A Study on Motion Responses of Classic Spar Platforms Subjected to Short Crested Waves

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***Abstract*— The wind generated seastate in the real sea condition is well represented by the short crested waves or the multi-directional waves. The short crested waves are identified as the linear summation of the randomly generatedlong crested waves that propagate to different directions. In this paper, experimental and numerical studies on the dynamic responses of the classic spar platforms subjected toshort crested waves are presented. The experimental study was performed in the Offshore Laboratory of Universiti Teknologi PETRONAS. In the study, the classic spar model was restrained by four mooring lines and subjected to short crested waves. A MATLAB code was developed to analyze the dynamic responses of the classic spar. The classic spar was modeled as a rigid body with three degrees of freedom in surge, heave and pitch motions. In each time step of the analysis, the mass, damping and stiffness matrices were computed. Newmark Beta method was employed to solve the dynamic equations of motion. Response amplitude operators (RAO) were estimated and compared with the measurements. The results compared well.**

***Index Terms* -Short crested waves; Model tests, Wave basin, Response amplitude operator, Dynamic responses**

I. INTRODUCTION

In the design of offshore structures, the major parts of the total environmental force consist of the wave force. Waves are categorized as long crested and shore crested based on the wave propagation directions. Waves propagated to one direction are classified as long crested waves. On the other hand, waves propagated to two or more directions are classified as short crested waves. In other words, the short crested waves are defined as the linear summation of different long crested waves from different directions. The short crested waves indeed provide better accuracy for the wind generated seastate as compared to long crested waves [1]. Short crested waves are found to be three dimensional, complex and short crested [2].

Researches focused on short crested waves have begun since 1970s, where the studies are mainly focused on directional wave force, directional wave spectrum, wave kinematics and vertical circular cylinder. Zhu and Satravaha [3] presented a closed form solution for the velocity potential up to second order wave amplitude of the nonlinear short crested wave's diffraction by vertical cylinder. Another solution for the diffraction of short crested wave incident on a circular cylinder was presented by Zhu [4], where the short crested incident wave loading obtained by using plane incident waves would be overestimated. This theory was then extended by Jian et al [1] to take account of the effect of a uniform current for different incident angles. In the study, an analytical solution of diffraction of short crested incident wave along positive x-axis direction on a large circular cylinder with current was derived. Zhu and Moule [5] studied the short crested wave forces on vertical cylinders with various cross sections i.e. the circular, elliptical and square cross sections. The safety of using the reduced 3D loads in the offshore design was studied by Aage [6], and it was proven that the wave load exerted on cylinder in 3D wave was smaller than that for 2D waves with identical spectra or even identical wave elevation time series. Huntington and Gilbert [7] studied the theory to obtain extreme force in short crested seas. The theory of linear diffraction was extended by Huntington and Thompson [8] to suit the condition of short crested multi-directional random waves exerted on a large surface piercing cylinder.

Limited resources of measured directional data for waves, and wave directional spectra for design purposes caused the directional wave statistics not widely been used. Therefore, Borgman [9] developed a directional spectral model for design use. Fernandes [10] studied the measured directional spectrum by the phase-time-path-difference (PTPD) method. Another method to estimate the directional spectra using high frequency ocean radar was studied by Hisaki [11]. Hogben and Cobb [12] established a method for parametric modeling of directional spectra that could account for wind generated sea and swell waves. Haver [13] studied the choice of wave spectrum on extreme response and the effects of wave directionality on a deep water jacket. A high resolution wave model was designed and it evaluated the performance under hurricane wind focus on various observed data by Moon et al [14]. A method to obtain an analytical expression of spectral density function for ocean surface elevations and slopes in transverse and longitudinal along the straight line path of vehicular moment in a fully developed short crested sea was investigated by Li [15].

To develop directional wave spectra that are defined as a product of frequency or point spectrum and spreading function, spreading function such as $\cos^2$, stereo wave observation project (SWOP), Mitsuyasu etc. are adopted. The characteristics of directional spread parameters at intermediate water depth by $\cos^{2s}$ directional spreading model was studied by Kumar et al [16]. Also, the wave directional spreading in shallow water and variations in estimated wave direction using first and second order Fourier coefficients was well studied by them [17][18].

To prove the effectiveness of the short crested wave statistics for the design of offshore structures, an experimental study, the wave tank test, focused on the dynamic motion responses of a classic spar model subjected to long and short crested waves was performed and is presented in this paper. Also, the dynamic motion responses were numerically computed and verified with model tests. The dynamic motion responses obtainedby both methods arecomparedand discussed.

II. METHODOLOGY

A. Wave tank tests

An experimental study was performed to study the dynamic motion responses of the classic spar model subjected to long and short crested waves. The study was performed in the wave tank located in the Offshore Laboratory of Universiti Teknologi PETRONAS. Fig. 1 and 2 show the wave tank and wave generator.

Fig 1 Wave tank of Offshore Laboratory in UTP

1) Model description

In this study, a classic spar with a scale of model 1:100, constructed from steel plates was investigated. Table I shows the summary of the calculated structural data of the classic spar (in full scale). The classic spar model was tested for multi-directional waves with $\cos^2$ spreading function, generated by the wave generator in the wave tank of UTP. The model was restrained by mooring lines and the dynamic motion of the model was measured by optical tracking system as shown in Fig. 3 and 4.

Fig 2 Wave Generator of the wave tank

TABLE I MODEL DIMENSIONS

Description	**Model (m)**	**Prototype (m)**
Diameter	0.300	30.00
Hull Length	0.899	89.90
Draft	0.699	69.90

Fig 3 Optical tracking system

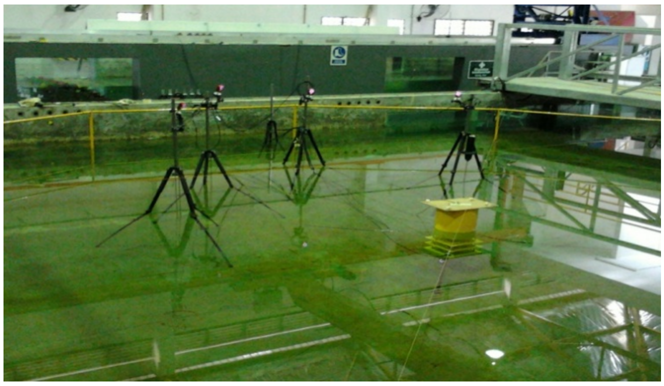

Fig 4 Model setup with optical tracking system

2) Wave data details

The wave generator defines the multi-directional waves as a product of wave spectra and spreading function. In this study, spreading function, cosine square ($\cos^2$) and Mitsuyasu incorporated with JONSWAP wave spectrum were considered. Table II shows the details of the wave data generated for multi-directional waves on classic spar model.

TABLE II WAVE PROPERTIES

	Wave Frequency (Hz)	Wave period (s)	Significant Wave Height (m)
A	0.50	2.00	0.08
B	0.63	1.60	0.07
C	0.71	1.40	0.06
D	0.83	1.20	0.05
E	1.00	1.00	0.04
F	1.25	0.80	0.04

3) Sea-keeping test

To determine the sea-keeping motion responses in the real sea condition of the model, it was tested for multi-directional waves. Fig. 5 shows the setup of the test; where on the fore and aft side of the model springs with steel wires were attached. Wave data as discussed were programmed and generated. The dynamic motion responses of the classic spar model in three degrees of freedom, the surge, heave and pitch were recorded.

4) Data post-processing

Raw data obtained from the system was analyzed by post-processing program to determine the response spectra using the Discrete Fast Fourier Transformation method. The dynamic motion responses of the classic spar are presented in terms of Response Amplitude Operators (RAO). The RAO for surge, heave and pitch were obtained by the following equation.

$$RAO = \sqrt{\frac{S_R(f)}{S(f)}} \quad (1)$$

Where S_R give as the motion response spectrum of surge, heave and pitch respectively, S is the wave spectrum and f is the wave frequency.

B. Numerical Analysis

The dynamic responses of the classic spar model subjected to short crested waves was studied numerically by Kurian et al [19]. In the paper, numerical code was developed by using MATLAB program incorporatingthe diffraction effects at the vicinity of the structure due to large structure like classic spar. Hence in this paper, the numerical predicted responses from the paper were adopted and compared with the measured responses obtained from this study. The comparisons of both methods to obtain the dynamic motion responses are presented in the next section.

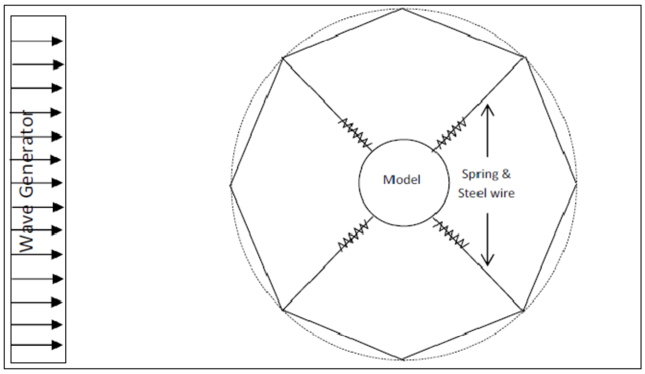

Fig 5 Plan view of the experimental setup

III. RESULTS AND DISCUSSION

In this study, an attempt to investigate the dynamic motion responses of a classic spar subjected to short crested waves was performed. Fig. 6 and 7 show the measured wave profile for short crested wave and the measured surge response of classic spar. In Fig. 8, the comparison of the model surge RAO due to short crested wave by numerical and experimental analysis was shown. It was found that the model surge was the maximum at a wave frequency 0.063Hz, where 0.323m/m and 0.286m/m were the measured and predicted responses. Maximum difference of about 60% was found at wave frequency 0.088Hz. The magnitude reduced as the wave frequency increased. Fig. 9 and 10 show the measured heave response of the classic spar, and the comparison of heave RAOs, measured and predicted. The greatest heave responses of the classic spar model of about 0.5655m/m and 0.519m/m were found at 0.056Hz for the experimental and numerical analysis respectively. Also, at 0.063Hz, maximum difference of heave RAO of about 55% was found. Fig. 11 and 12 show the measured pitch responses and the comparison of classic spar pitch RAOs by numerical and experimental methods. Maximum difference of about 21% was found at frequency 0.063Hz. The pitch RAO was found to be maximum at the low frequency region, and reduced as the frequency increased.

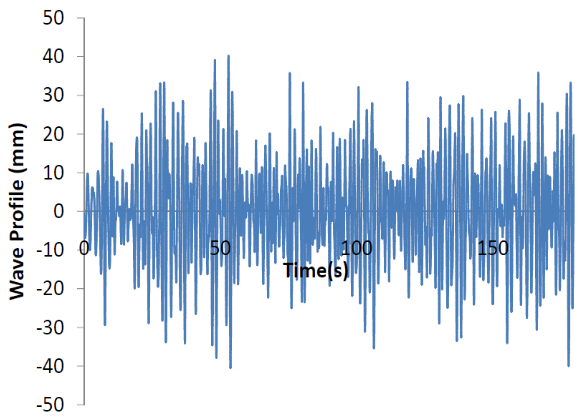

Fig 6 Measured wave profile (model scale)

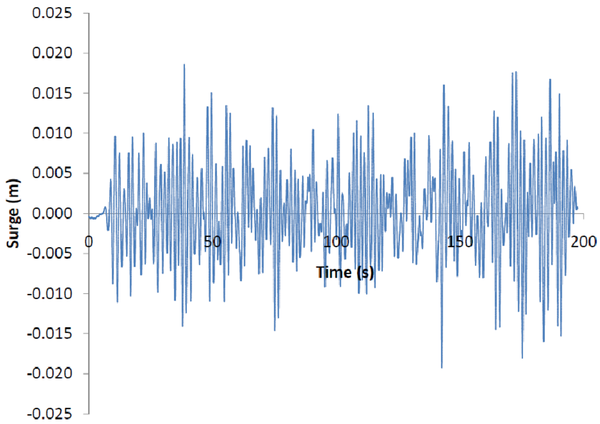

Fig 7 Measured surge response

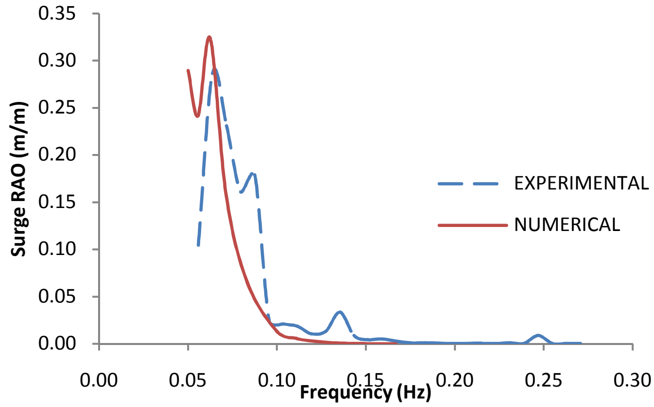

Fig 8 Surge RAO comparison of the classic spar model

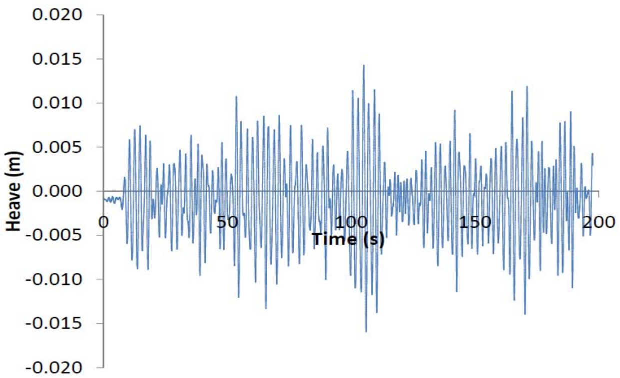

Fig 9 Measured heave response

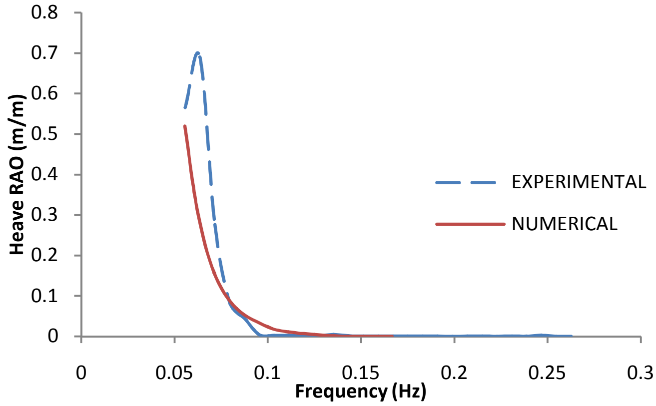

Fig 10 Heave RAO comparison of the classic spar model

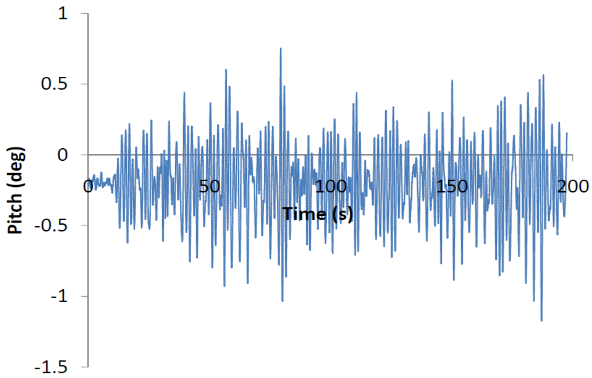

Fig 11 Measured pitch response

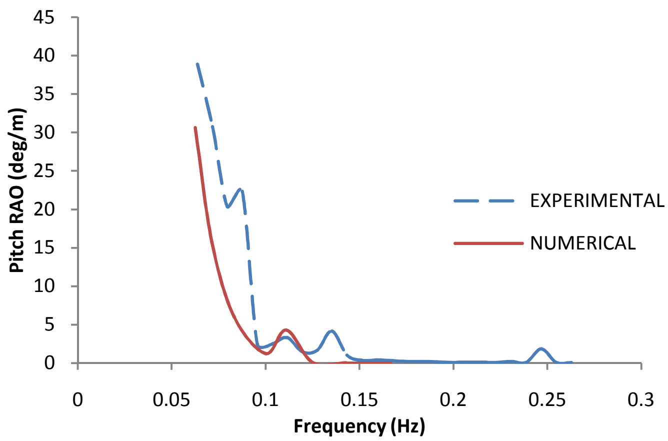

Fig 12 Pitch RAO comparison of the classic spar model

IV. CONCLUSION

In this study, an experimental program was performed to investigate the dynamic motion responses of the classic spar subjected to short crested waves. A classic spar was modeled with model scale of 1:100. Multi-directional waves were generated to study the dynamic motion responses of the model. From the study, the following conclusions were drawn:

- Maximum surge RAO occurred at wave frequency 0.063Hz, where 0.323m/m was predicted numerically and 0.286m/m was measured experimentally.

- Maximum heave RAO of about 0.5655m/m was measured and 0.519m/m was predicted at wave frequency 0.056Hz.
- At wave frequency 0.063 Hz, a maximum pitch RAO of about 38.895deg/m and 30.663deg/m were obtained by experimental and numerical methods respectively.
- All the three RAOs have a similar trend of maximum at the low frequency region. The RAOs gradually reduced as the wave frequency increased.

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