



DYNAMIC BEHAVIOUR OF FPSO IN KIKEH FIELD UNDER DIFFERENT LOADING CONDITIONS

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ABSTRACT

The depletion in natural gas and oil in shallow waters due to extensive extraction along with the increase in its demand has led engineers to develop the floating production platforms which can thrive well in the adverse conditions of deep waters. Floating production Storage and Offloading (FPSO) system has proven to be one of the most promising platforms in the development of offshore oil and gas resources that would be otherwise impossible or uneconomical to tap. In this study, an uncoupled dynamic analysis is performed using the Sesam HydroD software to study the response of FPSO under the action of unidirectional random waves in Malaysian waters in operating conditions in the Kikeh Field. The results can be referred for conceptual design of the FPSO system in Malaysian waters.

Keywords: FPSO, uncoupled dynamic analysis, HydroD.

INTRODUCTION

Over the past 32 years, ship – shaped offshore units have proven to be reasonably reliable solutions for deep water offshore fields. These include FPSOs and FSOs operating in harsh environmental areas and also waters of more than 1000m depth. Oil storage and shuttle tanker – mooring facilities using converted trading tankers existed in late 1960s. The first tanker-based single-point moored FPSO facility for oil is said to be the Castellon for Shell offshore Spain in 1976. This facility was meant to produce oil from a subsea completed well, 65 km offshore Tarragona. It began operations in 1977, and was designed for a 10-year field life. Compared to the early days, the technology now enables production far beyond the water-depth constraints of fixed-type offshore platforms and provides a flexible solution for developing short-lived fields with marginal reserves and fields in remote locations where installation of a fixed facility would be difficult (Paik and Anil 2007). Out of a total of 151 FPSOs operating now globally, 10 are in Western Australia offshore, 3 are in Malaysia offshore, 7 are in Vietnam offshore and 14 are in China offshore region (Nutter, 2014).

FPSOs are usually ship shaped floating structures which are either spread moored or turret moored. As the FPSO is more sensitive to the global environment direction due to its large aspect ratio (L/B ratio) in the range of 5 to 6, the spread mooring system helps to maintain a fixed orientation of FPSO in global coordinates (England *et al.* 2001).

Wichers initiated a comprehensive study for numerical simulations of a turret moored FPSO in irregular waves with wind and current (Wichers, 1988). He derived the equations of motion of such model in the time domain using an uncoupled method and solved rigid body and mooring line dynamics separately. Heurtier *et al* compared the coupled and uncoupled analysis for a moored FPSO in harsh environments and suggested that the uncoupled analysis results are efficient to be used in

the early design phase of the mooring system (Heurtier *et al.* 2001). There was relatively good agreement between the uncoupled and coupled analysis values even though the maximum values were different. Kim *et al* developed a program in time domain for simulating the global motion of a turret moored FPSO (Kim *et al.* 2005). They also conducted physical model tests to study the vessel motion and mooring tension for non-parallel wind, wave, current and 100 year hurricane condition in Gulf of Mexico. Since the nonlinear drag force has less effect, frequency domain method gives satisfactory results and the computation time is less compared to time domain method (Chakrabarti, 1987). Wadam calculates the wave potential and equation of motion in frequency domain (DNV, 2010). Not much studies have been reported on the motion analysis of FPSO with Malaysian metocean data even though the Malaysian waters has become a new promising oil and gas field with the installation of new FPSOs and FLNGs to be completed soon.

In the present study, the Berantai FPSO is modelled using Sesam Genie V5.3-10 and the uncoupled hydrodynamic analysis of FPSO is done in HydroD V4.5-08. The spread moored FPSO is subjected to unidirectional random waves and is free to move in surge, sway, heave, roll, pitch and yaw directions. The mooring line connecting the FPSO to the seabed is considered as a linear spring with negligible mass. Diffraction theory is used to calculate the wave load on FPSO and Airy's linear wave theory is used to calculate the fluid particle velocity and acceleration. The inertia effects and hydrodynamic loading on mooring lines are neglected. The procedure for doing the modelling and dynamic analysis using Sesam Genie V5.3-10 and HydroD V4.5-08 are given in this paper along with the dynamic response of Berantai FPSO in full load and partially loaded conditions in Kikeh field.



VALIDATION OF UNCOUPLED MODEL

Modelling of Vessel

The ship lines were generated using Rhinoceros 5 software and the lofted ship hull was then imported to Sesam Genie V5.3-10 where the rest of the modelling and verification was done. Materials and properties were assigned to the plate and the model was scaled up to the required mass density. In order to do the hydrodynamic analysis in HydroD a panel model, a Morison model and a structural model were prepared using Sesam Genie V5.3-10. The meshed model is shown in Figure-1. In order to validate the uncoupled motion performance of the vessel, an uncoupled frequency domain analysis was performed using Sesam HydroD V4.5-08 with the vessel particulars as shown in Table-1 (Xie *et al.* 2015).

Table-1. Main particulars of the vessel.

Designation	Quantity	Unit
Length between Perpendiculars	330	m
Breadth	61	m
Depth	37	m
Draft	16.80	m
Displacement	302237800	kg
Centre of gravity above base	22.60	m
Centre of gravity from AP	161.98	m
Radius of roll gyration	23.47	m
Radius of pitch gyration	85.21	m
Radius of yaw gyration	86.01	m
Water Depth	1500	m

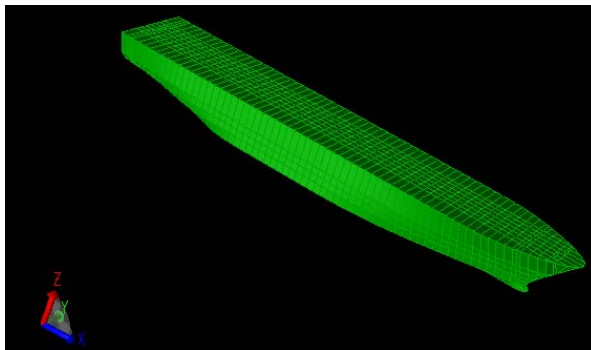


Figure-1. Finite element model of FPSO.

Frequency Domain Analysis of Vessel

The uncoupled frequency domain analysis was performed using Sesam HydroD V4.5-08 for 75% loading condition of the vessel at a water depth of 1500m. The vessel was subjected to head sea (wave direction – 180°) and crossing sea (wave direction – 150°) conditions. The vessel was anchored to position using four soft mooring lines which has limited influence on the vessel motion. The vessel responses are compared with the published experimental results (Xie *et al.* 2015) for the white noise wave condition with significant wave height ranging from

0 to 3.24m and peak period ranging from 5 to 25s. The Response Amplitude Operators (RAOs) in the six degrees of freedom obtained from the uncoupled analysis using the software is plotted along with the published experimental results and given in Figures-2 to 7. The surge, heave and pitch motions of the vessel is studied for the head sea condition while the sway, roll and yaw motions are studied for crossing sea condition. The simulated motions match well with the published experimental data.

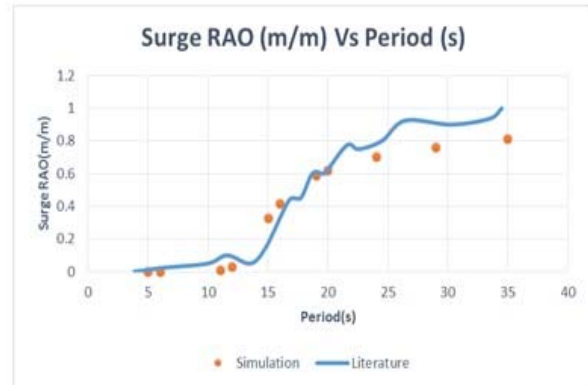


Figure-2. Surge RAO plotted against period.

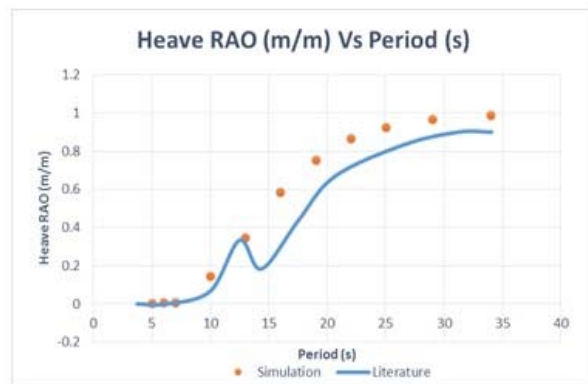


Figure-3. Heave RAO plotted against period.

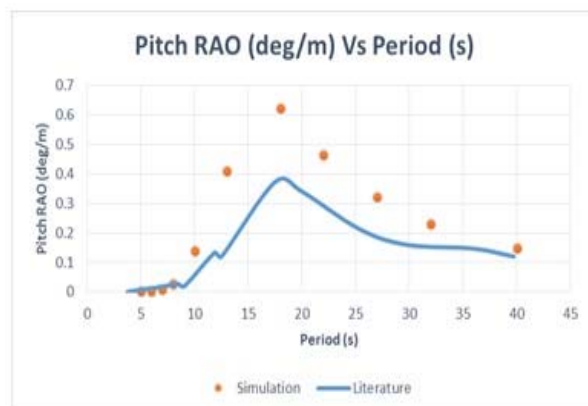


Figure-4. Pitch RAO plotted against period.

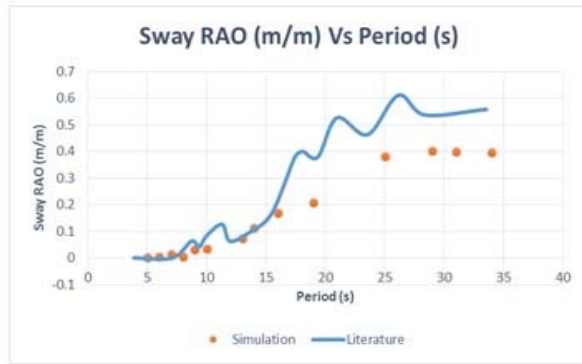


Figure-5. Sway RAO plotted against period.

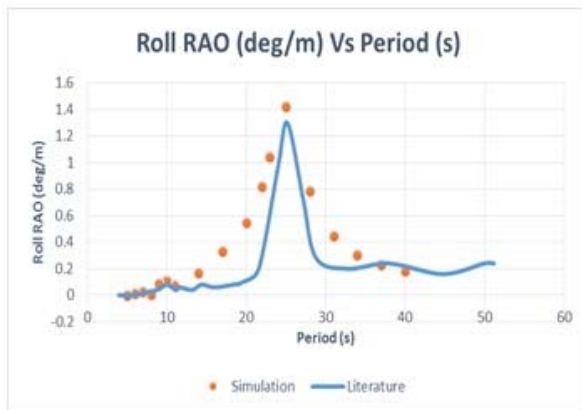


Figure-6. Roll RAO plotted against period.

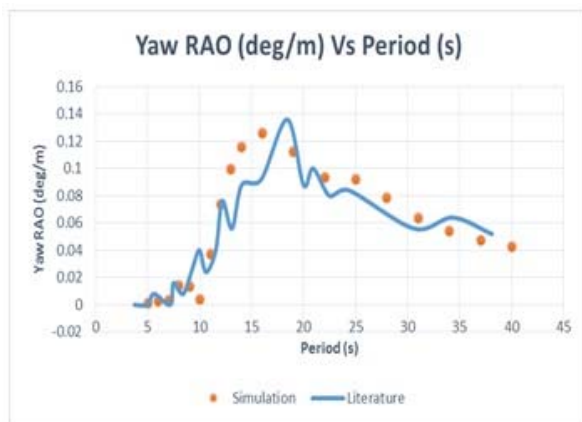


Figure-7. Yaw RAO plotted against period

DYNAMIC ANALYSIS OF FPSO IN KIKEH FIELD

Model Details

Berantai FPSO is chosen to study the response behavior in Kikeh field, one of the deepest oil field in Malaysia. The Kikeh field is located 120km northwest of the island of Labuan, offshore Sabah, East Malaysia in water depths of around 1,300m as shown in Figure-8. The main particulars of the FPSO is given in Table-2.

Table-2. Main particulars of FPSO.

Designation	Quantity	Unit
Overall Length	207.43	m
Beam	32.25	m
Depth	16.75	m
Draft	12.6	m
Displacement	68305760	Kg



Figure-8. Kikeh oil field.

The FPSO is spread moored using 12 mooring lines with pretension 2297kN. The mooring lines are in four groups with three in each group at 5° apart. The moored FPSO model which is analyzed in HydroD is shown in Figure-9.

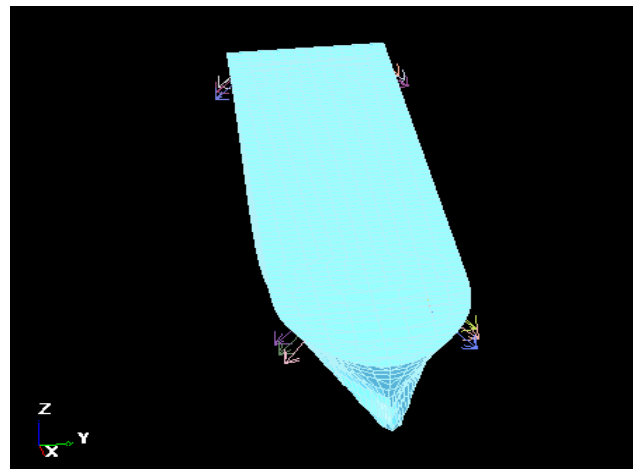


Figure-9. Spread moored FPSO.

Loading Condition and Metocean Data

For the analysis, two loading conditions were considered where the FPSO is fully loaded and it is partially loaded. Compartments were generated using Sesam Genie and the loading conditions are given accordingly. The FPSO was subjected to unidirectional



random waves with one year return period. The meteocean data for the study is given in Table-3.

Table-3. Meteocean data.

Direction	$H_s(m)$	$T_p(s)$
0°	10.83	9.6
225°	11.15	8.5
315°	11.48	12.4

Jonswap five parameter spectrum is used for developing the wave loading conditions.

RESULTS AND DISCUSSION

In this study, the response behavior of the Berantai FPSO for fully and partially loaded conditions under the action of the meteocean conditions described as above are investigated. The response amplitude operators obtained in the surge, heave and pitch directions for the following sea condition, when the FPSO is fully loaded and subjected to $H_s=10.83m$ and $T_p=9.6s$ are plotted against wave period in Figure-10.

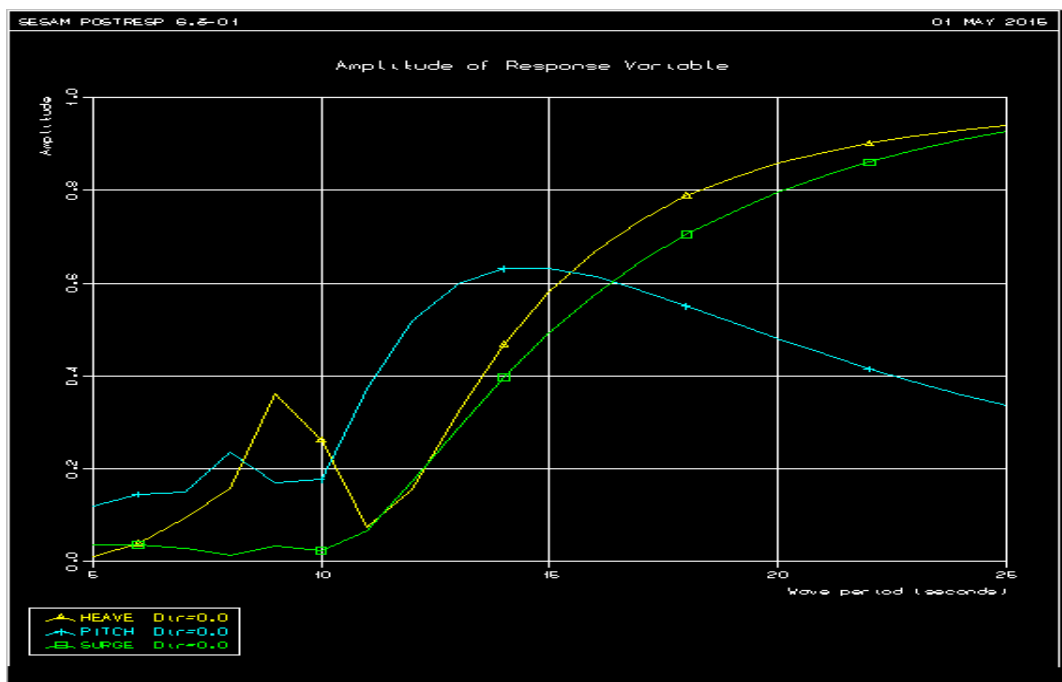


Figure-10. RAO for FPSO when $H_s=10.83m$, $T_p=9.6s$.

The sway, roll and yaw motions are negligible in this condition. While the FPSO is fully loaded and subjected to $H_s=11.15m$ and $T_p=8.5s$ at crossing sea condition at an angle of 225° , there is significant motion of FPSO in all the six DOF with maximum in the heave direction having RAO 0.9676m/m. The RAO's are plotted against wave period and shown in Figure-11.

When the FPSO is subjected to crossing sea condition with the wave direction 315° , then also the six dof RAOs are significant and the response pattern is similar to Figure-12.

The maximum responses when the FPSO is fully loaded and partially loaded for the surge, heave and pitch motion are compared and tabulated in Table-4.

Table-4. Meteocean data.

DOF	Fully loaded RAO	Partially loaded RAO
Surge	0.6722	0.6079
Heave	0.9673	0.9798
Pitch	0.5835	0.7029

The maximum RAOs are within safe limits. The RAOs when the FPSO is partially loaded and subjected to $H_s=11.48m$ and $T_p=12.4s$ at wave direction of 315° are plotted against wave period and are shown in Figure-12.

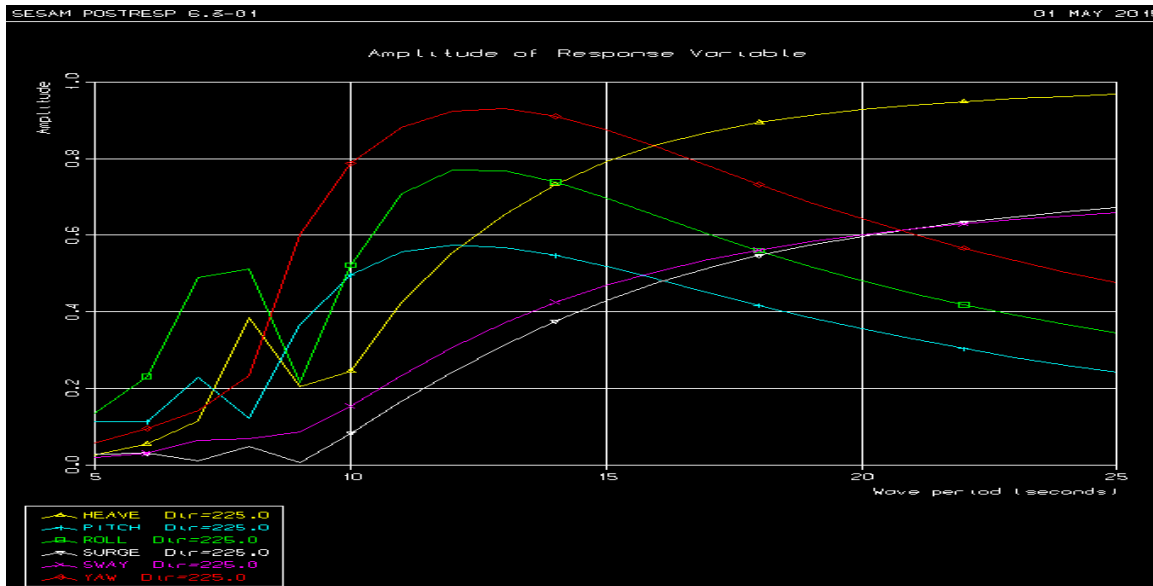


Figure-11. RAO for FPSO when $H_s=11.15\text{m}$, $T_p=8.5\text{s}$.

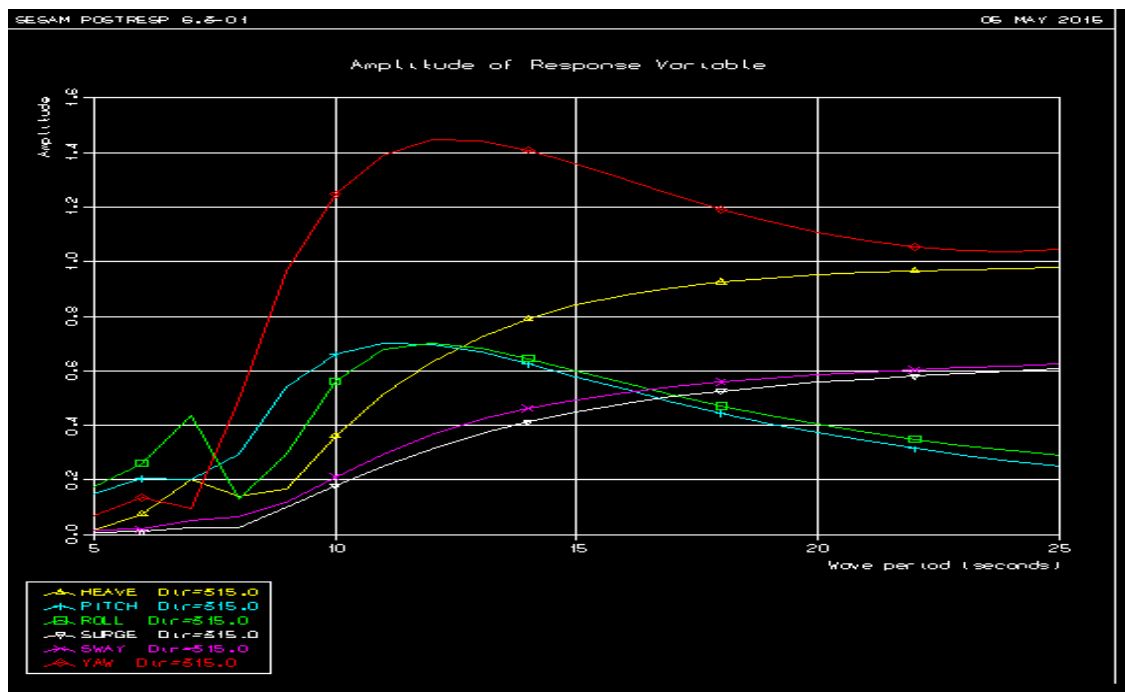


Figure-12. RAO for partially loaded FPSO in crossing sea.

CONCLUSIONS

This paper especially deals with the response behavior of FPSO in Kikeh field under the action of unidirectional waves with one year return period. The six DOF motion response amplitude operators were calculated using uncoupled frequency domain analysis in HydroD V4.5-08. The FPSO studied has good motion performance in the Kikeh field with small response amplitude operators which are in the safety range (Chen et al. 2013).

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