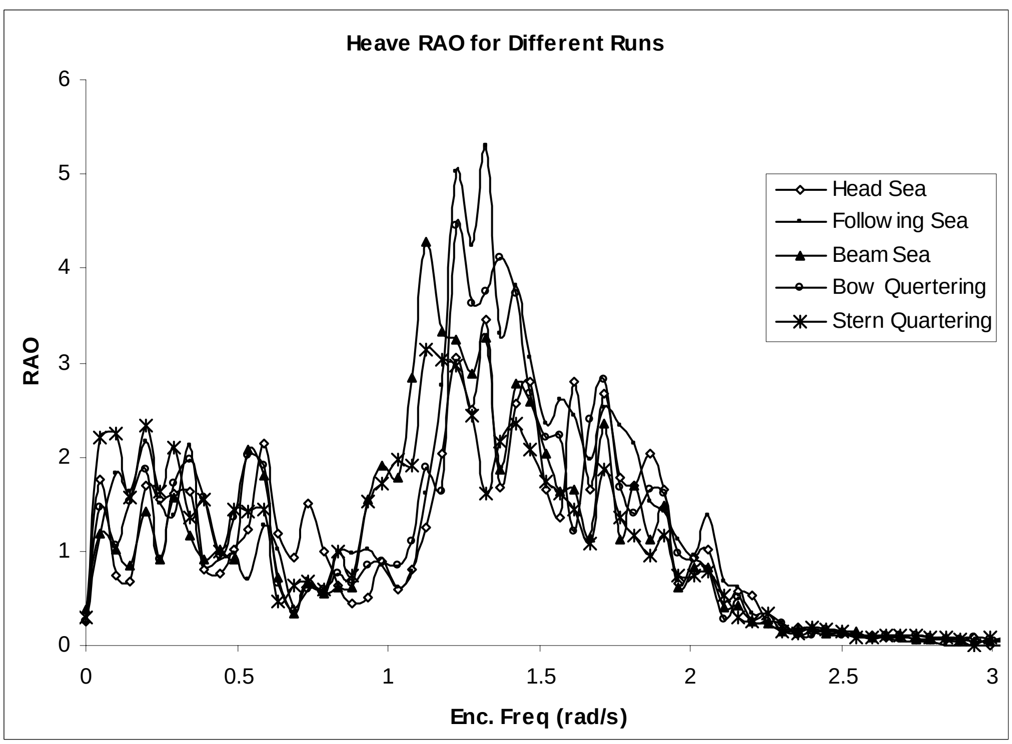


Figure 11: Heave RAO for different runs

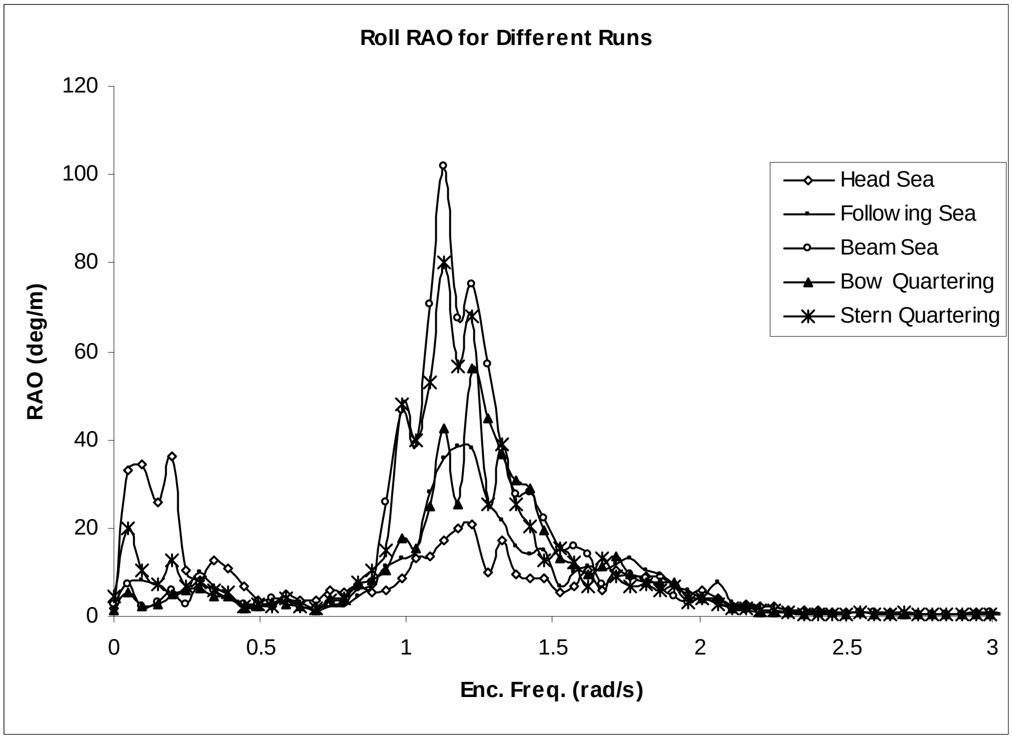


Figure 12: Roll RAO for different runs

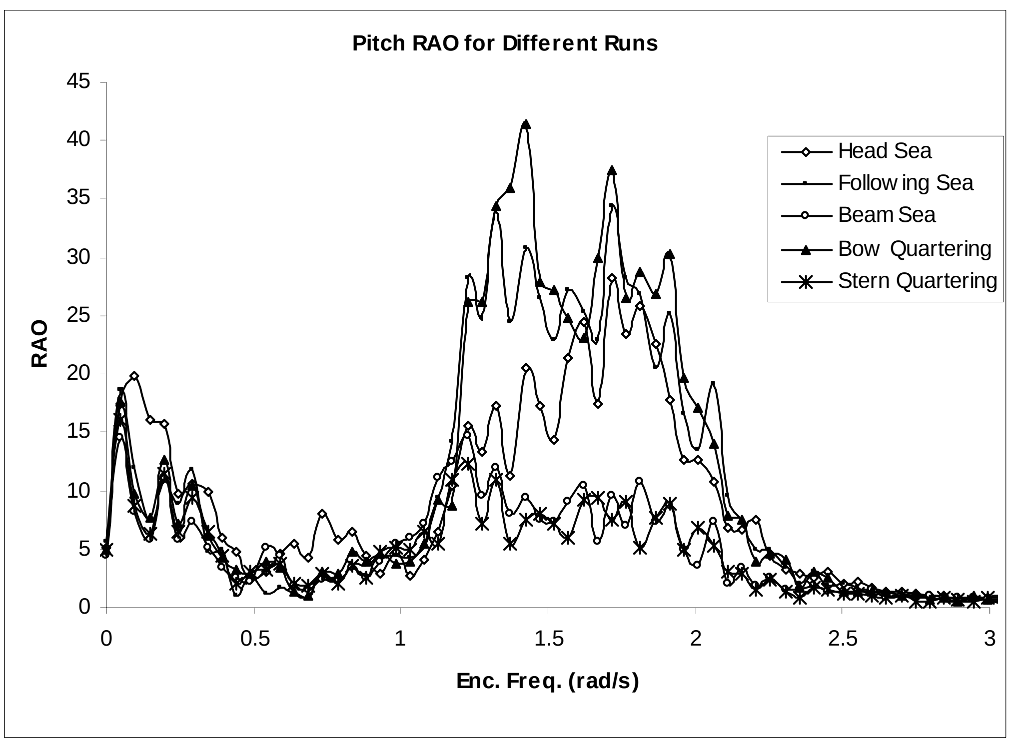


Figure 13: Pitch RAO for different runs

DISCUSSION

The wave spectra obtained from the wave buoy is plotted in Figure 6. This wave spectrum is the result of total 80 minutes, which is quite enough for the accuracy of full-scale data. The data has been averaged on each 20 minutes. The quality of the data from the wave buoy seem to be better except the in the frequency range from 2-3 rad/s. Theoretically the spectral density in this range should be zero, because at high frequency the net energy content becomes zero. The measured wave spectra are compared with three theoretical standard spectra such as Pierson-Moskowitz, JONSWAP and Bretschneider. Figure 7 shows that among the theoretical spectra, the JONSWAP spectral density is too high compared to others, the Pierson-Moskowitz and Bretschneider spectra fits well with the measured spectra. But the peak of Pierson-Moskowitz is little bit lower to the measured, whereas Bretschneider spectral peak is almost similar with the measured one. But the peak is shifted to the left. This may be due to the fact that the peak frequency chosen in the formulation is different with the measured one. The RMS values of the measured and theoretical spectra are shown in table 5. They are almost equal except the JONSWAP spectra. From the RMS values of the measured and theoretical wave spectra the H_S were calculated. From this point of view the Pierson- Moskowitz and Bretschneider spectra are quite similar with the measured one.

Figure 8 shows that the heave response is higher in beam and head sea. In Figure 9 it is clearly visible that the roll motion is higher in Beam Sea, which is usual but the heave response is less in this plot. In Figure 10 the pitch response is higher in bow quartering and head sea**.** From figure 9 &10 one thing can be noted. The area under the response spectra for roll is less than that of pitch. This is due to the small amount of wave that passing through the body which creates roll motion. For the pitch motion a larger amount of wave passes though the body which creates pitch motion. Therefore the energy in roll motion is less than that of in pitch. Figure 11 and 12 shows that the RAO for Heave and Roll are quite consistent. Overall they are acceptable. But question arises regarding to the peak value of RAO. However it gives us important information where the maximum response will occur. The peak frequency of these RAO shows the natural frequency for heave, pitch and roll. From the RAO curve it clear that the RAO for Heave and roll in head and beam sea is high as seen in Figure 11 and 12. From here the result is clear-cut. But from figure 13 it is visible that the Pitch RAO is not consistent. This may be due to the fact that large amount of wave from different direction were passing while considering the pitching motion. The wave affects greatly on the pitching motion of the boat. There may have some influence of the boat motion, which prevents the system to gain the correct data.

CONCLUSION

A methodology for measuring the wave spectra and vessel motion has been presented in this paper. The spectra obtained from the wave buoy seem to be acceptable because from the area under the spectra the significant wave height was calculated which is quite similar with the predicted wave height on that day. Overall the results from the VMMS are better except for the pitching motion. From the comparison of wave spectra with theoretical, it can be concluded that Pierson-Moskowitz spectra or Bretschneider spectra can be used for the design of Malaysian ship or floating structures. The RAO for Heave and Pitch can be used to predict the motion of similar fishing vessel in Malaysian water. But the Pitch RAO seems to be not consistent. The data acquisition from the VMMS should be improved specially for pitch motion. More and more wave buoy data in different season of the year at different locations should be taken for the establishment of spectra for Malaysian water.

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NOMENCLATURE

$S_r(\omega e)$ = Encountered response spectra
$S\varsigma(\omega e)$ = Encountered wave spectra
$H_{1/3}$ = Significant Wave Height in meter
Tz = Zero crossing period in second
$T_{1/3}$ = Significant wave period in second
Ω = Peak frequency in rad/s
γ = Peak enhancement factor

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