Maritime Technology and Society
Vol. 3(1): 33-42, February 2024
https://doi.org/10.62012/mp.v3i1.31699

Analysis of The Effect of Mooring Depth & Fatigue Damage on Mooring Line FPSO Ship Azurite In The Masela Block

*Anisa Eka Ramadani, and Fuad Mahfud Assidiq

Ocean Engineering Department Hasanuddin University, Indonesia
*Correspondence author: anisaekaramadani6@gmail.com ; Tel.: +62-8579-6345-443

Received 10 November 2023; Received in revised form 19 February 2024; Accepted February 2024

Abstract

Oil & gas drilling in the open sea cannot be avoided with the use of FPSO. Floating Production Storage and Offloading (FPSO) is a facility in the form of a floating production storage and unloading vessel in the form of crude oil and natural gas originating from the seabed. The selected type of floater that will be operated in the Abadi field, Masela Block, Arafura Sea is the Azurite FPSO ship. In its operation, the FPSO will not be separated from the influence of dynamic loads such as sea waves, ocean currents and wind on the mooring rope structure periodically. This may cause damage to the structure mooring line which influences the performance of the structure. The aim of this research is to analyze motion trajectory (surge and sway), mooring line stress, and fatigue damage on the mooring system catenary by making comparisons using variations in mooring depth. Dimensions mooring line type chain on fairlead with six (6) variations in mooring depth, namely 1000, 900, 800, 700, 600 and 500 meters which will then be analyzed fatigue damage from mooring line the. Observation result Motion Trajectory It was found that the shallower the mooring depth mooring line then value ΔOffset or movement surge & sway will get bigger. Meanwhile in observations Mooring Line Stress and Fatigue Damage obtained both are directly proportional where the greater the tension mooring line then the ratio of damage that occurs due to fatigue in the structure will also be greater. This is because the mass of the rope used is not proportional to displacement boat. And in this numerical analysis simulation it only reaches the initial movement, namely at 100 seconds, where the ship's condition has not yet reached the stable condition it should be.

Keywords: Azurite FPSO; Fatigue damage; Mooring depth; Mooring line stress; Motion trajectory

1. Introduction

FPSOs are the future of the offshore oil and gas industry. This can be said because FPSOs can be moved freely so they can be a more economical solution for more marginal locations. The FPSO can be moved once the original location has been exhausted. Can we imagine the average oil rig semi-submersible takes three to four years to install and build as wellrig jack up which takes two to three years, meanwhile FPSO can be implemented in just a few months to one year.

In connection with this, the author raised the title of this research at the location of the Abadi field in the Masela block, which is a deep sea gas field with the largest gas content in Indonesia, which is about 160 kilometers from the coast of Yamdena Island, located in the Arafura Sea with water depths of 400 to 800 meters. With the selected floater type is the Azurite FPSO ship.

The use of the Azurite FPSO during the production phase will of course not be free from the influence of waves, currents and winds which can disrupt or damage the Azurite FPSO mooring system during gas production. Waves and high current speeds can result in the offset distance of the moored Azurite FPSO being large enough to cause a

E-ISSN: 2828-6669; P-ISSN: 2828-7010
This work is licensed under a Creative Commons Attribution 4.0 International License.

high voltage response in the mooring system. This can also disrupt the production process and even damage the structure and other operational load factors [1]. Meanwhile, one of the things that influences the success of the production process is the mooring depth of the FPSO itself. Therefore, a good anchoring depth position is needed so that the production process can run well and smoothly, so that it does not result in a gradual ratio of damage due to fatigue.

2. Materials and Methods

The research applied in this paper was carried out using numerical modeling simulations to analyze performance mooring line as well as the ratio of structural damage due to fatigue to mooring line Azurite FPSO ship according to the depth variations used. Six (6) types of configurations were used for varying depths, namely depths of 1000, 900, 800, 700, 600 and 500 meters. For all depth variations, the Azurite FPSO dimensional data as listed in Table 2, mooring rope data in Table 3, and environmental data in Table 4 are used.

Modeling mooring system using software assistance Time Domain. The results of the analysis of the motion response of the Azurite FPSO obtained a voltage range for each mooring line. Voltage range on each mooring line obtained from time domain analysis of catenary mooring system based on the motion response of the Azurite FPSO in a direction of 180° (Surge and Sway). Next, on each mooring line calculations are carried out fatigue damage between stress-failure range and material characteristics mooring line used in accordance with API criteria (American Petroleum Institute) using the help of the Excel program.

Calculation Hot Spot Stress (HSS) of each mooring line using the following equation.

$$\sigma = \frac{F}{A} \qquad (1)$$

Information:

σ : Tension (N/m^2)
F : Cable force (N)
A : Material cross-sectional area (m^2)

The ratio of structural damage due to fatigue (Fatigue damage)

$$D = \frac{Pi}{Ni \times Ti} \qquad (2)$$

Information:

D : Fatigue damage
Pi : Probability value of wave occurrence
Ti : Wave period (seconds)
Ni : Number of wave events per stress range

The Pi value is obtained from wave scatter or selected wave distribution data. The pi value used is 20,8% or 0,208.

The Ni value is obtained from the S-N curve. The result of the S-N curve is a plot between voltage (S) and number of cycles (N). This curve is used to interpret the material used for its fatigue characteristics due to cyclical loads with a constant magnitude. The analytical equation of the S-N curve is:

$$Ni(s) = aD.s^{-m} \qquad (3)$$

Information:

Ni (s) : Cycle of failure
S : Tension range (N/m^2)
aD : Intercept parameter of kurva S-N
m : The slope of the S-N curve

Meanwhile, an explanation of the parameters aD and m can be obtained in Table 1 below.

Table 1. S-N Curve Parameters

Tipe Mooring	aD	M
Stud Chain	1,2 x 10^{11}	3,0
Studles Chain (Open Link)	6,0 x 10^{10}	3,0
Six-Strand Wire Rope	3,4 x 10^{14}	4,0
Spiral Strand Wire Rope	1,7 x 10^{17}	4,8

By linearizing the above equation using logarithms, the Ni equation can be expressed as follows.

$$\log(n_c(S)) = \log(aD) - m.\log(S) \qquad (4)$$

By using material type mooring Stud Chain then obtained,

$$\ln = \frac{1,2 \times 10^{11}}{S^3} \qquad (5)$$

Where the S (Stress Range) value is obtained from the following equation.

$$S = HSS \times DAF \qquad (6)$$

Information:

HSS : Hot Spot Stress (N/m^2)

DAF : Dynamic Amplification Factor

On calculations Stress Range value is required Dynamic Amplification Factor (DAF).

$$DAF = \frac{1}{\sqrt{\left\{1-\left(\frac{Tn}{T}\right)^2\right\}^2 + 2\beta\left(\frac{Tn}{T}\right)^2}} \qquad (7)$$

Information:

Tn : Natural period of structure (seconds)

T : Wave period (seconds)

β : Damping ratio (20%) based on API RP2A

FPSO Azurite Data

Fig. 1. FPSO Azurite

Table 2 below contains the data dimension Azurite FPSO to be used in modeling and analysis mooring system as well as fatigue damage.

Table 2. FPSO Azurite Data

Description	Data	Units
Length (LOA)	228,4	m
Widht (B)	45	m
Height (H)	27	m
Draft (T)	19,7	m
Displacement (Δ)	181.470	ton

Mooring Line Data

Data mooring line or rope used on mooring system The Azurite FPSO for installations on the high seas is presented in Table 3.

Table 3. Mooring Rope Data

Description	Data	Units
Material Name	Chain on Fairlead	-
Diameter	0,1588	m
Wet Weight	438,90	kg/m
Minimum Breaking Load	19563,30	kN
Length	140,208	m
Stiffness	1842397,80	kN

Mooring Configuration

In this study, six variations of mooring depth configurations with catenary mooring system (CSM) as seen in Figure 2. The first configuration seen in Figure 2 consists of four anchor ropes installed at the bow and stern at an angle of 45° at a depth of 1000 meters. The second, third, fourth, fifth and sixth configurations are the same as the first configuration with 4 anchor ropes installed at the bow and stern at an angle of 45° at depths of 900, 800, 700, 600 and 500 meters respectively. All configurations use a radius of 3000 meters Center Of Gravity (CoG) FPSO.

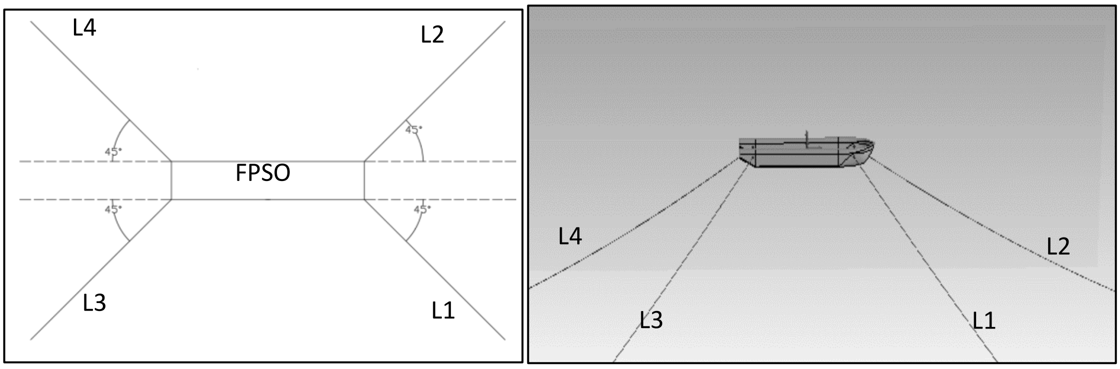


Fig. 2. Mooring Configuration

Environmental Data

This research was carried out at the Azurite FPSO installation location, namely in the Abadi field, Masela Block, Arafura Sea. Wave distribution data in the Masela Block and Masela Block wind and current data [2]. Environmental data at this location is as contained in Table 4.

Table 4. Enviromental Data

Description	Data	Units
Significant Wave Height (H_s)	3	m
Peak Period (T_p)	12	detik
Wind Speed (U_c)	16,91	m/s
Current Speed	0,5	m/s

3. Results

3.1 Hydrostatic Analysis

To obtain reliable results from Azurite FPSO modeling that match reality, the model design needs to be validated. The hydrostatic analysis results data reviewed include: Displacement, shape coefficient, location of the center of buoyancy (Center of Buoyancy), Wetted Surface Area (WSA), and others. Hydrostatic analysis results are obtained from hydrodynamic diffraction which considers movement heave, roll, and pitch. Hydrostatics results from the geometric characteristics of the FPSO model.

The hydrostatic modeling carried out is for volumetric displacement, position center of buoyancy, COG to COB distance and metacentric height due to the vertical mode of motion (heave, roll and pitch). This model has a stiffness factor that can influence the damping factor to be smaller, so that it will produce the highest characteristic results as presented in Table 5.

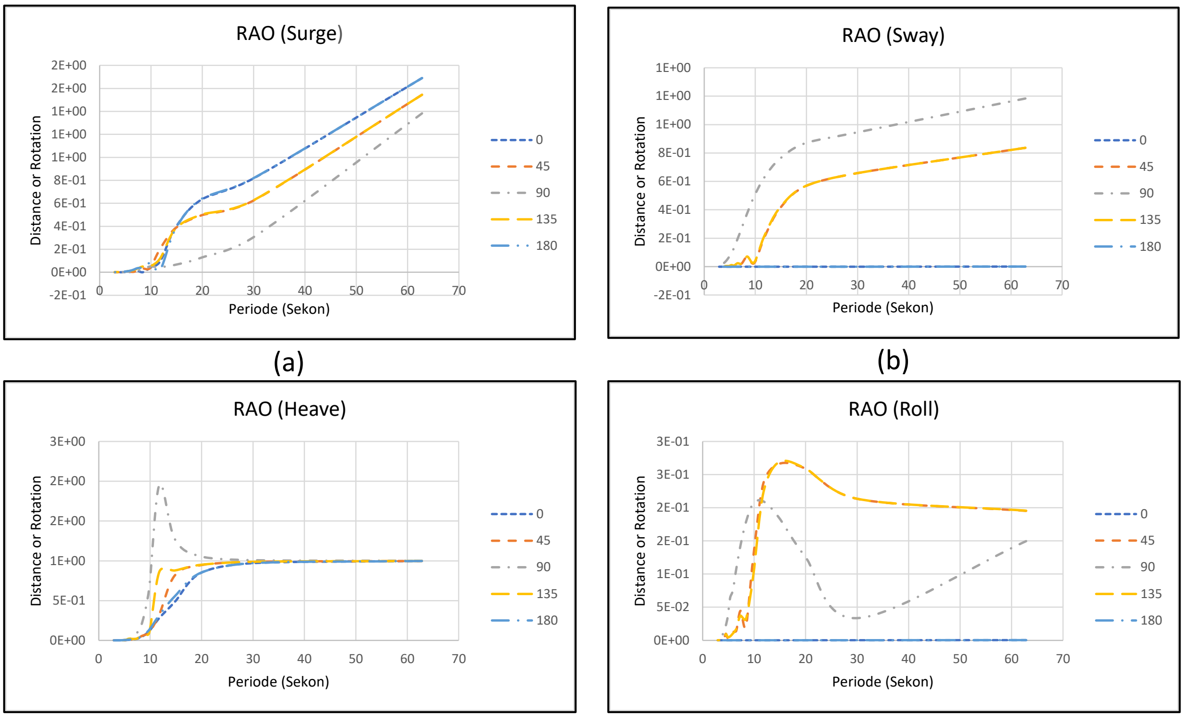
Table 5. Hydrostatic Analysis Results

Hydrostatic Stiffness			
Centre of Gravity Position	**X**: 0. m	**Y**: 0. m	**Z**: 0. m
	Z	**RX**	**RY**
Heave (Z)	97640344 N/m	130,60045 N/°	9997994 N/°
Roll (RX)	7482,855 N.m/m	-17196122 N.m/°	90,042328 N.m/°
Pitch (RY)	5,72843e8 N.m/m	90,042252 N.m/°	6,47594e9 N.m/°

Hydrostatic Displacement Properties			
Actual Volumetric Displacement	177044,27 m^3		
Equivalent Volumetric Displacement	177043,91 m^3		
Centre of Buoyancy Position	X : -4,0896831 m	Y : -1,4116e-4 m	Z : -9,4371853 m
Out of Balance Forces/Weight	FX : -4,5236e-3	FY: -2,6937e-8	FZ : 2,0858e-6
Out of Balance Moments/Weight	MX : -9,9734e-5 m	Y : 4,1076984 m	MZ: -3,1383e-7 m
Cut Water Plane Properties			
Cut Water Plane Area	9713,7012 m^2		
Small Angle Stability Parameters			
C.O.G to C.OB.(BG)	9,4371853 m		
Metacentric Heights			
GMX:	-0,5536394 m		
GMY:	206,60828 m		
COB to Metacentre			
BMX:	8,8835459 m		
BMY:	216,04546 m		
Restoring Moments			
MX:	-300129,13 N.m/°		
MY:	1,12003e8 N.m/°		

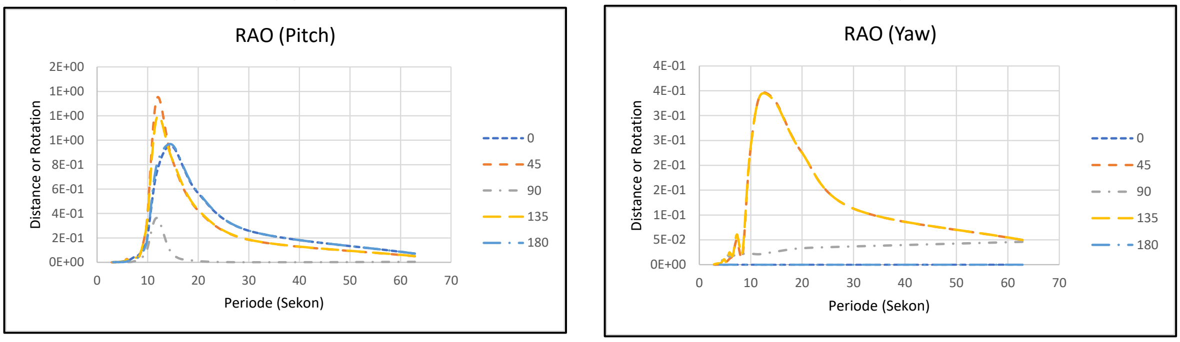
3.2 Analysis Response Amplitude Operator (RAO)

Transfer Function which is also known as RAO (Response Amplitude Operator) is the response function that occurs due to waves in a certain frequency range hitting offshore structures. RAO is referred to as transfer function because it functions to transfer wave loads in the form of a response to a structure [3]. The motion response that occurs in each direction is divided into 2, namely RAO translational motion and RAO rotational motion. RAO translational motion consists of RAO heave, RAO surge and RAO sway. Meanwhile, RAO rotational motion consists of RAO pitch, RAO yaw, and RAO roll. The results of the RAO analysis can be seen in Figure 3. Wave entry angle (wave heading) is the direction of the wave arrival measured from 0° at the stern to 180° at the bow of the FPSO ship.



(a) (b)

(c) (d)

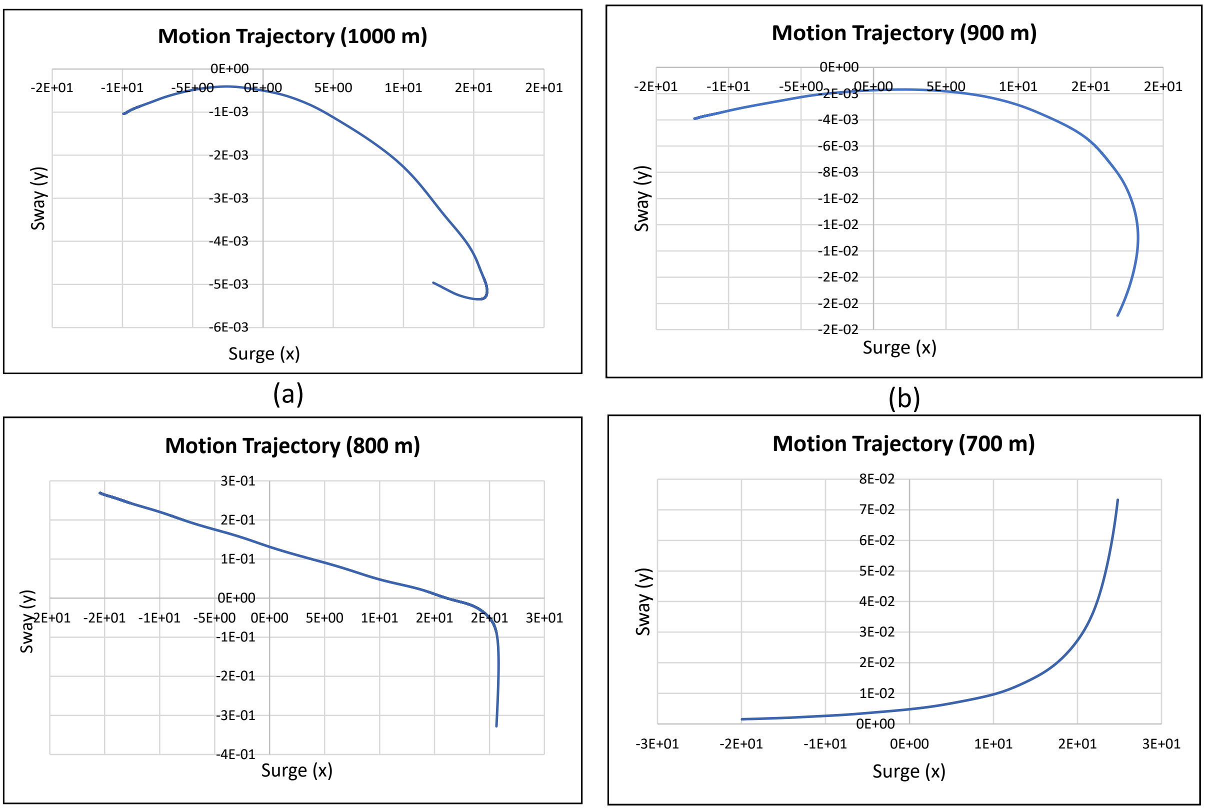


(d) (e)

Fig. 3. Comparison graph of RAO against direction Following seas 0°, Stern Quartering seas 45°, Beam seas 90°, Bow Quartering seas 135°, and Head seas 180°; (a) Surge motion; (b) Sway motion; (c) Heave motion; (d) Roll motion; (e) Pitch motion; and (f) Yaw motion.

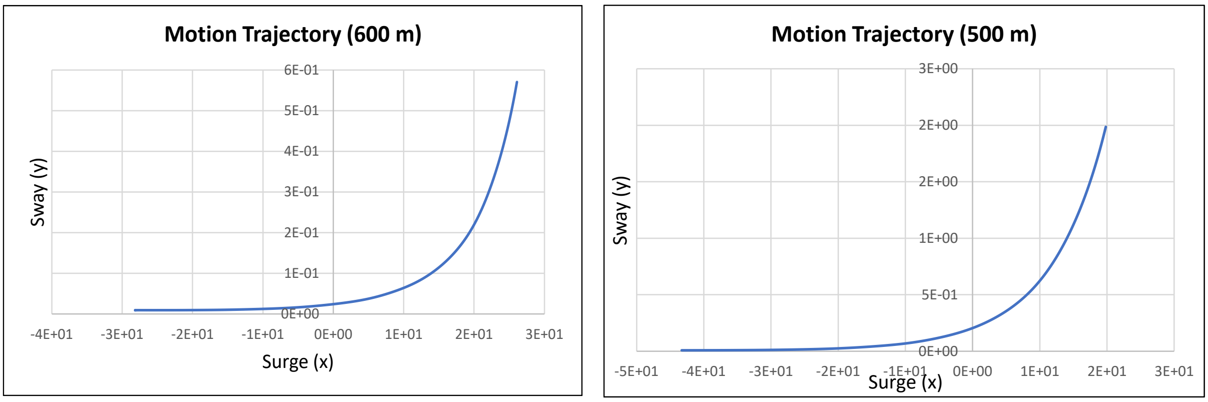
3.3 Results of FPSO Movement Analysis Based on Variations in Mooring Depth (Motion Trajectory)

In this study, the trajectory characteristics of the FPSO Azurite ship in relation to movement were analyzed surge (back and forth) andsway (right-left) at different mooring depth variations so that the most ideal mooring depth variation can be identified for use in Azurite FPSO mooring at the selected location.



(a) (b)

(c) (d)



(e) (f)

Fig. 4. Translational movement graph surge and sway on the Azurite FPSO; (a) 1000 meter depth variation; (b) 900 meter depth variation; (c) 800 meter depth variation; (d) 700 meter depth variation; (e) 600 meter depth variation; (f) 500 meter depth variation

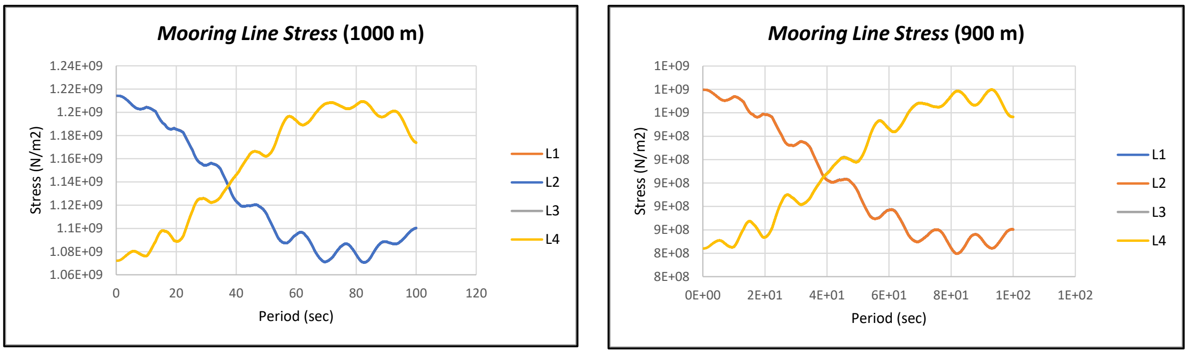
Table 6. Maximum value of translational movement surge and sway on variations in rope depth mooring

	Depth Variation of Mooring Line (meter)											
Movement	1000		900		800		700		600		500	
	Surge	Sway	Surge	Sway	Surge	Sway	Surge	Sway	Surge	Sway	Surge	Sway
Offset$_{max}$	15,95	0,00	18,26	0,00	20,83	0,27	24,79	0,07	26,10	0,57	19,82	1,99
Offset$_{min}$	-9,94	-0,01	-12,36	-0,02	-15,45	-0,33	-19,95	0,00	-28,16	0,01	-43,29	0,01
ΔOffset	25,89	0,00	30,63	0,02	36,27	0,60	44,73	0,07	54,26	0,56	63,12	1,98

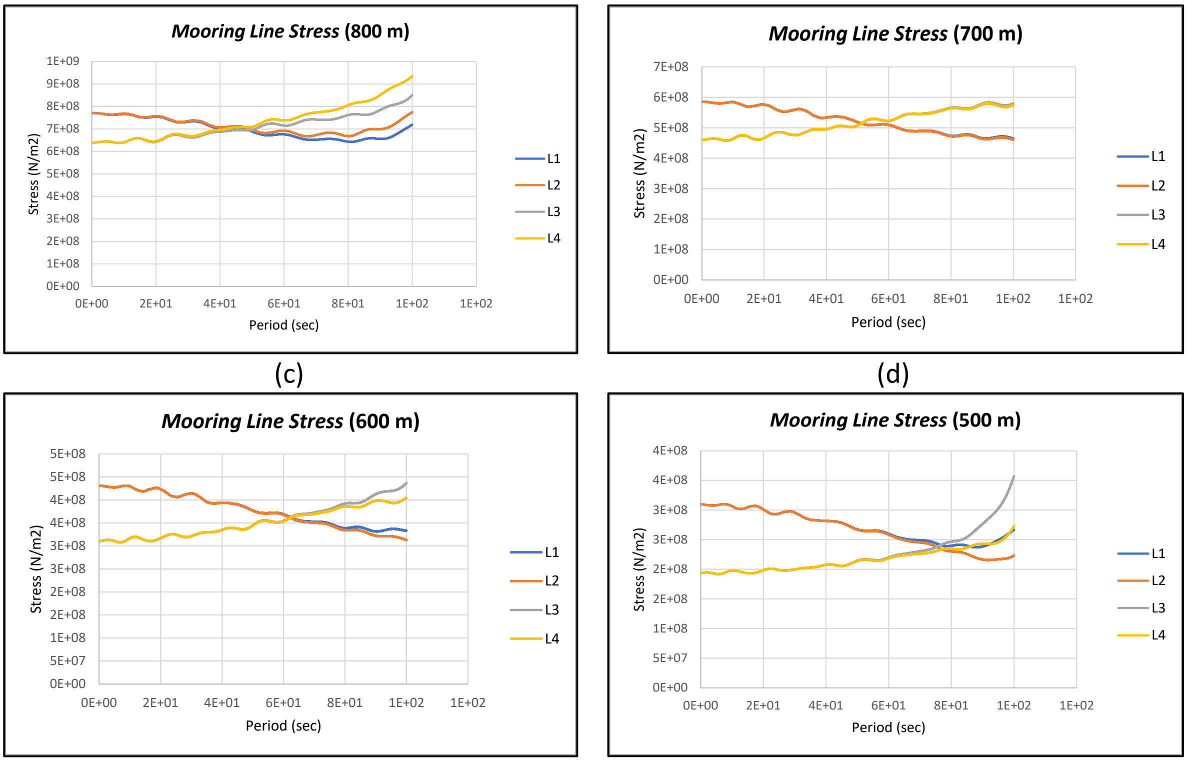
3.4 Results of Mooring Rope Tension Analysis (Hot Spot Stress)

In this research, simulation or dynamic modeling of FPSO ship mooring moored conditions at selected locations are modeled using software assistance Time Domain. This simulation was carried out over a time span of 100 seconds under operating environmental conditions as shown in Table 3. The main output obtained from this simulation was the tension in the rope for each time. The results obtained are then summarized in a tabulation of maximum values for the six variations of modeled depth configurations. Calculation of voltage for each mooring line using equation 1.

In the first to sixth configurations where the mooring depth used in modeling is 1000 meters to 600 meters, the maximum value of rope tension is obtained at each mooring line. Can be seen in Figure 5 & Table 7.



(a) (b)



(c) (d)

(e) (f)

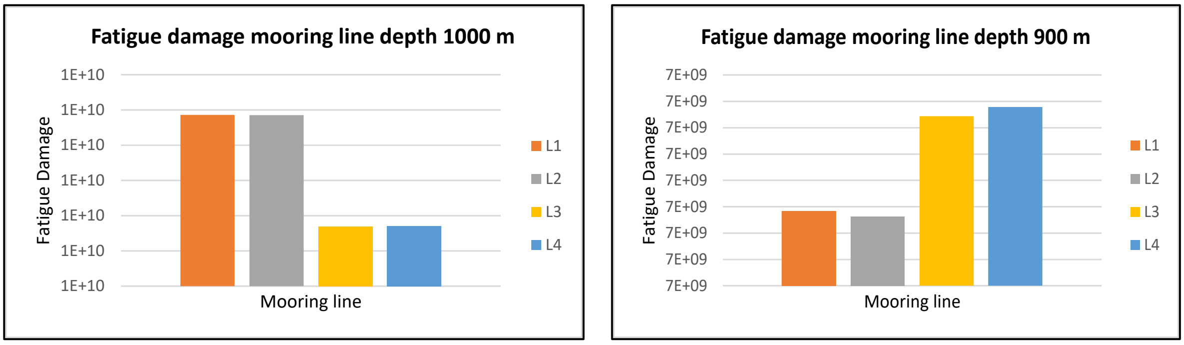
Fig. 5. Chart mooring line stress; (a) 1000 meter depth variation; (b) 900 meter depth variation; (c) 800 meter depth variation; (d) 700 meter depth variation; (e) 600 meter depth variation; (f) 500 meter depth variation

Table 7. Maximum value mooring line stress for each depth variation

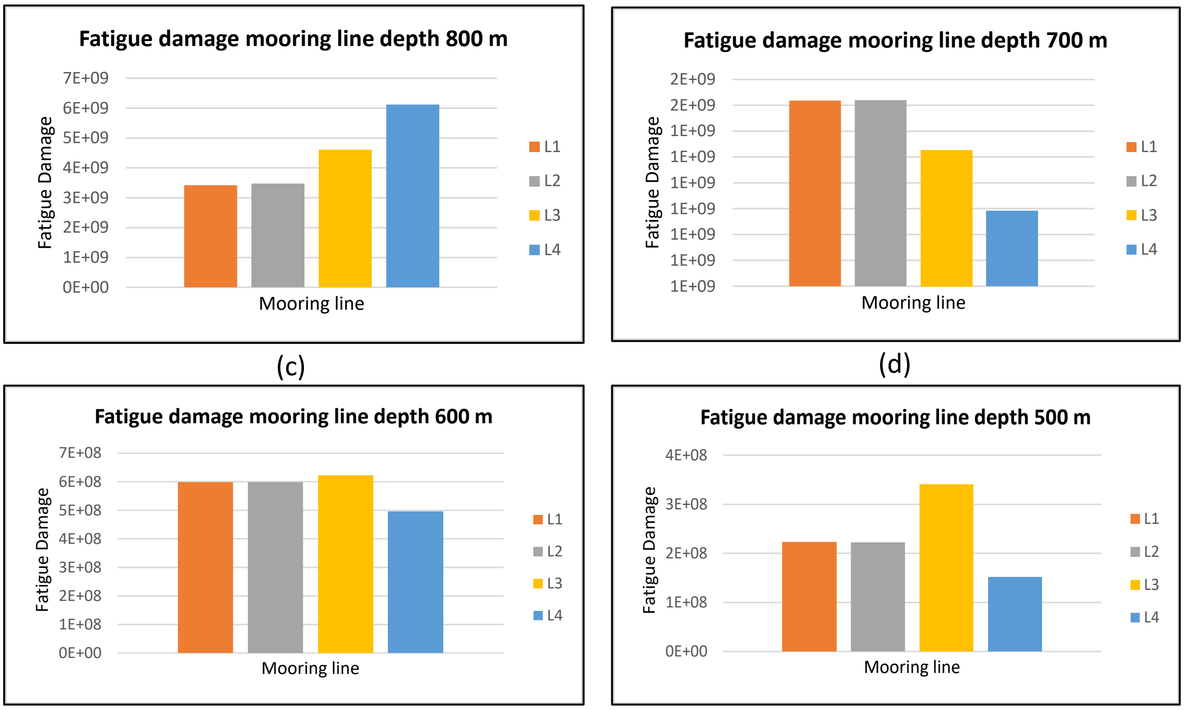
Depth Variation (m)	Maksimum Mooring Line Stress (N/m^2)			
	L1	L2	L3	L4
1000	1E+09	1E+09	1E+09	1E+09
900	1E+09	1E+09	1E+09	1E+09
800	8E+08	8E+08	9E+08	9E+08
700	6E+08	6E+08	6E+08	6E+08
600	4E+08	4E+08	4E+08	4E+08
500	3E+08	3E+08	4E+08	3E+08

3.5 Analysis Results Fatigue Damage

Damage due to structural fatigue (fatigue damage) can be calculated using equation 2. The results of the analysis can be seen in Figure 6 and Table 8.



(a) (b)



(c) (d)

(e) (f)

Fig. 6. Chart fatigue damage; (a) 1000 m depth variation; (b) 900 m depth variation; (c) 800 m depth variation; (d) 700 m depth variation; (e) 600 m depth variation; (f) 500 m depth variation

Table 8. Fatigue damage mooring line

Depth Variation (m)	Mooring Line			
	L1	L2	L3	L4
1000	1E+10	1E+10	1E+10	1E+10
900	7E+09	7E+09	7E+09	7E+09
800	3E+09	3E+09	5E+09	6E+09
700	2E+09	2E+09	1E+09	1E+09
600	6E+08	6E+08	6E+08	5E+08
500	2E+08	2E+08	3E+08	2E+08

4. Discussion

From the results of the numerical study, it was found that the highest ratio of structural damage due to fatigue at the Al Zaafarana FPSO occurred at a depth of 1000 meters. One of the reasons is that the mass of the rope is not proportional to the displacement of the ship, so a larger mass of rope or an additional number of ropes is needed. In addition, the numerical study simulation only uses 100 seconds so that the movement process only reaches transient movement, namely temporary changes that occur in the transition phase before reaching a stable condition. It is hoped that future researchers will carry out a numerical study simulation for a minimum of 3 hours or 10,800 seconds or until steady movement is achieved, which is the stable state of the Azurite FPSO.

5. Conclusions

Simulations have been carried out to see the influence of six (6) mooring system depth configurations in Azurite FPSO production operations on the high seas. Referring to the results of calculations, simulations and analysis that have been obtained, it can be concluded that in analyzing the effect of mooring depth on the ratio of fatigue damage to structures catenary FPSO Azurite, six variations in mooring depth, namely 500, 600, 700, 800, 900 and 1000 meters. The research results show that variations in depth of 500 meters produce value mooring line stress low and low damage ratio. Vice versa, the variation of 1000 meters of belay produces a value mooring line stress which is quite high which then causes a high level of damage ratio.

It can also be seen in the results of the analysis of the movement of the Azurite FPSO based on variations in mooring depth (Motion Trajectory) that the translational movement (surge and sway) The largest of these ships occurred at a depth of 500 meters. Where in the direction surge moving forward as far as 19.82 meters and backward as far as 43.29 meters. This is caused by one of the reasons that the mass of the rope used is not proportional to the mass of the rope used displacement ship so that additional mass or number of ropes is required. The next cause is because the length of the rope used loosens as the depth variation decreases. Therefore, the length of the mooring rope will also play a key role in ensuring the pre-tensioning strength. Depth variations have a key role if they are adjusted to the length of rope used and are also calculated properly using existing equations to produce the level of damage, ship drift and mooring line stress The low one. Finally, in the numerical analysis simulation carried out it only reaches the initial movement (transient) namely at 100 seconds where the ship's condition has not yet reached a stable condition (steady) which should. It is hoped that the simulation will then be carried out until the ship is truly in a stable condition in order to obtain more detailed results.

References

[1]. F. M. Assidiq, D. Paroka, M. Z. Muis, dan S. Klara, “Fatigue Analysis of Catenary Mooring System due to Harsh Environment in Head Seas", EPI International Journal of Engineering, Vol. 1, hal. 30-38, 2018.

[2]. Mahdarreza A, “Analisis Perilaku Floating LNG Pada Variasi Metocean Terhadap External Turret Mooring System Berbasis Simulasi Time Domain,” Surabaya. Tugas Akhir Jurusan Teknik Kelautan ITS 2010.

[3]. N. Arifannisa, N. Syahroni, dan M. Mustedjo, “Analisis Umur Kelelahan Pada Anchor Chain Single Point Mooring 3”, Jurusan Teknik Kelautan, Fakultas Teknologi Kelautan, Institut Teknologi Sepuluh November, Hlm. 30, 2016.

[4]. Zhang, X., Li, Y., & Li, C. "Influence of water depth on the dynamic response of FPSO mooring systems." Ocean Engineering, 166, 1-13, (2018).

[5]. Wu, Y., & Li, Y. "Fatigue damage assessment of mooring lines for deepwater FPSOs in the South China Sea." Ships and Offshore Structures, 14(2), 143-157, (2019).

[6]. Sutarto, T. A., & Suherman, T. "Numerical study on the mooring system of FPSO in the deepwater Masela Block." Procedia Engineering, 170, 191-198, (2017).

[7]. Peng, X., & Hong, S. "Fatigue damage analysis of mooring lines for FPSO in deepwater Masela Block." Journal of Offshore Mechanics and Arctic Engineering, 142(3), (2020).

[8]. Zhu, L., & Zhao, Y. "Dynamic analysis of mooring system for FPSO in the Masela Block." Marine Structures, 48, 42-57, (2016).