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NUMERICAL SIMULATION ON THE EFFECT OF MOORING ARRANGEMENT TO THE CYLINDRICAL FPSO'S STATION KEEPING BEHAVIOR

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ABSTRACT

Non-ship shaped FPSO has more advantages than ship-shaped FPSO. It has more efficient storage shape, smaller sloshing forces, allows for larger freeboard and simple block construction. In addition, round shape FPSO is designed to have similar motion characteristics from all directions and eliminate yaw excitation. This eliminates the need for a costly turret and swivels, minimizes the bending loads and fatigue and increases the storage capacity per plated area. Mooring line configuration is critical for floating structure. Mooring designer need to ensure the mooring system can maintain the position and limit the motion of floating structures due to the environment loads such as wave loads, wind loads and current forces. A study on effect of mooring arrangement to the dynamic response of cylinder FPSO has been conducted. The main objective of this research is to predict the mooring forces as well as to simulate moored motion of cylindrical FPSO in different mooring arrangement. In this research, four different mooring configurations have been developed and simulated by using Ansys AQWA to obtain the response amplitude operator (RAO), structure actual response in six degrees of freedom and the tension in each of mooring line. From the simulation, it is observed the number of cluster and mooring lines have influenced to the structure motions. By further analysis, the research conclude that 3 X

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4 mooring configuration able to provide better structure motion control and lower tension in compare to other mooring configurations

Keywords *Mooring Configuration, Cylindrical FPSO, RAO*

1.0 INTRODUCTION

The ship-shaped FPSO has been widely used offshore structure platform in oil and gas industry. However, the disadvantages of this FPSO is it has poor hydrodynamic performance in heave and roll motions, high construction and operating costs. Besides that, the limitations of ship-shaped FPSO is it has unsatisfactory oil storage efficiency because it is not originally designed to fulfil the role as FPSO [1].

Sevan Marine has developed round shaped FPSO since 2006 [2]. The advantages round shaped FPSO according to Siow et al. [3] and Srinivasan et al. [4] are, it has more efficient storage shape, smaller sloshing forces, allows for larger freeboard and simple block construction. In addition, round shape FPSO is designed to have similar motion characteristics from all directions and eliminate yaw excitation. This eliminates the need for a costly turret and swivels, minimizes the bending loads and fatigue and increases the storage capacity per plated area. Siow et al. [5] presented the experiment procedures to study the hydrodynamic characteristic of round-shaped FPSO. it is observed that the round FPSO which stationary by mooring lines experienced two types of horizontal motion there are wave frequency motion and slow varying motion due to drift and mooring effect. While the vertical motion of this FPSO is only experience wave frequency motion. Siow et al. [3] has conducted a study on wave induce motion of round-shaped FPSO. One of the finding of their study is the simulation results showed that the round-shaped FPSO has good wave frequency response and the motion response is kept in low amplitude in most of ocean environment. From the research, it is obtained that the designed round-shaped FPSO has good dynamic stability where this is an important factor to reduce the down time of FPSO in normal operation.

A mooring system of a floating vessel consist of many different types such as spread mooring or single point mooring, with different shapes, for example catenary, taut or semi-taut. Design of mooring system depend on the purpose of the floating structure including their characteristic and environmental conditions such as wave, wind and current forces. The general purpose of the mooring system is to keep the floating vessel safely at a required position and to limit the horizontal offset of the floating structure to an acceptable limit. By doing this, the integrity of risers and umbilical are maintained, safe distance to other structures is maintained, helps to control the mean offset and low-frequency motions and absorb the wave-frequency motions. Siow et al. [6] conducted experiment to study the mooring line selection process and preparation for round shape FPSO.

Mooring line configurations have been studied by various authors [7-11]. Montasir et al. [9] investigated the effect of symmetrical and asymmetrical mooring line configuration on the dynamic response of a truss spar platform. They developed MATLAB codes to analyse the mooring lines and the dynamic response of the structure. They observed the effects of symmetrical configurations on the mean position of the platform is relatively smaller than asymmetrical configuration. In addition, the RAO and the mean position of the platform reduce as the number of mooring lines increases. Similar results also have been observed by Huang et al. [10]. They conducted experiment to investigate three different types of mooring configurations on the tunnel pontoons system subjected to irregular waves. The mooring configuration they used in the study are four cables with length 200 m and 350 m and six cables with length 350 m. They found that the more mooring lines in a configuration will result better stability of the structure motions and mooring tension distributions. Besides that, mooring configuration with longer line has small mooring tension but larger structure excursion. Muslim & Kamil [11] investigated effect of mooring line configuration on turret moored FPSO based on Malaysia seawater using Ansys AQWA. They used different number of mooring lines; 4 line, 8 lines and 12 lines to evaluate the mooring line tension acting on the floating structure. Similar to previous researchers, they also observed the number of mooring lines in a configuration has influence to the tension produced by each cable. Kim et al. [12] investigated three different types of mooring arrangement for a floating LNG bunkering terminal at East Sea of South Korea. They selected mooring configurations of 3x4, 3x5 and 3x6 to be analysed in this study. They found that, the more the number of mooring lines in a cluster, the lower mooring tension limit, the higher the safety margin of the mooring system.

Due to limited study on mooring configurations on non-ship shaped FPSO, a study will be conducted to evaluate the effect of mooring arrangement to the cylindrical FPSO's station-keeping behaviour. The study will focus more on the mooring arrangement and the effect towards the station-keeping behaviour of the vessel. The objective of this study is to determine the best mooring arrangement for cylindrical FPSO based in Malaysia seawater.

2.0 DESIGN CONDITION

Environmental Condition

It is assumed that the cylindrical FPSO is installed in offshore Bintulu, Sarawak with water depth 200 m. In this study, 100-year return sea-state lasting for 5 hours (18,000 sec) has been chosen to investigate the dynamic response of the structure during its operation. Details about the environmental parameters as showns in Table 1.

Table 1 : Environment Load Parameters

Location	: Offshore Bintulu, Sarawak
Water depth	: 200 m
Significant wave height, Hs	: 1.0 m
Wave Period, Tp	: 6.0 s
Wind Speed, Vw	: 3.10 m/s
Current Speed, Vc	: 0.85 m/s

Platform and Mooring System

For this research, a model of cylindrical FPSO (Figure 1) was selected according to previous research study conducted by Siow [13]. In the study, same model was used to analyze the hydrodynamic behavior of new generation round shape FPSO. The model particular of cylindrical FPSO in the Table 2 below.

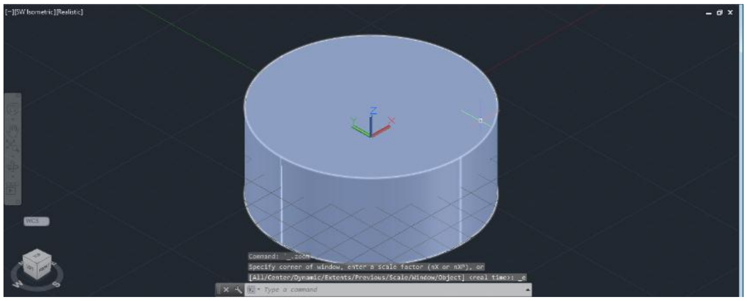
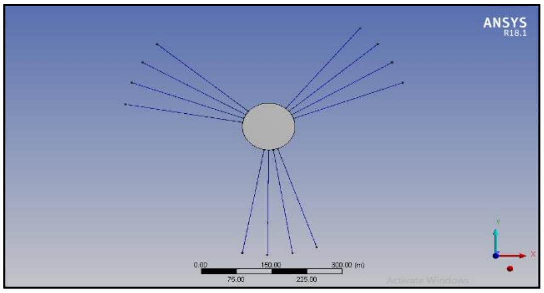


Figure 1 : Cylindrical shape FPSO

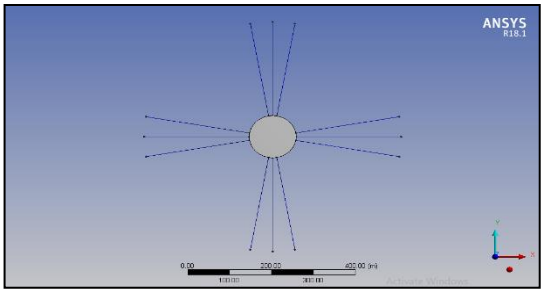
Table 2 : Model particulars for cylindrical FPSO

Particulars	**Unit**	**Full Scale**
Diameter, D	m	111.98
Depth, d	m	48.41
Draught, T	m	31.91
Displacement, ∀	m^3	314,249
Waterplane Area, A_w	m^2	9,849
KG	m	32.915
GM	m	7.6

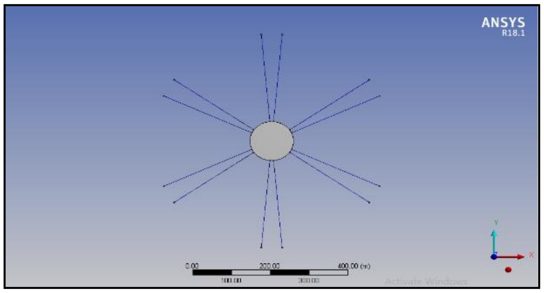
Different mooring patterns and configuration also will be use in the simulation which consist of grouped mooring pattern and equally spread mooring pattern. For this study, 4 different catenary mooring arrangements will be used in the simulation which is 3X4, 4X3, 6X2 and equally spread mooring system (Figure 2).



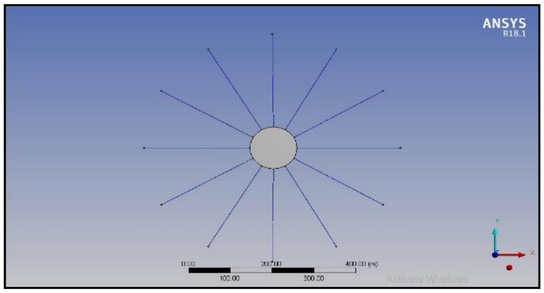
a) 3x4



b) 4x3



c) 6x2



d) Equally spread mooring

Figure 2 : Four different catenary mooring configurations

The total length of mooring line of catenary mooring system is 350 m. Each mooring line is designed to be 350 m length to ensure the endpoint is still tangent to the seabed when the floating body offsets to the maximum allowable value. Each mooring line consists of three segments chain, wire rope and chain. The mooring lines are installed separately on the seabed by Suction anchors, pile anchors or vertical anchor. The mooring line properties are summarized in Table 3.

Table 3 : Mooring Line Properties

Segment	Chain	Wire Rope	Chain
Type	R4	Spiral Strand	R4
Diameter (m)	0.1800	0.1365	0.1800
Length (m)	50	250	50
Submerged Weight (kN/m)	6.075	1.128	6.075
Breaking Strength (kN)	26,277.696	16,769.025	26,277.696
Axial Stiffness (kN)	2,916,000	3,080,000	2,916,000
Pretension (kN)	1600		

3.0 DYNAMIC ANALYSIS

To analyse the effect of mooring configurations to the dynamic response of cylinder floating structure, a time domain method will be used. Ansys AQWA hydrodynamic diffraction will analyse the structure motion in wave frequency, while hydrodynamic time response will evaluate the mooring system and floating structure response in low frequency.

4.0 Experiment And Simulation Results

Structure RAO

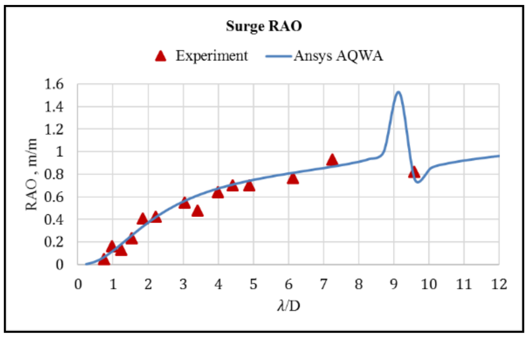
Data collected from a cylindrical shaped FPSO experiment conducted by Siow [14] has been used to compare with the Ansys AQWA simulation by using the graphical method. The setup in the Ansys AQWA is designed to meet similar condition with the experiment.

The comparison between the surge RAOs of the cylindrical shaped FPSO is shown in Figure 3a**Error! Reference source not found.**. It can be observed the surge RAO predicted by experiment and Ansys AQWA almost similar when the λ/D. The result from Ansys AQWA is based on frequency domain calculation, hence any disturbance from surrounding is not included. The values of the maximum surge also particularly similar.

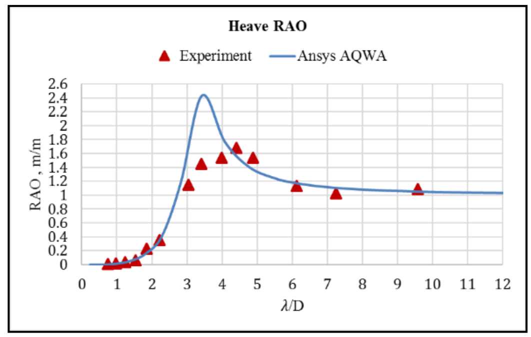
Figure 3b shows the heave RAO patterns for the cylindrical shaped FPSO. The patterns produced are almost similar. Compared experiment result to Ansys AQWA, it was observed the peak heave RAO was shifted to longer wavelength region in the experiment. According to Heurtier et al. [15], there is limited mooring effect on the heave motion. However, the existing mooring system can cause the stiffness and mass of the floating structure increases. This later causes the RAO predicted by the experiment test is shifted slightly into longer wavelength region. Besides that, the Ansys AQWA could not detect the shift of peak heave RAO is because of the underestimated of heave added mass. Diffraction theory method typically predicts the heave added mass 10% to 20% lower than the experiment value [16].

Lower prediction of heave added mass coefficient could be the reason the peak heave value in Ansys AQWA in the shorter wavelength region.

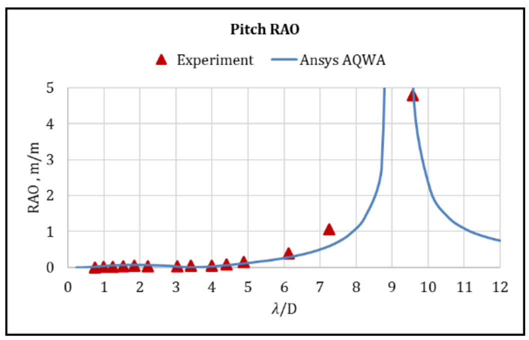
It can be observed in Figure 3c that both methods have a similar pattern of pitch RAO. From the graph also, it is observed the pitch motion response is small in short wavelength region and start to increase exponentially at λ/D, equal to 4. This is because the pitch damping coefficient is high the short wavelength region and almost zero at the long wavelength region. It can be concluded this cylindrical shaped FPSO is very stable at short wavelength region. It can be concluded, the RAO result from Ansys AQWA is reliable for motion analysis in moored structure.



a) Surge RAO



b) Heave RAO



c) Pitch RAO

Figure 3 : Cylindrical FPSO RAO Predicts by Experiment and Ansys AQWA

Structure Position (Actual Response)

Table 4 shows that the comparison of maximum surge excursion when the structure is connected with different mooring arrangement. From the table, it is observed that 6 X 2 mooring arrangement has the highest structure excursion in surge motion, whereby 3 X 4 mooring arrangement has the lowest excursion. It was observed that the structure only experiences maximum surge motion at the period of approximately 10000 s for all of 4 mooring arrangement.

Table 4 : Comparison of Maximum Surge Excursion for Each Mooring Configuration

Mooring Configurations	Surge Maximum Excursion
3 x 4	8. 164 m
4 x 3	11.009 m
6 x 2	11.047 m
Equally Spread	11.005 m

Mooring Line Tension

Table 5 shows the comparison of maximum line tension experience by the mooring cable of each arrangement. The comparison has been made based on the maximum line tension from each arrangement. From the simulation results, it can be seen that 4 X 3 arrangement has the biggest maximum line tension meanwhile, 3 X 4 arrangement produce the smallest maximum line tension with the tension of 473211.75 N.

Table 5 : Comparison of Maximum Line Tension of each arrangement

Mooring Configurations	Maximum Line Tension
3 x 4	473,211.75 N
4 x 3	480,945.53 N
6 x 2	477,663.41 N
Equally Spread	480,942.28 N

5.0 DISCUSSION AND CONCLUSION

Through this study, the effect of mooring configuration to the dynamic response of cylinder floating structure has been investigated using Ansys AQWA. The simulation has been conducted in time domain response. In this study, the time domain simulation is only focused in head sea condition. However, one must be known that the angle of wave, wind and current attack has significant effects to the mooring tension. From this comparative study, it can conclude that the most optimum mooring arrangement in head sea condition is 3 X 4 mooring configuration. The reason for the 3 X 4 mooring configuration have the lowest movement and the lowest mooring line tension in head sea condition is there are one group of mooring lines are arranged in parallel to the wave propagation direction. Therefore, the restoring force from this group of mooring lines can be totally contributed to restrict the motion of FPSO. In continue, the tension in the mooring lines can be lower compare to other arrangements since larger amount of the mooring tension can be contributed as restoring force for the FPSO if the motion of FPSO is in parallel to the mooring lines.

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