SEAKEEPING ANALYSIS OF A FISHING VESSEL OPERATING IN MALAYSIAN WATER

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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 more 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.

Keywords: *Seakeeping, response amplitude operator (RAO), full-scale measurement, wave spectra*

1.0   INTRODUCTION

Fishing vessels in Malaysia are mostly traditionally built. During their operations they have to work in relatively rougher weather as compared to the larger commercial vessels. Since there is no formal design processes involved during their building, the safety of these vessels operating in the hostile seaway is questionable. It is thus necessary to analyse the performance of these vessels in the seaway of which they operate.

The motion analysis of vessels behaviour in a seaway is commonly referred to as Seakeeping. The modern study of Seakeeping began its roots in early 1950's. The study was initiated by the application of hydrodynamic theory, in the use of

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experimental model technique and in the collection of full-scale empirical data. The paper by St. Denis and Pierson [1] are of particular importance. It showed that the ship motion in random waves could be calculated using the technique of spectral analysis borrowed from the field of electromagnetic communications. A significant paper by Ursell [2], indicates the flow around a circular cylinder oscillating in a free surface could be theoretically calculated. These findings, paved the way for the prediction of 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.

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.

In the study of seakeeping, the correct selection of wave spectrum for a particular seaway is essential. Measurements and analysis of wave heights for the Malaysian waters were carried out by Yaakob and Maimun [5]. 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 wave pressure sensor. Though the results were not conclusive, it mainly indicates that standard spectra of Pierson-Moskowitz type could be used for the Malaysian waters.

2.0   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.

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 $S_r(\omega e)$ then the response spectra of the vessel in that particular seaway is given by:

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

Similarly, from the above equation, the RAO of the vessel can also be derived if the response spectrum, S_r (ω_e) and encountered wave spectrum, S_ζ (ω_e) are known.
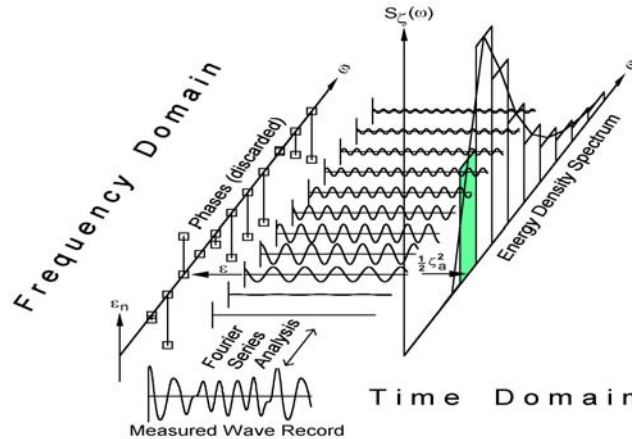

Figure 1: Principle of conversion from time domain to frequency domain

3.0   FULL SCALE MEASUREMENT

The aim of full-scale sea trial is to give a better understanding vessel behavior in the real environment. It also helps in correlating results between theoretical calculations and model tests.

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

The field measurement was carried out on the 18th September 2005 using a Malaysian fishing vessel belonging to Universiti Teknologi Malaysia (UTM). The main particulars of the vessel are shown in the Table 1. A total of 5 runs were carried out and the details of the locations with various conditions are shown in the Table 2. Run number 1 was carried out in Head Sea, run 2 in Following Sea, run 3 in Bow quartering, run number 4 in Beam Sea and run number 5 in Stern quartering sea.
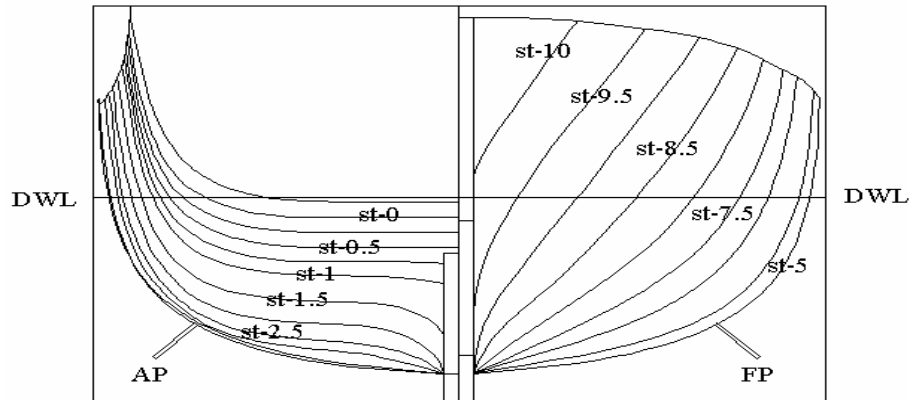

Figure 2: Body plan of TRF 1010

This fishing vessel is provided with a pair of bilge keel whose dimensions are given below:

Bilge keel specifications**:**

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 full-scale measurement

Conditions	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5
Start					
Latitude	$05^014'$	$05^013'$	$05^016'$	$05^017'$	$05^016'$
Longitude	$103^032'$	$103^032'$	$103^031'$	$103^030'$	$103^028'$
Ship speed (Knots)	4.2	5.7	5.1	3.7	3.5
End					
Latitude	$05^013'$	$05^013'$	$05^017'$	$05^017'$	$05^016'$
Longitude	$103^032'$	$103^032'$	$103^030'$	$103^028'$	$103^027'$
Ship speed (Knots)	4.3	5.9	5.3	3.9	3.7

4.0   MEASURING EQUIPMENT

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 in the following:

4.1   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 mainly comprised of a microwave wave height sensor, wind sensor, compass, a set of accelerometers and gyroscopes (placed in the Inertia box), a connection box and a processing unit shown in Figure 3. The processing system and data analysis of VMMS is shown in Figure 4.
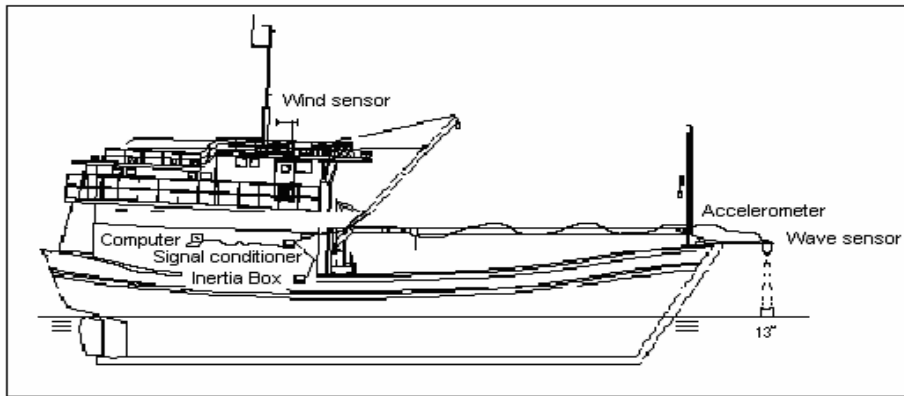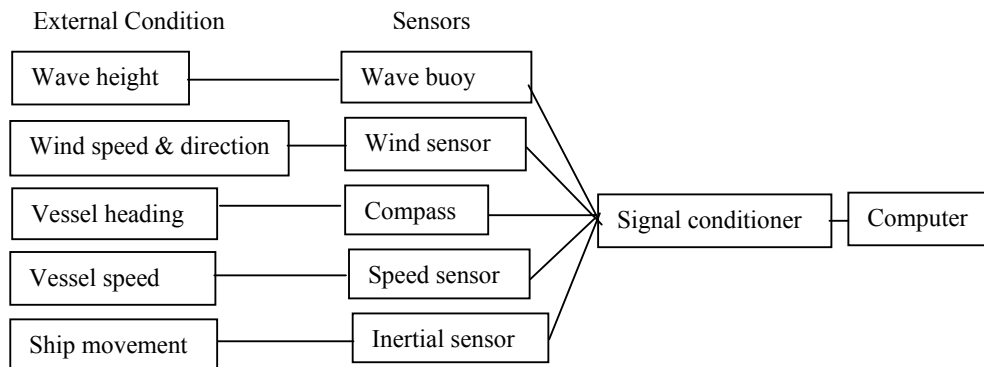

Figure 3: Typical installation of VMMS

Figure 4: Flow of data processing and analyzing

4.2   Wave Buoy
The UTM wave buoy was used to measure the wave heights at sea. The wave
buoy developed at UTM is equipped with an accelerometer, Data acquisition,
GPS, battery, and a flashing light. Wave heights were derived from the heaving
motions of the buoy measured by the accelerometer. Vertical motions of buoy
were obtained by double integrating acceleration using LabVIEW software. The
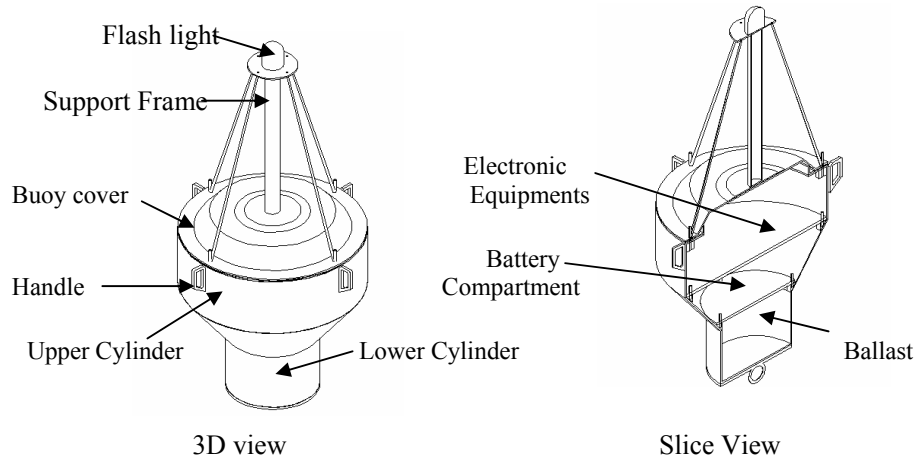wave height spectrum was derived by spectral analysis.

Figure 5: UTM 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

5.0   RESULTS AND DISCUSSION

The results of wave and motion measurements are 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]:

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

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:

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

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

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

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where: $\Omega = \left(\frac{4}{5\pi}\right)^{\frac{1}{4}} \frac{2\pi}{T_Z}$ is peak frequency, and $\gamma = 7(1 - 2.18 \times 10^{-5} \frac{g^2 T_z}{H_2^2})$

Usually γ is in the range $1<\gamma<5$. For the particular case, value $\gamma = 2.5$ is taken.

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

g is acceleration due to gravity in m/sec^2

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

$T_{1/3}$ is significant period of waves

σ is the relative measure of width of the peak

$\sigma = 0.07$ for $\omega < \omega_p$

$\sigma = 0.09$ for $\omega > \omega_p$

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 for every 20 minutes of sampling duration. The quality of the data from the wave buoy seem to be better except in the frequency range from 2-3 rad/s. Theoretically the spectral density in this range should be zero, because at high frequencies 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 3. They are almost equal except the JONSWAP spectra. From the RMS values of the measured and theoretical wave spectra, the significant wave heights, H_S were calculated. From this point of view the Pierson-Moskowitz and Bretschneider spectra are quite similar with the measured one.
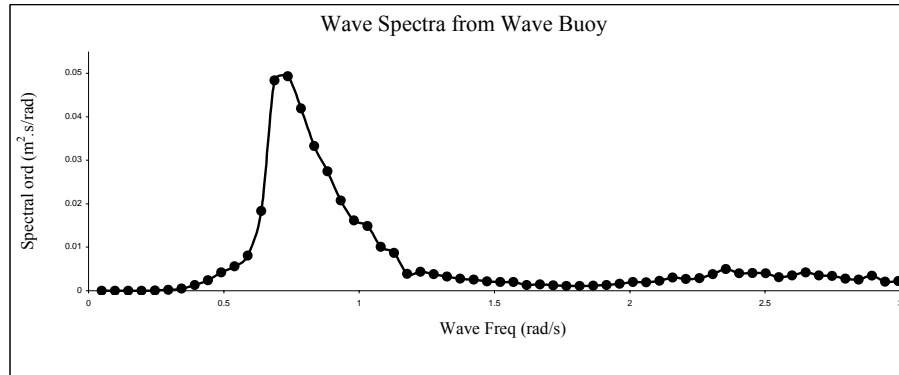
Figure 6: Wave spectrum from the wave buoy data

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 8 shows that the heave response is higher in beam and head seas. In Figure 9 it is clearly seen that the roll motion is highest in beam sea. In Figure 10 the pitch response are highest in bow quartering and head seas. From the results, it is noted that roll has a peaky response spectra in the region near to its natural frequency. Whereas, for pitch the response is more flattened and dispersed. Firstly, this is due to along the length of the vessel the pitch motion has more interactions with waves of different frequencies and directions. Secondly, pitch restoring moment is much larger than roll restoring moment. Thus, the exciting moment and energy required to pitch the vessel is much more than to roll it. Figure 11 and 12 show that the RAOs for heave and roll are quite consistent with their maximum responses occurring near their natural frequencies. The RAOs for heave and roll are highest in head and beam seas respectively. However, for pitch, as expected Figure 13 shows RAOs obtained were not consistent. This is as a consequence of the flattened and disperse nature of response spectrum for pitch.
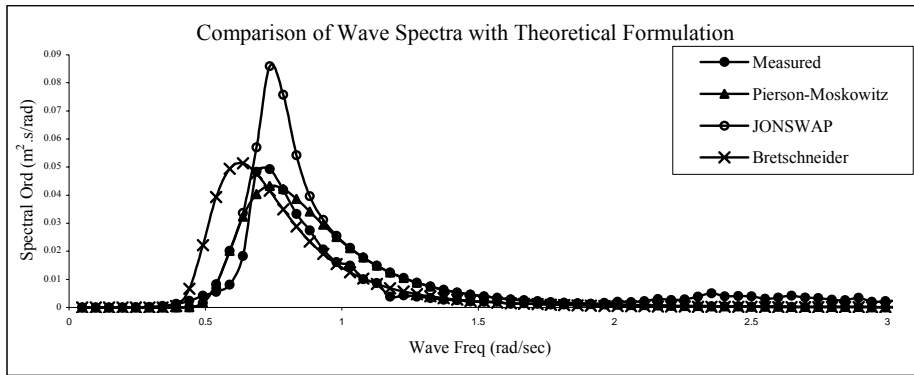
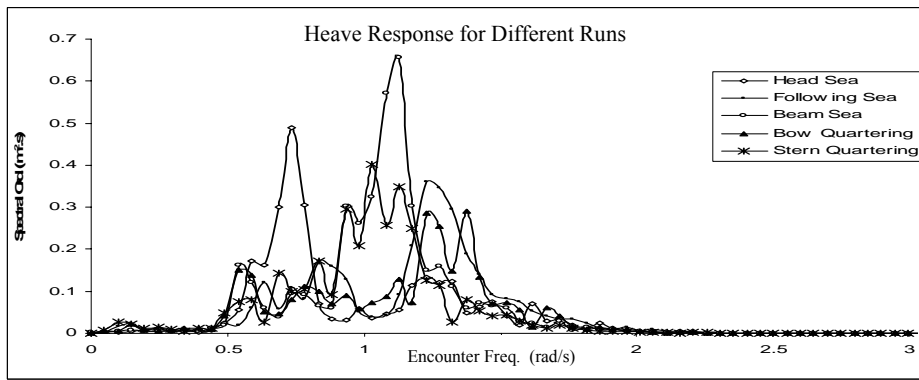Figure 7: Comparison of wave spectra with theoretical formulation

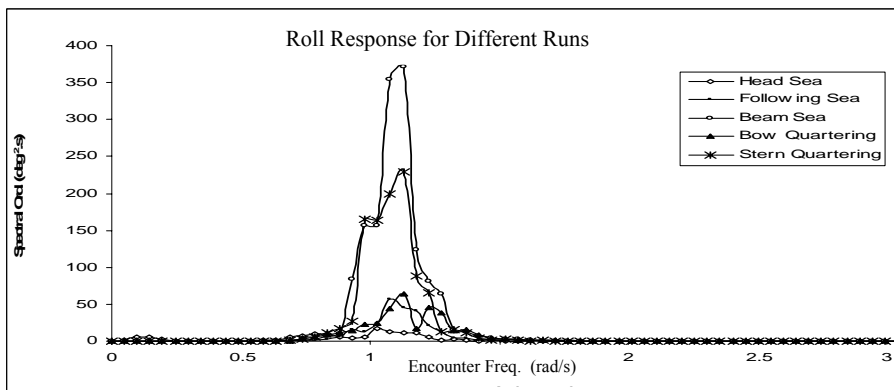Figure 8: Heave spectra for different runs
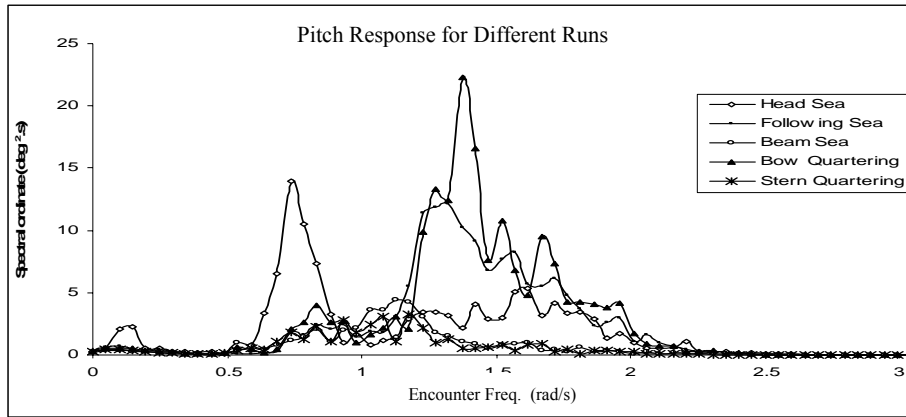

Figure 9: Roll spectra for different runs

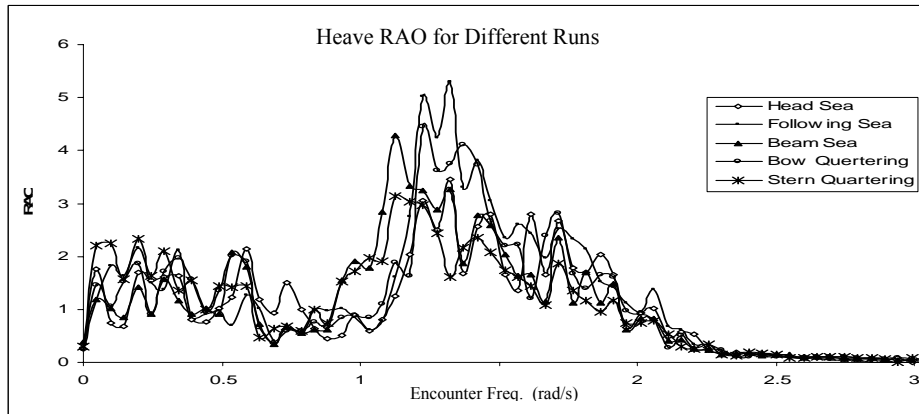Figure 10: Pitch spectra for different runs
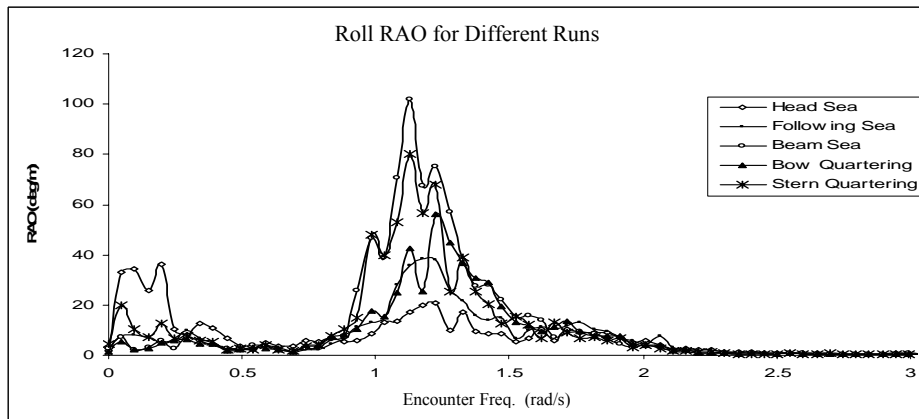

Figure 11: Heave RAO for different runs
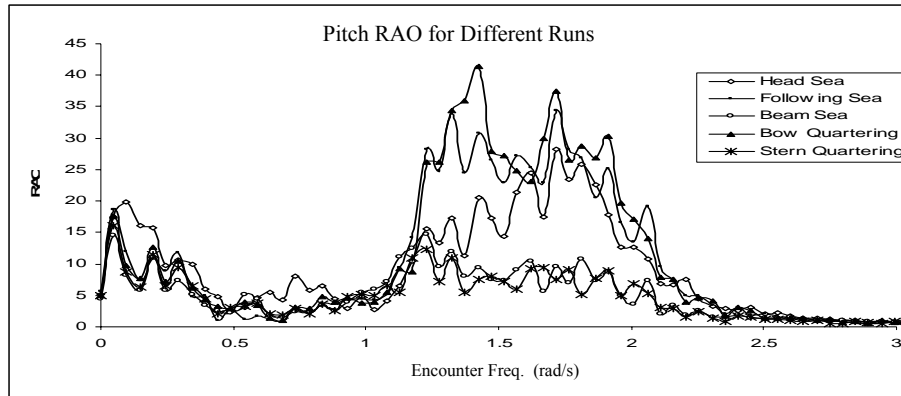

Figure 12: Roll RAO for different runs

Figure 13: Pitch RAO for different runs

6.0   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. Comparison of wave spectra between measured and theory, shows that Pierson-Moskowitz or Bretschneider spectra can be used for the seakeeping assessment of Malaysian vessels or offshore structures.

The motions response spectra derived using the VMMS are generally acceptable except for the pitching motion. The derived RAOs for Heave and Roll can be used to predict the motions of similar fishing vessels operating in Malaysian waters.

The measuring and data acquisition system should be improved especially for pitch motion. More wave data should be collected for different seasons of the year at different locations for the establishment of wave spectra for Malaysian waters.

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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