Journal of Subsea and Offshore
-Science and Engineering-, Vol.10

June 30, 2017

Effect of Turret Location on Hydrodynamic Motion of Ship-Shaped FPSO

Adibah Fatihah Mohd Yusof,[a], Siow C.L,[a] and J.Koto,[a,b,*]

[a)]*Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia*
[b)]*Ocean and Aerospace Research Institute,Riau, Indonesia*

*Corresponding author: jaswar@utm.my, jaswar.koto@gmail.com, scheeloon@utm.my

Paper History

Received: 20-April-2017
Received in revised form: 20-June-2017
Accepted: 30-June-2017

ABSTRACT

As Malaysia has start deep water oil exploration near offshore Sabah, more floating structures have been installed. However, less study has been conducted on FPSO with turret mooring system in Malaysia seawater especially in offshore Borneo. Even though offshore Borneo is part of South China Sea, the environmental condition is milder and its exhibit strong current from depth 50m to 150m. Hence, the present study analyzed the influence of turret location to surge, sway, heave, pitch, roll and yaw motions effect on the FPSO Kikeh operating in Kikeh Field. A simulation on FPSO Kikeh with five different turret locations in regular wave and collinear sea states have been done. From the analysis on the simulations, it is found that yaw motions become critical as turret distance from bow increases. Besides that, roll motion increases as yaw motion increases and this is due to coupling effect. Turret at bow is the best design for FPSO operating in Kikeh because it has the lowest structure excursion and lowest mooring lines tension. In addition, the environmental force exerted on the structure also low.

KEY WORDS: *Turret Mooring System, Location, FPSO, Malaysia*.

NOMENCLATURE

API	American Petroleum Institute
ΔT	Temperature Difference in and out
F_T	Thermal Expansion
L_A	Anchor Length
ΔL	Expansion
F_P	Pressure Force
F_F	Friction Force
ε_{sd}	Design Compressive Strain
ε_c	Critical Strain

1.0 INTRODUCTION

All floating structures must have mooring system. Mooring system is important because it function as station-keeping. Mooring system consist of hanging lines connecting the offshore platform to anchors at the seabed. Mooring designer must ensure the mooring system could avoid excessive forces on the platform and making it stiff enough to prevent excessive offset.

Most of the FPSOs used turret mooring as their mooring system compared to spread mooring system [1]. Advantage of turret mooring system is vessel can weathervane freely and helped to reduce the environmental loads caused by sea waves, current and wind. Besides that, turret mooring is more economical and reliable than single point mooring [2]. There are two types of turret mooring system; internal turret and external turret. Internal turret system is a turret system that is integrated into the hull structure at the bow of the vessel. It can be used for harsher environments and allow for the inclusion of a greater amount of risers. However, the installation cost is higher because of the complex hull integration. Besides that, it reduced the cargo space and volume. External turret mooring system is a turret system that is located at the extreme end of an outrigger structure attached to the bow of the vessel. It is suitable for mild to medium environments. The cost for installation is lower compared to internal turret and it is easy to integrate into the vessel. However, the disadvantages of external turret are it required a cantilever to avoid risk of anchor legs/hull interference and limited number of risers can be installed on the turret. Besides that, it has higher motions owing to the distance between the turret axis and the vessel mid-ship.

A lot of studies have been conducted on single point mooring system. Wichers (1988) [3] has initiated a numerical simulation for horizontal motion of turret moored FPSO in irregular waves. O'Donoghue and Linfoot (1991) [4] has conducted an experiment on a turret moored vessel in irregular waves and reported that turret location has influence to vessel motions and mooring line tensions. E. W. Huang et al. (1993) [5] has conducted a study on turret moored FPSO in South China Sea. The analytical calculation of green water effects, vessel and turret motions, and turret and mooring lines load are compared with the model test. Jiang et al. (1995) [6] has numerically conducted the horizontal motions and mooring line loads of single point moored tanker. Liu et al. (1999) [7] has conducted a model testing of a moored monohull with varying turret locations to examined the yaw motion of the monohull in regular wave. Thiagarajan and Finch (1999) [8] has conducted an experimental investigation of the influence of turret locations on the FPSO to the vessel vertical motions and accelerations. K. Huang (2000) [9] has identified critical issue related to mooring system design for turret moored FPSO. Soares et al. (2005) [10] has conducted an experiment to study the dynamic of the mooring system in vertical motions and green water effect. Tahar and Kim (2003) [11], Kim (2004) [12] and Kim et al. (2005) [13] has developed a program to analyse the global motions and mooring line tension of a turret moored FPSO in non-parallel environment. Kannah and Natarajan (2006) [14] has conducted an experiment on influence of internal turret locations to FPSO motions and mooring line forces under regular sea waves. Cho et al. (2013) [15] has performed an experiment to analyse the horizontal motions and stability analysis in regular waves for turret moored vessel. Ismail and Koto (2014a) [16] and Ismail and Koto (2014b) [17] has conducted an experimental investigation and computational analysis on turret moored twin hull FPSO to compare the dynamics behavior to the FPSO and it mooring lines. Xie et al. (2015) [18] has conducted a study on the effects of turret locations in irregular waves to the horizontal stability of the turret moored FLNG. The coupled analysis has including the vessel motions and mooring dynamic. The study is designed to be in South China Sea.

From the literature review, it is found that less study has been conducted on FPSO with turret mooring system in Malaysia seawater especially in offshore Borneo. Even though offshore Borneo is part of South China Sea, the environmental condition is milder and its exhibit strong current from depth 50m to 150m. Hence, the present study analyzed the influence of turret location to surge, sway, heave, pitch, roll and yaw motions effect on the FPSO Kikeh operating in Kikeh Field

2.0 METHODOLOGY

To investigate the influence of turret locations on FPSO response, a numerical simulation by using ANSYS AQWA will be performed. From the literature review conducted, coupled dynamic analysis will give better and more accurate results for FPSO operating in deepwater because it captured the direct environment loads and damping forces due to the mooring lines.

FPSO Kikeh has been selected for this project. FPSO particulars are shown in Table 1. This FPSO is operating in Kikeh Field and has external bow turret with catenary mooring system. The design environment for this project is offshore Borneo because Kikeh Field is located at Sabah and South East Asia sea conditions are difference from the South China Sea conditions. The analysis will be conducted in regular waves for easy comparison and to get the maximum value of motion [19].

Table 1 : FPSO Kikeh Particulars

Length	337.00 m
Breadth	54.56 m
Depth	27.00 m
Draft	13.51 m
Mass displacement	273,000 tonnes
Kzz	87.62 m
Kxx	18.53 m
Kyy	84.25 m

Five turret locations has been chosen for this study. Internal turret and external turret mooring system will be used for this study. All vessel conditions during this study are in full laden.

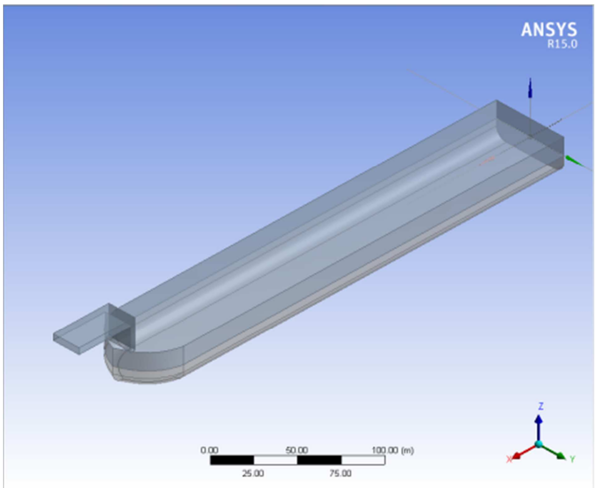


Figure 1: Turret at Bow

JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415

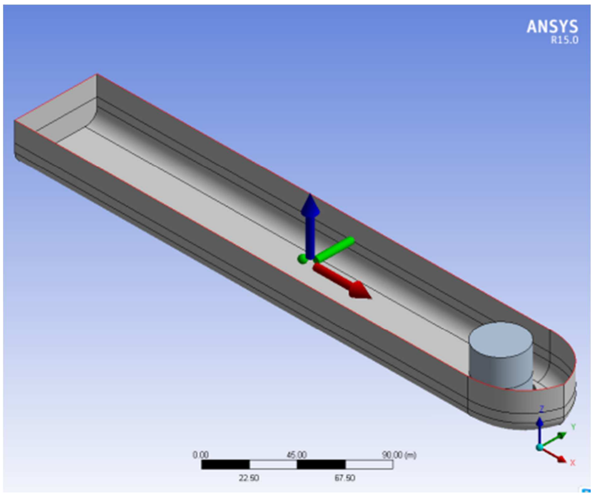


Figure 2: Turret 25% from bow

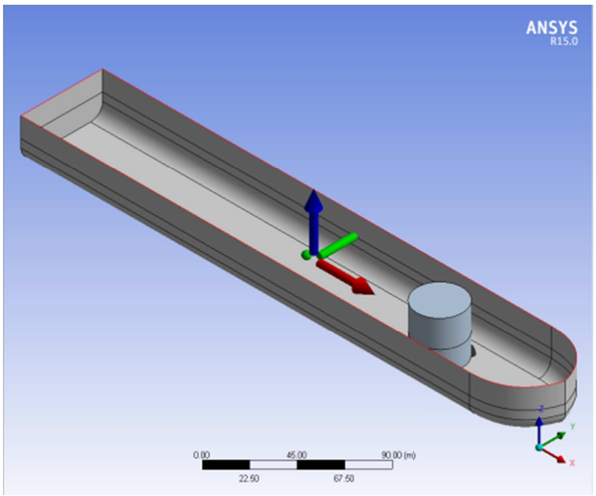


Figure 3: Turret 50% from bow

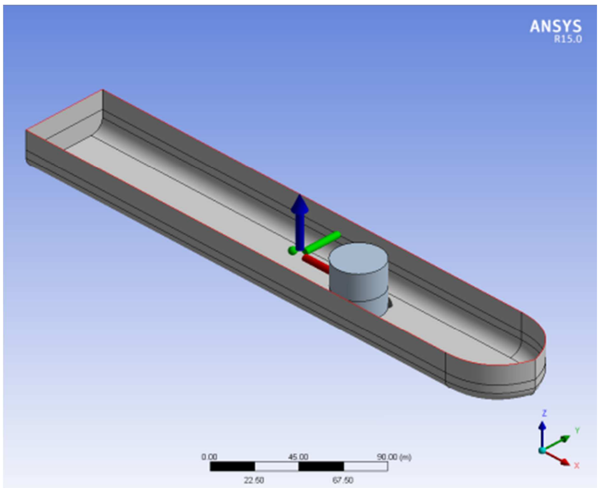


Figure 4: Turret 75% from bow

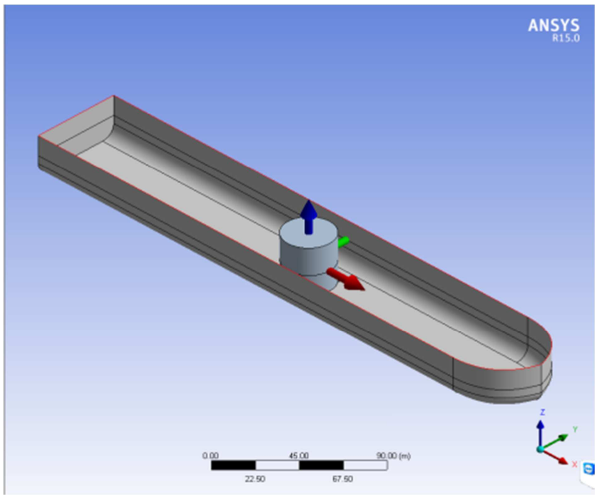


Figure 5: Turret at Midship

In this study, 100-year return sea-state lasting for 3 hours (10,000 seconds) has been chosen to investigate the hydrodynamic performance of the FPSO vessel during its operation. Regular wave and collinear sea states have been adopted. Details about the environment parameters are shown in Table 2.

Table 2: Environmental Load Parameters

Water depth	: 1,350 m
Significant wave height, Hs	: 6 m
Wave Period, Tp	: 11.7 s
Wind Speed, Vw	: 19 m/s
Current Speed, Vc	: 1.46 m/s
Wave, wind and current attack	: Head seas

FPSO Kikeh used permanent mooring line with 10 anchor legs with 4-3-3 configuration. The material for mooring line in this project is combination of chain-wire-chain with diameter 127 mm for chain and 98mm for wire. Turret weight is 2,300 tonnes [20].

JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415

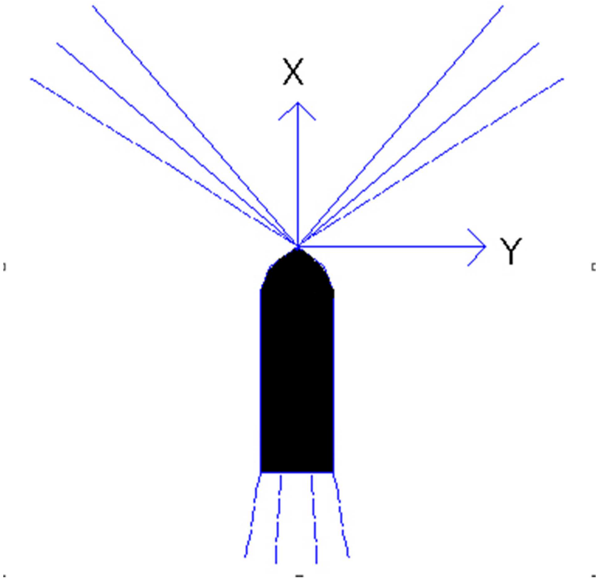


Figure 6: Mooring Lines Configuration

3.0 RESULTS AND DISCUSSION

Figure 7 shows the RAO of FPSO in each motion. The RAO of the FPSO with five different turret locations were plotted in the same graph for easier comparison of the RAO tendency obtained at five different turret locations.

From the graphs, it can be observed the patterns for all motions are similar even though the turret locations are different. For pitch RAO, turret at bow has the highest RAO. This is due to VCG of external turret is higher compare to internal turret. Besides that, the radius of pitch gyration (K_{yy}) is also big.

Structure excursion is the position of the vessel after expose to environment load. A good mooring system is the system that results on minimum excursion to the FPSO.

Figure 8 until Figure 10 show the structures excursion in surge, sway and yaw motion for five different turret locations. FPSO with turret at bow has the smallest excursion in horizontal plane motion. Whereas, FPSO with turret at midship has highest excursion in transient state, small excursion in steady state, except for yaw motion. This is due to the system is unstable in the original position of equilibrium, the FPSO reached a new condition of equilibrium with a vessel ship heading of about 90 degrees. In this new position, it is exposed to beam wind, waves and current. This has caused the sway and surge motions are lower than FPSO with 50% and 75% turret from bow during steady state.

In Figure 10, it can be observed also FPSO excursion in yaw motion increases as the turret location from bow increases. This is because of wave spreading effect. Hence, when the distance of turret location from bow increases, the yaw vessel magnitude increases. Therefore this gives effect to vessel roll motion.

Table 3 shows maximum cable forces for each condition. Cable force is force occurrence by the cable to withstand the environmental load and to keep the FPSO stationery and stay on the same coordinate.

It can be observed the maximum cable forces increases as the turret distance from bow increases, thus the safety factor for mooring line decreases. From Figure 11 to Figure 15, it can be observed also the tension for windward cables are higher than leeward cables. This is because the direction of waves, wind and current is 180^0, head seas. All the critical mooring lines are windward cables.

Table 3: Maximum Cable Force

Motion	Cable #	Cable Force (kN)	Safety Factor
Turret At Bow	#4	2710.3	4.01
Turret 25% From Bow	#3	2972.5	3.66
Turret 50% From Bow	#3	2838.6	3.83
Turret 75% From Bow	#4	7642.1	1.42
Turret At Midship	#6	8609.7	1.26

5.0 CONCLUSIONS

FPSO responses on influence of turret locations in regular wave have been considered. Results show that FPSO with turret at the bow is the best design for FPSO operating in Kikeh Field. FPSO excursion when turret located at the bow is the smallest. Besides that, the mooring lines force to counter the environmental load also less. Hence, objective of the study to analyze the influence of turret location to the FPSO response has been successfully conducted.

ACKNOWLEDGEMENTS

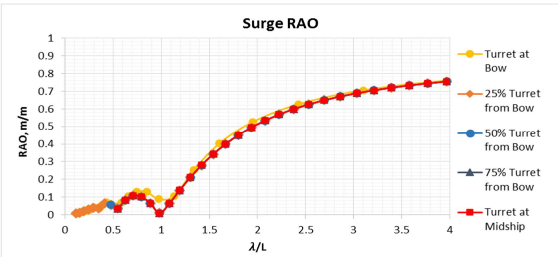
The authors would like to convey a great appreciation to Universiti Teknologi Malaysia, and Ocean and Aerospace Engineering Research Institute, Indonesia for supporting this research.

REFERENCE

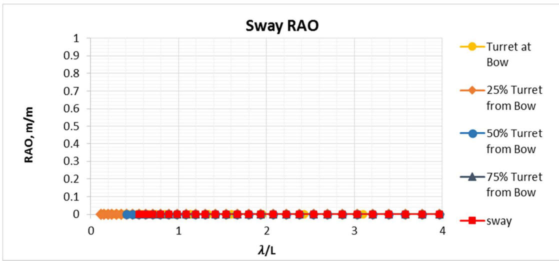
1. Paik, J. K., & Thayamballi, A. K. (2007). *Ship-shaped offshore installations: design, building, and operation*: Cambridge University Press.
2. Chakrabarti, S. K. (2006). *Handbook Of Offshore Engineering* (Vol. 2). The Boulevard Langford Lane, Kidlington, Oxford OX5 lGB, UK: Elsevier Ltd.
3. Wichers, J. E. (1988). *A simulation model for a single point moored tanker* (Vol. 797): Technische Universiteit Delft.
4. O'Donoghue, T., & Linfoot, B. T. (1991). An experimental study of turret-moored floating production systems. *Applied Ocean Research*, 127-139.

5. Huang, E. W., Beynet, P. A., Chen, J. H., Li, J. X., & Lu, Z. G. (1993). *FPSO Model Tests and Analytical Correlation.* Paper presented at the Offshore Technology Conference.
6. Jiang, T., Schellin, T. E., & Sharma, S. D. (1995). Horizontal motions of an SPM tanker under alternative mooring configurations. *Journal of Offshore Mechanics and Arctic Engineering, 117*(4), 223-231
7. Liu, F., Brown, D. T., & Fang, J. (1999). Yawing of turret-moored monohull vessels in response to regular waves. *Journal of ship research, 43*(3), 135-142
8. Thiagarajan, K. P., & Finch, S. (1999). An Investigation Into the Effect of Turret Mooring Location on the Vertical Motions of an FPSO Vessel. *Journal of Offshore Mechanics and Arctic Engineering, 121*(2), 71-76. doi: 10.1115/1.2830080
9. Huang, K. (2000). *Mooring system design considerations for FPSOs.* Paper presented at the The Tenth International Offshore and Polar Engineering Conference.
10. Soares, C. G., Fonseca, N., & Pascoal, R. (2005). Experimental and Numerical Study of the Motions of a turret Moored FPSO in Waves. *Journal of Offshore Mechanics and Arctic Engineering, 127*(3), 197-204.
11. Tahar, A., & Kim, M. H. (2003). Hull/mooring/riser coupled dynamic analysis and sensitivity study of a tanker-based FPSO. *Applied Ocean Research, 25*(6), 367-382.
12. Kim, M. H. (2004). Dynamic Analysis Tool for Moored Tanker-Based FPSO's Including Large Yaw Motions. *Final Report Prepared for the Minerals Management Service under the MMS/OTRC Cooperate Research Agreement*, 2-4.
13. Kim, M. H., Koo, B. J., Mercier, R. M., & Ward, E. G. (2005). Vessel/mooring/riser coupled dynamic analysis of a turret-moored FPSO compared with OTRC experiment. *Ocean Engineering, 32*(14), 1780-1802.
14. Kannah, T. R., & Natarajan, R. (2006). Effect of turret location on the dynamic behaviour of an internal turret moored FPSO system. *Journal of Naval Architecture and Marine Engineering, 3*(1), 23-37.
15. Cho, S. K., Sung, H. G., Hong, S. Y., Kim, Y. H., & Choi, H. S. (2013). *Study of the Stability of Turret Moored Floating Body.* Paper presented at the Proceedings of International Ship Stability Workshop, Brest, ISSW.
16. Nik Ismail, N. M. K., & Koto, J. (2014). Review On Dynamic Behaviour of Moored Twin Hulls FPSO. *Science and Engineering, 14*.
17. Nik Ismail, N. M. K., & Koto, J. (2014). Theoretical Study on Effect of Turret Location on Dynamic Response of Moored Twin Hulls FPSO System. *OMASE2014, 1*, 13.
18. Xie, Z.-T., Yang, J.-M., Hu, Z.-Q., Zhao, W.-H., & Zhao, J.-R. (2015). The horizontal stability of an FLNG with different turret locations. *International Journal of Naval Architecture and Ocean Engineering, 7*(2), 244-258.
19. Yu, R. (1995). *Dynamic response of a floating dock in regular and irregular waves.* Memorial University of Newfoundland.

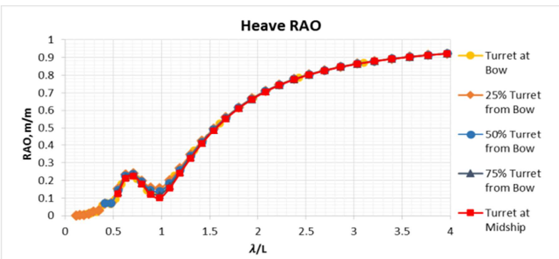
APPENDIX



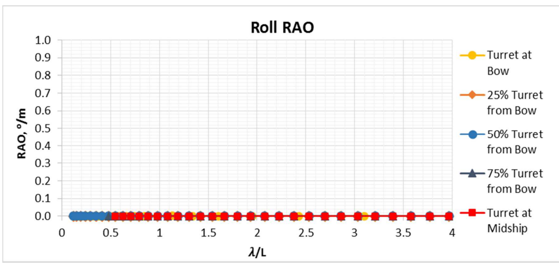
(a) Surge RAO



(b) Sway RAO

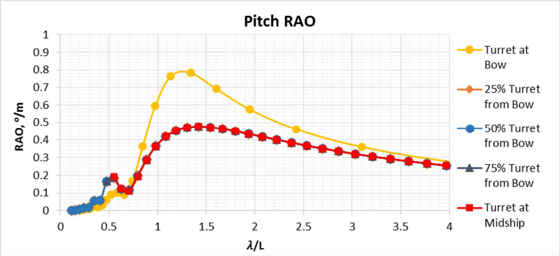


(c) Heave RAO

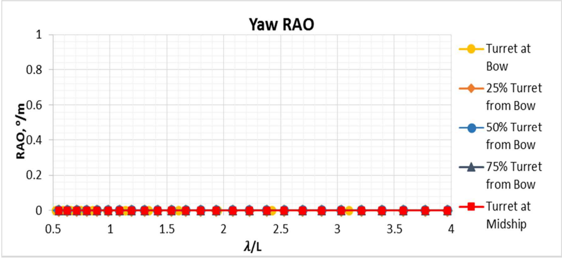


(d) Roll RAO

JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415



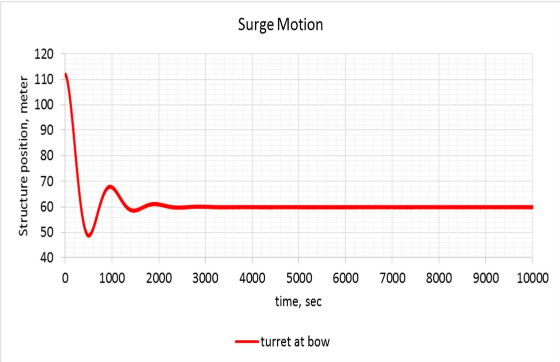
(e) Pitch RAO



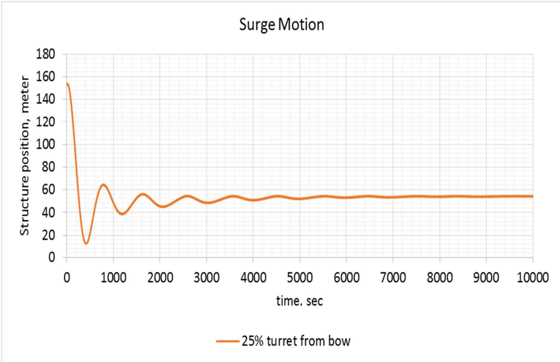
(f) Yaw RAO

Figure 7: RAO motions for FPSO with five different turret location
s

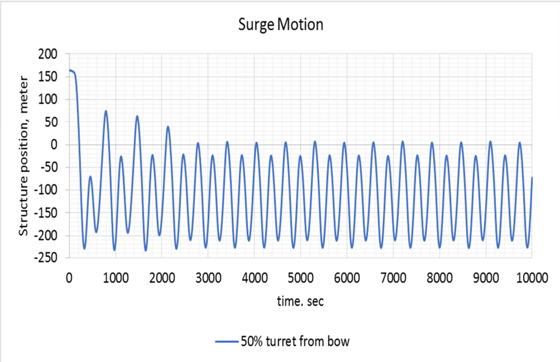
JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415



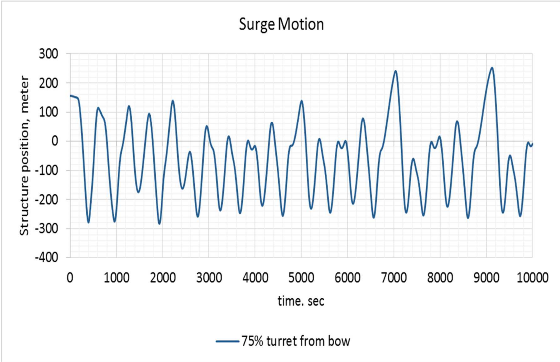
(a) Turret at Bow



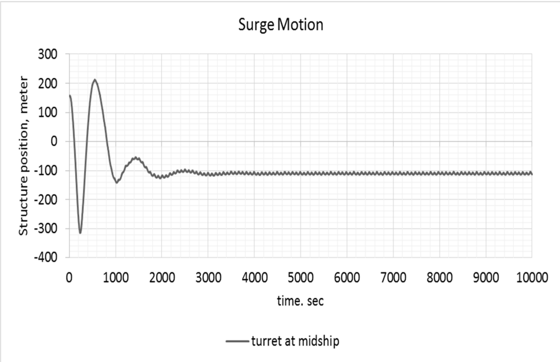
(b) Turret 25% from bow



(c) Turret 50% from bow

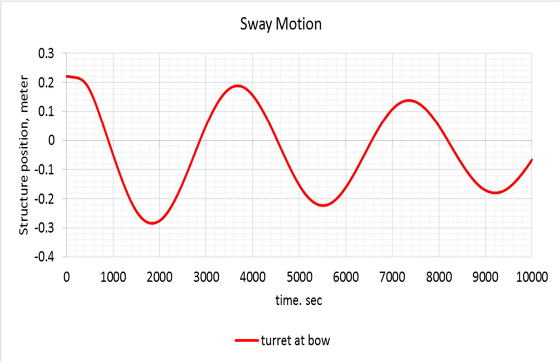


(d) Turret 75% from bow

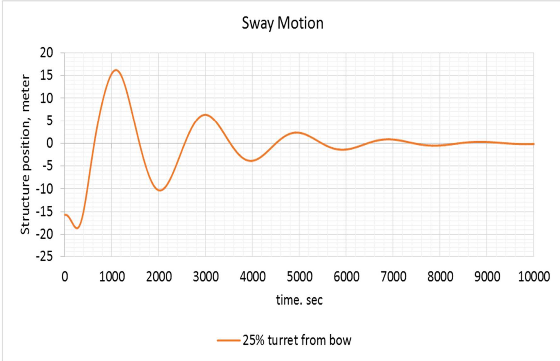


(e) Turret at Midship

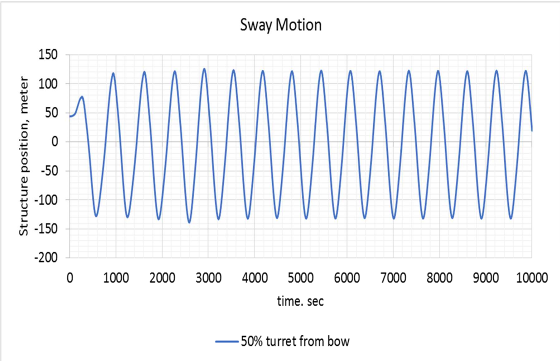
Figure 8: Structure Excursion in Surge Motion



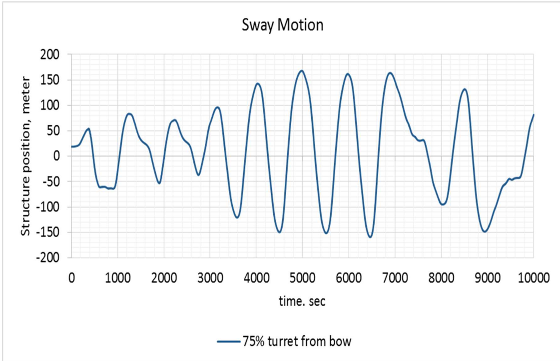
(a) Turret at Bow



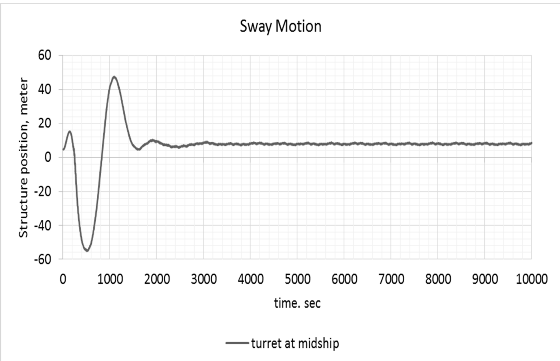
(b) Turret 25% from bow



(c) Turret 50% from bow



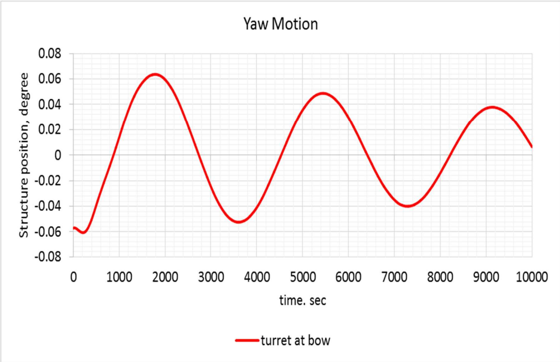
(d) Turret 75% from bow



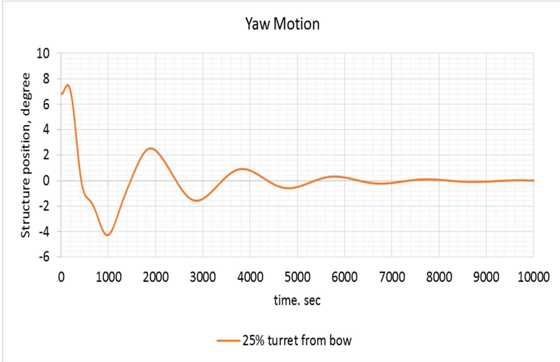
(e) Turret at Midship

Figure 9: Structure Excursion in Sway Motion

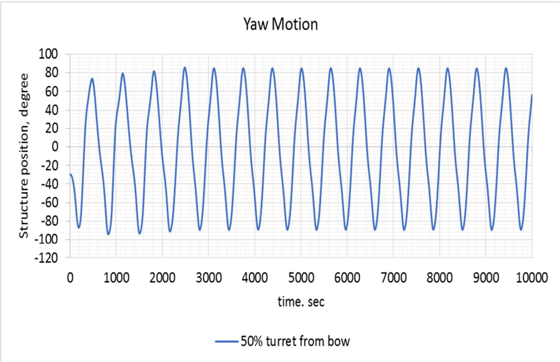
JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415



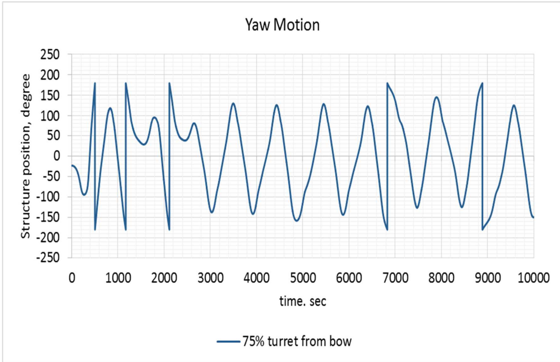
(a) Turret at Bow



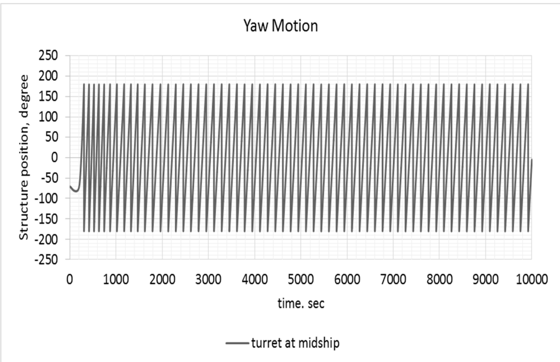
(b) Turret 25% from bow



(c) Turret 50% from bow



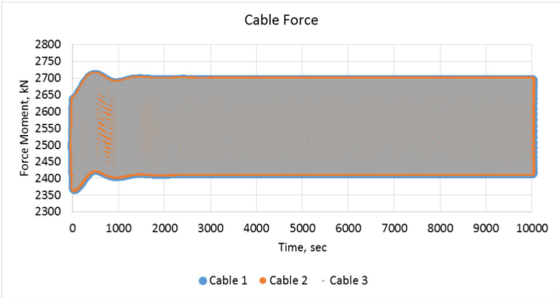
(d) Turret 75% from bow



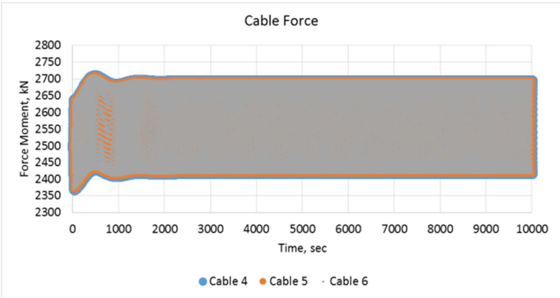
(e) Turret at Midship

Figure 10: Structure Excursion in Yaw Motion

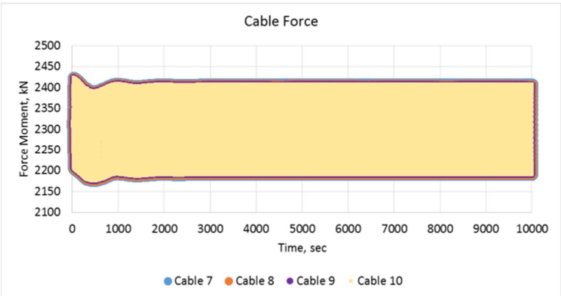
JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415



(a)

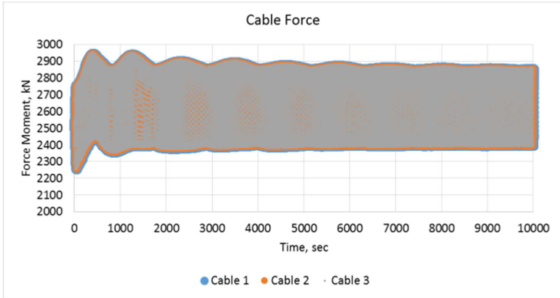


(b)

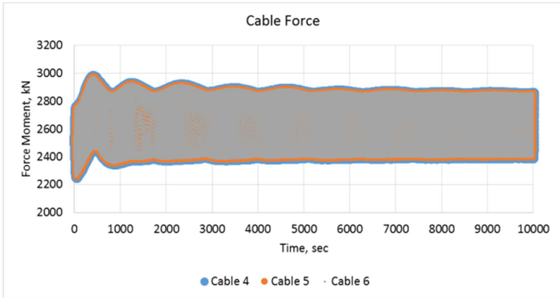


(c)

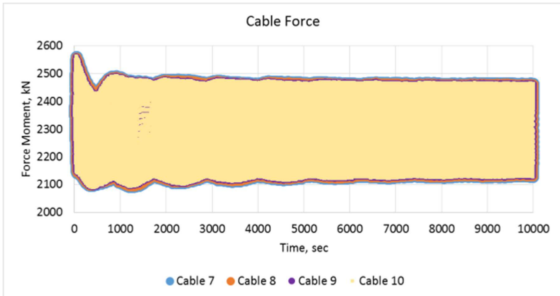
Figure 11: Cable forces for Turret at Bow



(a)



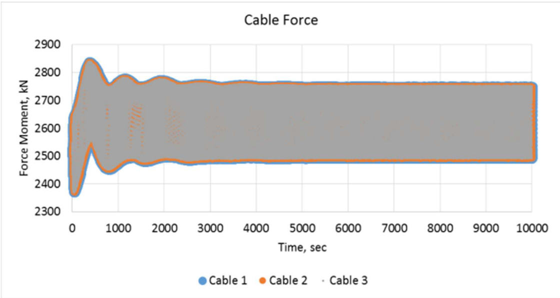
(b)



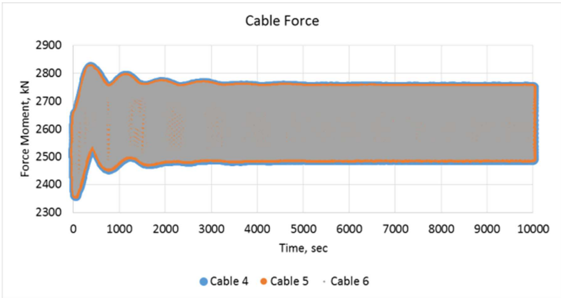
(c)

Figure 12: Cable forces for Turret 25% from Bow

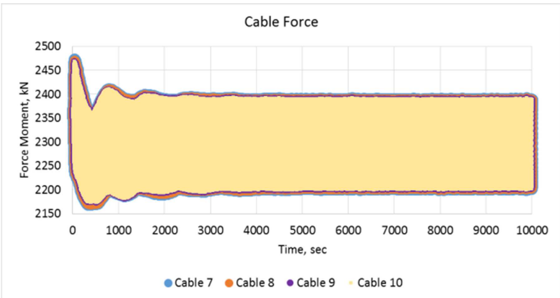
JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415



(a)

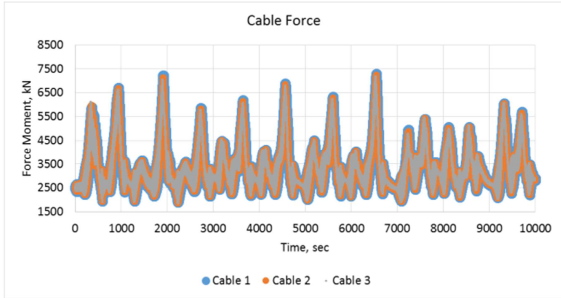


(b)

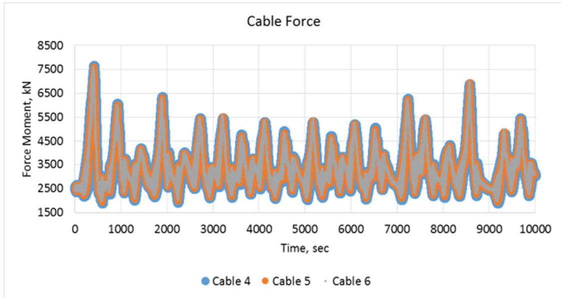


(c)

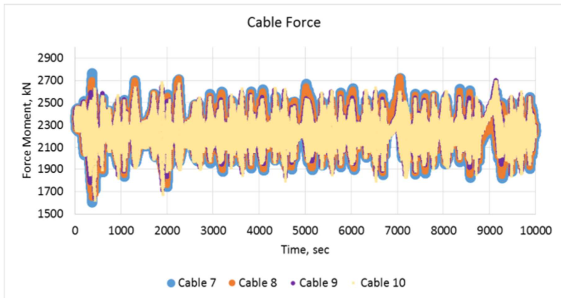
Figure 13: Cable forces for Turret 50% from Bow



(a)



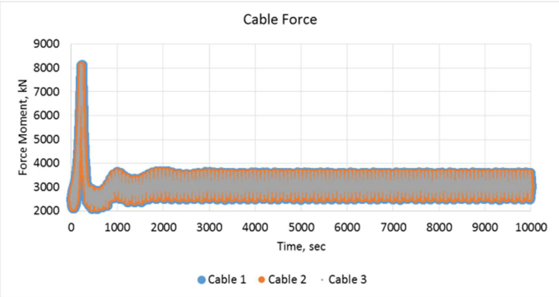
(b)



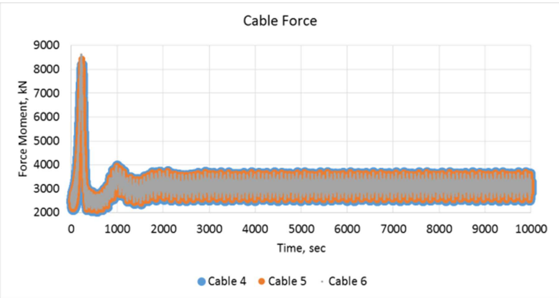
(c)

Figure 14: Cable forces for Turret 75% from Bow

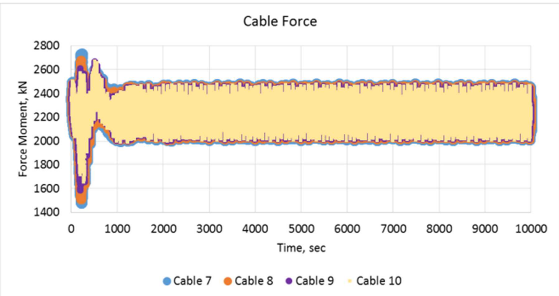
JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415



(a)



(b)



(c)

Figure 15: Cable forces for Turret at Midship

JSOse | Received: 20-April-2017 | Accepted: 30-June-2017 | [(10) 1: 9-20]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2442-6415