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Dynamic Responses of Classic Spar Platform: Short Crested Waves vs. Long Crested Waves

C.Y. Ng[1], V.J. Kurian[2], M.S. Liew[3]

NG Cheng Yee[1, a], VELLURUZHATHIL John Kurian[2, b] and MOHD. Shahir Liew[3, c]

[1, 2, 3] Civil Engineering Dept., Universiti Teknologi PETRONAS, Tronoh, Perak, Malaysia

[a] carrol.ng82@gmail.com, [b] kurian_john@petronas.com.my, [c] shahir_liew@petronas.com.my

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Abstract. The long-crested wave properties have been widely implemented in the design of offshore structures. However, long-crested waves are seldom found in the real sea condition. Many research papers have also stated that wave forces obtained by the waves would be overestimated. Indeed, the real sea conditions are better represented by the short-crested waves. Hence, in order to obtain an optimum design for the offshore structures with cost and time effective, consideration of the short-crested nature of waves is necessary. In this paper, a study comparing the responses of the classic spar due to short-crested waves and long-crested waves obtained experimentally has been performed. The model tests have been carried out in the wave tank of Offshore Laboratory for Universiti Teknologi PETRONAS. In the model tests, short-crested waves and long-crested waves were generated. Responses of the classic spar model were recorded by the Optical Tracking System (OptiTrack). The responses of the classic spar due to short-crested waves and long-crested waves were compared among. From the comparisons, the responses for short-crested waves in all the three degree of freedom (DOF) were found to be about 35% less than the responses for long-crested waves. Thus, it could be concluded that optimized and economical designs can be arrived at by considering the short-crestedness of the waves for classic spar structures.

Introduction

In the design of offshore structures, environmental condition is one of the important aspects that shall be considered. Wind, wave, current and iceberg are some of the common types of environmental force considered in the design. Wave forces are the dominating force among the total environmental forces. Wave forces are categorized as long-crested and short-crested based on the direction of the wave propagated. Long-crested waves (LCW) are defined as waves that propagate to only one direction. Short-crested waves (SCW) are defined as groups of LCW that propagate to various directions and the waves are randomly varying in the magnitude and direction. For the real sea conditions, waves would be better represented by SCW, whereby many aspects of the SCW shall not be ignored and could not be simulated by LCW [1]. The appearance of the SCW was found to be three dimensional, complex and short-crested [2]. By the wave properties of SCW in the design of offshore structures, optimum design of the structures with cost and time effectiveness could be arrived at.

Even though researches focused on wave forces have been widely performed, however the documents are concentrated mainly on LCW. Colby et al [3] performed a study focused on coupled and decoupled analysis of a deepwater spar in varying water depth subjected to LCW. Ran et al [4] performed a study focused on regular, bi-chromatic and long-crested irregular waves incorporated with and without currents to investigate the response characteristics of a spar by experimental and numerical method. A numerical simulation to investigate the coupled analysis of floaters subjected to LCW with current was developed by Ran [5]. In the simulation, tethered spar, classic spar, truss spar and tension leg platform were considered, where the results of coupled time domain analysis were systematically compared with the model test results of uncoupled analysis and frequency domain analysis. A relationship between the components, system performance of the offshore foundation and its mooring system of a spar was investigated by Young [6]. In this study, the reliability assessment of the platform under extreme environment for LCW was focused on the investigation. Sun [7] performed a study to analyze the force acting on a 3D cylinder with arbitrary cross section subjected to LCW. In his analysis, viscous effects such as viscous damping and viscous exciting force were considered. Experimental and theoretical study of wave forces and overturning moment acting on two geometrically similar concrete oil production platform subjected to LCW was performed by Garrison et al [8]. Pijfers and Brink [9] presented a method to obtain the mean and slowly varying drift force on a semi-submersible due to hydrodynamic loading in regular and irregular waves. From the survey, it was found that LCW were widely adopted in the study for offshore platforms, coastal platforms and so on, it is more precise to consider SCW wave properties in simulation of real sea condition. Researches on SCW were found since 1970s, which mainly focused on directional wave force, directional wave spectrum, wave kinematics and vertical circular cylinder. Zhu [10] developed a solution for diffraction of SCW incident on a bottom-seated circular cylinder. From this study, the wave loading from plane incident waves was found overestimated when incident waves were short-crested. Another solution in closed form for the velocity of the nonlinear diffracted SCW subjected to vertical cylinder was presented by Zhu and Satravaha [11]. The theory presented by Zhu was extended by Jian et al [12] to include the effect of a uniform current for different incident angles. An analytical solution for diffraction of short-crested incident wave along positive x-axis direction on a large circular cylinder with current was developed. The Zhu's theory again extended by Zhu and Moule [13] to incorporate the effect of wave induced forces due to SCW subjected to vertical cylinders with circular, elliptical and square cross section. Scaled Boundary Finite Element Method (SBFEM) was proposed by Tao et al [14] to solve the boundary value problem composed of short-crested incident wave diffraction on vertical circular cylinder. The method was presented as a novel semi-analytical method developed in elasto-statics and elasto-dynamic areas which used the advantages of both the finite element method and boundary element method. The method was extended by Song and Tao [15] to investigate the wave interactions of two cylinder systems with partially solid wall or opening subjected to 3D short-crested incident waves. Liu and Lin [16] [17] again extended the method to investigate the wave-platform interaction of the concentric platform with double layer arc-shaped perforated cylinders in SCW.

From the literature, very few numerical and experimental studies were found reported about the dynamic responses of spar platforms subjected to short-crested waves. In this paper, a study comparing the responses of the classic spar due to short-crested waves and long-crested waves that obtained experimentally is reported. The results have been compared and discussed.

Methodology

Wave tank tests were performed on the classic spar platform models to investigate the dynamic responses of the model subjected to both long-crested and short-crested waves in all the three DOF. The tests were conducted in the wave tank in the Offshore Engineering Laboratory of Universiti Teknologi PETRONAS. Details of the tests are illustrated as follow.

Laboratory facilities and instrumentations. The model tests were conducted in the wave tank measured approximately 22m total length, 10m width and 1.5m water depth as illustrated in Fig. 1 The wave maker is a multi-element wave maker that the paddles move individually forward and backward to generate various waves. Waves can be simulated to propagate in various angles such as bi-directional and multi-directional waves instead of uni-directional wave.

Model description. Classic spar model were fabricated by using steel plates with scaling factor 1:100 as shown in Fig. 2. Table 1 summarized the general structural data for the classic spar model.

Long-crested waves. Table 2 shows the random wave series considered for the wave spectrum method, where the JONSWAP spectrum with peak enhancement factor 3.3 was adopted. Data obtained from OptiTrack were analyzed and post-processed by Discrete Fast Fourier Transformation (DFFT) method to determine the response spectra. In this study, response in term of response amplitude operator (RAO) was considered, where RAO is given as

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

Where $S_R(f)$ is the motion response spectrum for the model, $S(f)$ is the wave spectrum and f is the wave frequency.

Figure 1. Wave tank in Offshore Laboratory of UTP

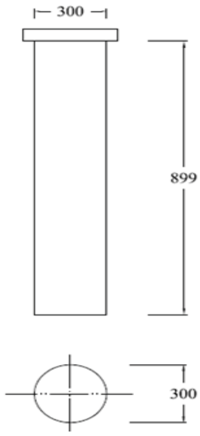

Figure 2. Drawing of classic spar model

Table 1. Structural data of classic spar model

Description	*Model (m)*	*Prototype (m)*
Diameter	0.300	30.00
Overall Length	0.899	89.90
Draft	0.699	69.90
Vertical CG from keel	0.31	31
Vertical CB from keel	0.40	40
Total mass, kg	13.302	13.302 x10^6

Table 2. Long-crested wave series

Wave series	*Wave Frequency, Hz*	*Wave Period, sec*	*Targeted Wave Height, m*
RD1	0.83	1.20	0.06
RD2	0.77	1.30	0.08
RD3	0.71	1.40	0.09
RD4	0.61	1.63	0.10

Short-crested waves. Spreading function technique is implemented with the method of modes to produce the short-crested waves. For each frequency in turn, the spreading function is integrated over the angular range corresponding to each mode, to obtain a series of factors. In the study, build in spreading function, $cos^2\theta$ was used. In this case, the formula is factored so that during the integration over the possible range of direction (±π/2), the result is 1.0 for the spreading function. Table 3 tabulated the short-crested wave series generated.

Table 3. Short-crested wave series

Wave series	*Directional Spreading Function*		*Spectrum*
MC2	Cos^2 Spread		JONSWAP
Wave series	*Wave Freq, Hz*	*Wave Period, sec*	*Targeted Wave Height, m*
A	0.50	2.00	0.08
B	0.63	1.60	0.08
C	0.71	1.40	0.08
D	0.83	1.20	0.08
E	1.00	1.00	0.08
F	1.25	0.80	0.08
G	0.71	1.40	0.07
H	0.83	1.20	0.07
I	1.00	1.00	0.06
J	1.25	0.80	0.06

Experimental set-up. The tests were intended to study the dynamic responses of the models subjected to long-crested and short-crested waves. The displacements and rotations of the models were recorded by the OptiTrack system. The system recorded the motion in surge, sway, heave; roll, pitch and yaw thru reflective markers installed on top of the models with varied additional heights to provide randomness. The arrangement of the model setup in plan view is shown in Fig. 3.

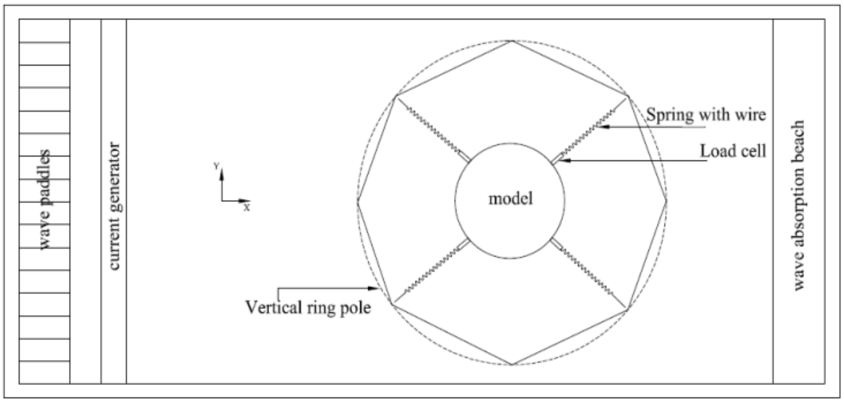

Figure 3. Model setup – Plan view

Results and discussion

The responses in surge, heave and pitch motion of the classic spar estimated by the numerical simulations for long-crested and short-crested waves are shown in Figs. 4 ~ 6. It could be observed from the figures that the trends of the responses agreed fairly well. Smaller responses by short-crested waves are observed in the comparison with the results by long-crested waves. The short-crested waves were found smaller than the responses due to long-crested waves for the surge, heave and pitch motions. Fig. 4 shows the surge RAO comparison due to long-crested and short-crested waves for classic spar. From the figure, it could be observed that the responses due to short-crested waves generally yield about 35% smaller compared to long-crested waves. It could be seen that similar trend generally yield, and the time phase different was found to be the reason that cause the peak occurred at f=0.05Hz. Fig. 5 shows the heave RAO comparison due to long-crested waves and short-crested waves for classic spar. The trend of the responses agreed quite well, where the responses decreased substantially from 0.06Hz to 0.07Hz, and slightly reduced to almost nil at high frequencies range. From the comparison, it could be summarized that the responses due to short-crested waves yield smaller responses compared to long-crested waves at the low frequency range. It can be understood that short-crested wave forces act horizontally to the structure; the vertical heave motion might not experience significant changes due to the wave directionality effects. Fig. 6 shows the pitch RAO comparison due to long-crested and short-crested waves for classic spar. From the figure it could be observed again that the responses due to short-crested waves yield about 38% smaller compared to long-crested waves.

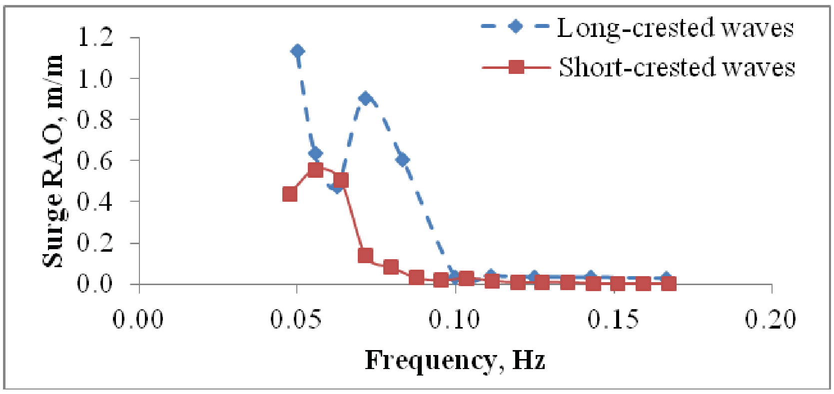

Figure 4. Surge RAO comparison for classic spar

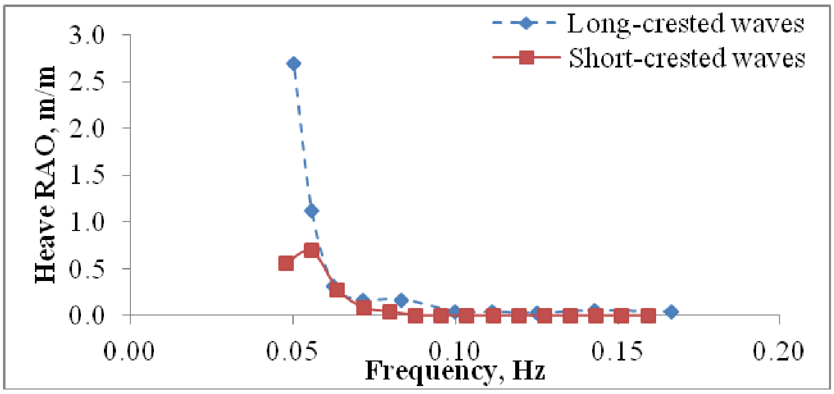

Figure 5. Heave RAO comparison for classic spar

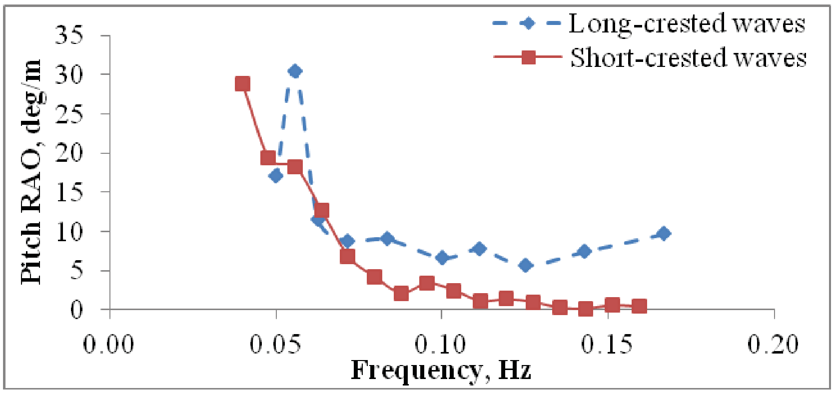

Figure 6. Pitch RAO comparison for classic spar

Conclusion

In this paper, a series of wave tank tests that have been carried out in order to study the dynamic responses of classic spar model due to long-crested and short-crested wave actions was presented. The results measured from the tests were compared and presented. From the results obtained the following conclusions were drawn. It could be observed that the results obtained from short-crested waves are about 35% smaller than that by long-crested waves for surge and pitch RAOs. This is mainly due to the assumption of large offshore platform stretch acted up on by long-crested waves. In this case, design considering the long-crested waves would be overestimated. On the other hand, in the real state, various short-crested waves will be hitting the stretch length in different angles and the net effect will be quite likely to be less. Hence, from the results obtained it could be concluded that the responses of the classic spar model that subjected to short-crested waves on the stretch length in different angle are expected to be less. It is important to highlight that this study only limited to uni-directional regular wave environment and classic spar platform.

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