eISSN: 2721-5717; pISSN: 2747-2124 https://journal.unhas.ac.id/index.php/zonalaut

ZONA LAUT

JOURNAL OF OCEAN SCIENCE AND TECHNOLOGY INNOVATION

Analysis Of Motion Trajectory And Fatigue Damage Ratio Fpso To Catenary Mooring Line Failure

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Abstract

Floating Production Storage and Offloading (FPSO) is a ship that produces floating oil and gas by having a catenary mooring type mooring system. The FPSO will produce oil and gas in the Abadi Field in the Masela Block of the Arafuru Sea (09˚ 07' 51" S / 130˚ 28' 00" E) where the area has sea waves, wind and currents which will affect performance FPSO ship. In this research, Response Amplitude Operator (RAO), motion trajectory and fatigue damage ratio will be tested with a ship mooring system of 12 ropes, 3 of which experienced failure. The conclusion of this research is that the more mooring ropes break, the farther the FPSO ship will move from its initial condition and the higher the maximum rope tension value, it will be directly proportional to the stress range on each mooring rope, while for the fatigue damage ratio, the higher the failure cycle value. then it will be inversely proportional to the fatigue damage ratio value for each mooring rope.

Keyword: FPSO, Catenary Mooring, Response Amplitude Operator, Motion Trajectory, Fatigue Damage Ratio

1. INTRODUCTION

Floating Production Storage and Offloading, often abbreviated to FPSO, is a ship that is considered good at producing oil and gas from offshore exploitation sites because of its ability to transport oil and gas relatively cheaply compared to other floating structures and is easier to move from one place to another. because the FPSO ship is not anchored to the seabed. FPSO has the characteristics of being able to be placed in water conditions where wave height, wind and currents are quite extreme. With this statement, a strong ship mooring system is also needed to deal with these extreme conditions. Therefore, knowledge is needed about the estimated response of a structure in a certain environment to more easily determine the risks that will occur to a structure later in the field.

In this case, the FPSO will be operated in the Abadi Field in the Masela Block which is estimated to have the largest gas reserves in Indonesia which will be exploited where in this area there are sea waves, winds and currents which will affect the ship's mooring system while drilling. Therefore, it is necessary to carry out an analysis to calculate the motion response to the rope tension that occurs as well as the fatigue damage ratio resulting from the FPSO ship being moored where when drilling for gas and oil there is a broken rope due to a failure in running the mooring system with the catenary mooring type. the FPSO ship.

2. METHOD

This research uses an analytical method using CFD (Computational Fluid Dynamics) based software, namely Ansys AQWA, which aims to investigate and analyze the mooring line system on the FPSO (Floating Production Storage and Offloading) which will be operated in the Abadi field, Masela block, Arafuru Sea (09˚ 07' 51" S / 130˚ 28' 00" E). Starting with collecting research supporting data which will later be input into

CFD. In this research, an error occurred in the performance of the mooring line where the cable on the FPSO broke which would affect the hydrostatic stiffness of the ship, namely translationally (Surge: x-direction motion, Sway: y-direction motion, and Heave: z-direction motion) and rotation (Roll: x-axis rotation, Pitch: y-axis rotation, and Yaw: z-axis rotation). The data used in this research include the following: . .

2.1. FPSO Vessel Data

- Total Length (LOA) = 280 m
- Width (B) = 59 m
- Height (H) = 31.5 m
- (T) = 23.03 m
- Displacement = 341039 ton

2.2. Data Mooring Line FPSO

- Mooring Type = Catenary (Chain)
- Type of Rope = Studless R4
- Total Rope = 12
- Radius Mooring Line = 3000 m
- Diameter = 0.1588 m
- Wet Weight = 438.90 kg/m
- Strap Length = 3100 m
- Axial Stiffness (EA) = 1842397800 N
- Maximum Breaking Load (MBL) = 19563300 N

2.3. Environmental Data

- Deep Sea = 1000 m
- Wave Height = 2 m
- Peak Periode = 12 m
- Wind = 16.91 m/s
- Current = 0.5 m/s

2.4. FPSO Ship Modeling

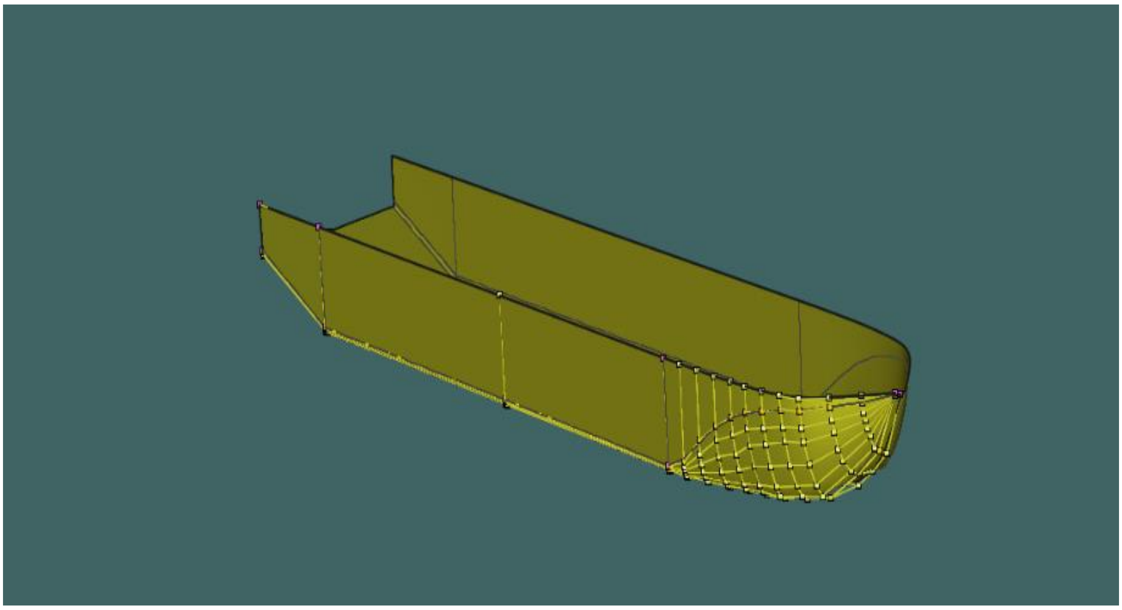


Figure 2.4.1 3 Dimensional View of the FPSO Ship

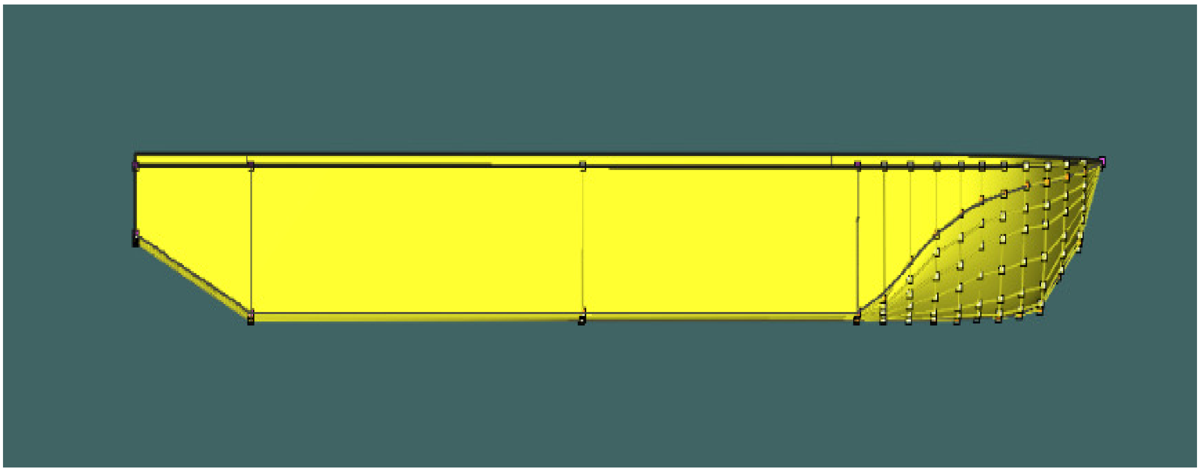


Figure 2.4.2 2 Dimensional Side View of the FPSO Ship

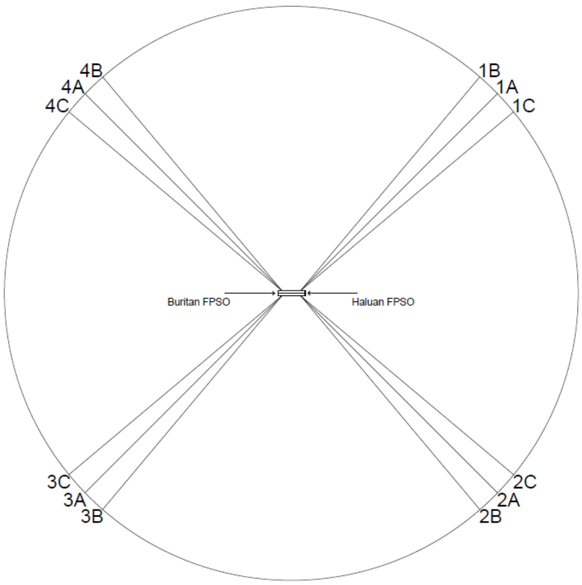


Figure 2.4.3 Top View of an FPSO Ship with a Mooring Line Radius of 3000 Meters

2.5. Mathematical Parameters & Equations

To determine the movement characteristics of structures in the deep sea, carry out an RAO analysis of the structure by considering the following equation [1]

RAO Translational Movement (surge, sway & heave)

$$\mathrm{RAO} = \frac{\zeta_{k0}}{\zeta_0} \quad (\mathrm{m/m}) \tag{1}$$

Wuth :

ζ_{k0} = amplitude structure (ω)

ζ_0 = Wave amplitude (ω)

RAO Rotational Movement (roll, pitch & yaw)

$$\mathrm{RAO} = \frac{\zeta_{k0}}{k_w \zeta_0} = \frac{\zeta_{k0}}{(\frac{\omega^2}{g})\zeta_0} \quad (\mathrm{rad/m}) \tag{2}$$

Dengan :

ζ_{k0} = amplitude structure (ω)

ζ_0 = Wave amplitude (ω)

ω = Wave frecuency (rad/det)
g = average acceleration due to gravity of the earth (m/s²)

To calculate the Dynamic Amplification Factor (DAF) for each wave period, Hot Spot Stress (HSS) on the riser, Stress Range (S) for each data, and the number of wave events for each Stress Range (Ni), the following equation is used:

$$\mathrm{DAF} = \frac{1}{\sqrt{\left\{1 - \frac{\mathrm{Tn}^2}{\mathrm{T}}\right\}^2 + 2\beta\left(\frac{\mathrm{Tn}}{\mathrm{T}}\right)^2}} \qquad (3)$$

With :

Tn = period natural structure (det)
T = period waveng (det)
B = damping ratio (20%) based on API RP2A

$$\mathrm{HSS} = \frac{\mathrm{F}}{\mathrm{A}} \qquad (4)$$

With :

F = Force (N)
A = Surface Area (m²)

$$\mathrm{S} = \mathrm{HSS} \times \mathrm{DAF} \qquad (5)$$

With :

HSS = tension (N/m²)
DAF = dynamic amplification factor

Fatigue analysis is defined as research that includes global dynamic motion and local stresses of catenary moorings. Existing methodologies do not have the level of consistency and transparency necessary to independently demonstrate the level of safety and conservatism in catenary design [2]
The basis of the S-N curve is mentioned between the voltage plot and the number of cycles (N). This curve is used to express the fatigue characteristics of a material due to a constant cyclical load [3]. The level of accuracy is influenced by determining the slope and intercept parameters of the S-N curve, the analytical expression of the S-N curve is [4]:

Ni(s)= aD × S^(-m)

$$\mathrm{Ni(s)} = \mathrm{aD} \times \mathrm{S}^{-\mathrm{m}} \qquad (6)$$

With :

S = stress range (N/m²)
aD = parameter in the S-N curve
m = slope of the S-N curve

Each mooring rope takes a fatigue life which is further processed between the number of cycles-tension range and the characteristics of the mooring rope [5]. Overview of fatigue life in surge, sway, heave, roll, pitch and yaw motion conditions in the direction of 1800 (head seas) is calculated as follows [2]:

$$\mathrm{n} = \frac{\mathrm{T}}{\mathrm{Ta}} \qquad (7)$$

$$\mathrm{D} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{\mathrm{n}}{\mathrm{Ni}} \qquad (8)$$

With :

n = number of cycles
D = fatigue damage ratio
T = design lifetime (sec)
Ta = voltage period range (sec)
Ni = failure cycle

The parameters aD (S-N curve) and m (slope of the S-N curve) are shown in Figure 2.5.1 and Table 2.5.1

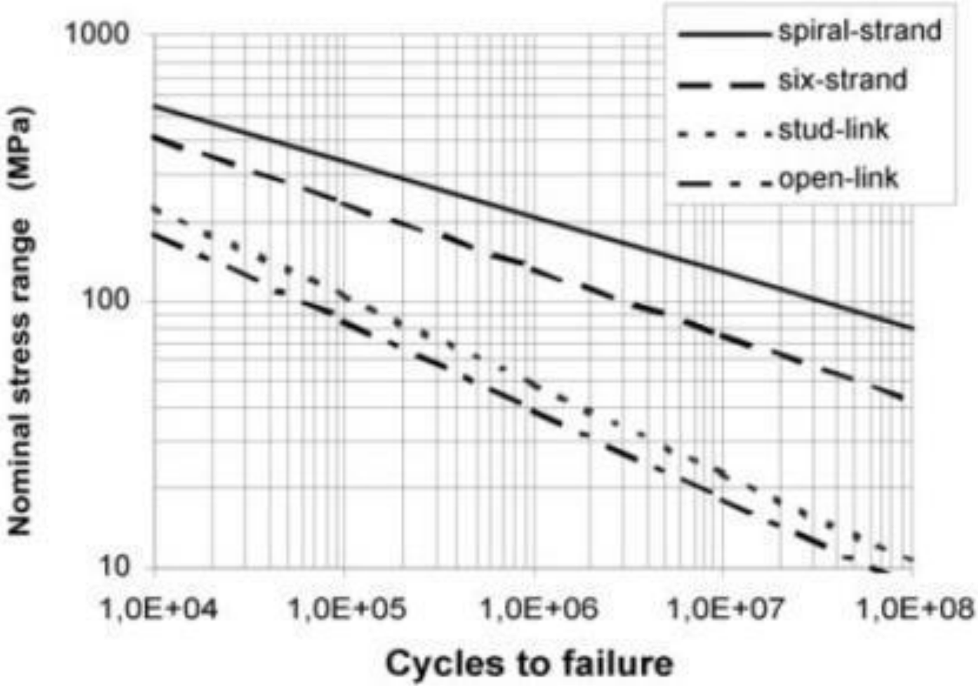


Figure 2.5.1 S-N curve

Table 2.5.1 Kurva S-N parameters

Jenis Mooring	aD	m
Stud Chain	1.2×10^{11}	3.0
Studless Chain (Open Link)	6.0×10^{10}	3.0
Six-Strand Wire Rope	3.4×10^{14}	4.0
Spiral Strand Wire Rope	1.7×10^{17}	4.8

Mooring systems usually have 8 to 16 mooring lines consisting of heavy chains, steel wire ropes and polyester material that connect the anchor to the seabed [6]. The catenary system line reaches the seabed horizontally, even though the moorings are anchored tightly to form an angle [7]. Another important difference is that the restoring strength in catenary moorings is generated by the weight of the components while the strength of mooring links comes from the elasticity of the mooring ropes.
When oil and gas extraction occurs in shallow or deep waters, the catenary system is more popularly used, but when identifying production from deep to deeper waters, the mooring system has limiting factors so that to overcome this, there must be a new solution developed as a mooring system. Figure 2.5.1 shows the mooring system configuration [8].

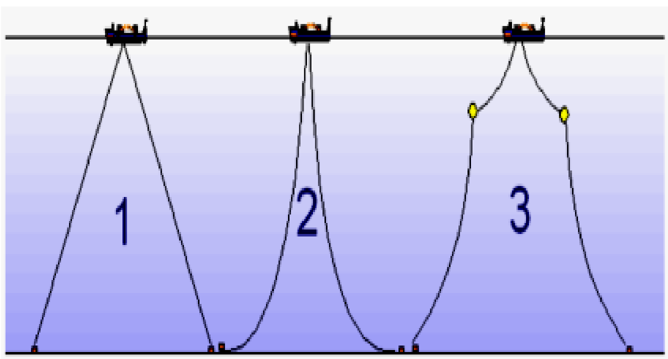


Figure 2.5.1. 1)Link Mooring 2) Catenary Mooring 3) Catenary Mooring with Buoyancy

The stress that occurs in mooring ropes can be divided into two, namely average stress and maximum stress. The average stress is the tension on the mooring rope which is related to the average displacement of the ship, while the maximum stress is the average maximum stress under the combined influence of wave frequency and low voltage frequency [9]..

3. RESULT AND DISCUSSION

This simulation analysis was carried out using Ansys AQWA software. The analysis results obtained RAO (Response Amplitude Operator) in free floating conditions with loading directions of 0°, 45°, 90°, 135° and 180° in six translational and rotational degrees of freedom: surge, sway, heave, roll, pitch and yaw . The analysis results of the motion trajectory were obtained from the Ansys AQWA Hydrodynamic Time Response with three variations which have been tested by reviewing the displacement of the FPSO ship in relation to surge and sway. The analysis results of the stress range and fatigue damage ratio were obtained from the Ansys AQWA Hydrodynamic Time Response on each mooring rope. Where the results of each analysis will be explained in the attached sub-chapter.

3.1. Table

Table 1. Maximum Free Floating RAO Translation Value Surge

Surge			Sway			Heave		
Direct	Maksimum	Period	Direct	Maksimum	Period	Direct	Maks	Periode
0˚	1.49E+00	6.28E+01	0˚	8.58E-05	3.18E+01	0˚	9.96E-01	6.28E+01
45˚	1.32E+00	6.28E+01	45˚	8.23E-01	6.28E+01	45˚	9.98E-01	6.28E+01
90˚	1.13E+00	6.28E+01	90˚	1.17E+00	6.28E+01	90˚	1.83E+00	1.28E+01
135˚	1.32E+00	6.28E+01	135˚	8.23E-01	6.28E+01	135˚	9.98E-01	6.28E+01
180˚	1.49E+00	6.28E+01	180˚	8.47E-05	3.18E+01	180˚	9.96E-01	6.28E+01

Table 2. Maximum Free Floating RAO Rotation Value Roll

Roll			Pitch			Yaw		
Direct	Maksimum	Period	Direct	Maksimum	Period	Direct	Maks	Periode
0˚	2.78E-03	3.18E+01	0˚	6.08E-01	1.60E+01	0˚	1.88E-05	9.15E+00
45˚	5.62E+00	3.18E+01	45˚	7.92E-01	1.28E+01	45˚	3.16E-01	1.60E+01
90˚	3.77E+00	3.18E+01	90˚	2.01E-01	1.28E+01	90˚	5.12E-02	3.18E+01
135˚	5.63E+00	3.18E+01	135˚	7.16E-01	1.28E+01	135˚	3.14E-01	1.60E+01
180˚	2.75E-03	3.18E+01	180˚	6.19E-01	1.60E+01	180˚	1.55E-05	9.15E+00

Table 3. Stress Range Values for Each Variation

Variationi 1		
Tali Tambat	Voltage Maksimum (N/m^2)	Stress Range (Pa)
Tali 1A	0	0
Tali 2A	1.10E+09	4.12E+07
Tali 3A	1.06E+09	3.97E+07
Tali 4A	1.06E+09	3.97E+07
Tali 1B	1.46E+09	5.48E+07
Tali 2B	1.13E+09	4.25E+07
Tali 3B	1.09E+09	4.11E+07
Tali 4B	1.11E+09	4.16E+07
Tali 1C	1.34E+09	5.03E+07
Tali 2C	1.07E+09	4.02E+07
Tali 3C	1.03E+09	3.86E+07
Tali 4C	1.03E+09	3.86E+07

	Variation	
Tali Tambat	Voltage Maksimum (N/m^2)	Stress Range (Pa)
Tali 1A	0	0
Tali 2A	1.10E+09	4.12E+07
Tali 3A	1.06E+09	3.97E+07
Tali 4A	1.06E+09	3.97E+07
Tali 1B	0	0
Tali 2B	1.13E+09	4.25E+07
Tali 3B	1.09E+09	4.11E+07
Tali 4B	1.09E+09	4.10E+07
Tali 1C	2.03E+09	7.62E+07
Tali 2C	1.07E+09	4.02E+07
Tali 3C	1.03E+09	3.86E+07
Tali 4C	1.03E+09	3.86E+07

	Variation 3	
Mooring Rope	Failure Cycle (Ni)	Fatigue Damage Ratio (D)
Tali 1A	0	0
Tali 2A	1.10E+09	4.12E+07
Tali 3A	1.06E+09	3.97E+07
Tali 4A	1.06E+09	3.97E+07
Tali 1B	0	0
Tali 2B	1.13E+09	4.25E+07
Tali 3B	1.09E+09	4.11E+07
Tali 4B	1.09E+09	4.10E+07
Tali 1C	0	0
Tali 2C	1.11E+09	4.17E+07
Tali 3C	1.03E+09	3.86E+07
Tali 4C	1.03E+09	3.86E+07

Table 4. Fatigue Damage Ratio Value in Each Variation

	Variation 1	
Mooring Rope	Failure Cycle (Ni)	Fatigue Damage Ratio (D)
Tali 1A	0	0
Tali 2A	1.71E-06	1.01E+04
Tali 3A	1.91E-06	9.06E+03
Tali 4A	1.92E-06	9.05E+03
Tali 1B	7.30E-07	2.37E+04
Tali 2B	1.57E-06	1.11E+04
Tali 3B	1.73E-06	9.99E+03
Tali 4B	1.67E-06	1.04E+04
Tali 1C	9.41E-07	1.84E+04
Tali 2C	1.85E-06	9.39E+03
Tali 3C	2.09E-06	8.31E+03
Tali 4C	2.08E-06	8.32E+03

	Variation 2	
Mooring Rope	Failure Cycle (Ni)	Fatigue Damage Ratio (D)
Tali 1A	0	0
Tali 2A	1.71E-06	1.01E+04
Tali 3A	1.91E-06	9.06E+03
Tali 4A	1.92E-06	9.05E+03
Tali 1B	0	0
Tali 2B	1.57E-06	1.11E+04
Tali 3B	1.73E-06	9.99E+03
Tali 4B	1.74E-06	9.96E+03
Tali 1C	2.71E-07	6.39E+04
Tali 2C	1.85E-06	9.39E+03

Tali 3C	2.09E-06	8.31E+03
Tali 4C	2.08E-06	8.32E+03

Variation 3

Mooring Rope	Failure Cycle (Ni)	Fatigue Damage Ratio (D)
Tali 1A	0	0
Tali 2A	1.71E-06	1.01E+04
Tali 3A	1.91E-06	9.06E+03
Tali 4A	1.92E-06	9.05E+03
Tali 1B	0	0
Tali 2B	1.57E-06	1.11E+04
Tali 3B	1.73E-06	9.99E+03
Tali 4B	1.74E-06	9.96E+03
Tali 1C	0	0
Tali 2C	1.66E-06	1.05E+04
Tali 3C	2.09E-06	8.31E+03
Tali 4C	2.08E-06	8.32E+03

3.2. Pictures and Graphics

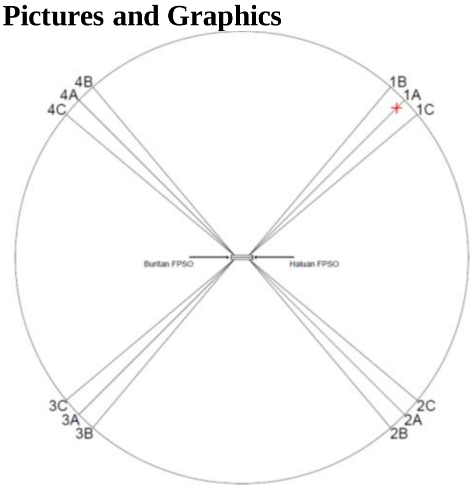


Figure 1. Variation 1 Mooring Line with Broken 1A Rope

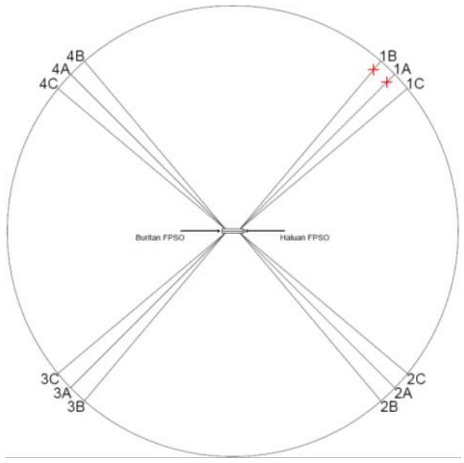


Figure 2. Variations of 2 Mooring Lines with Broken Rope 1A and Rope 1B

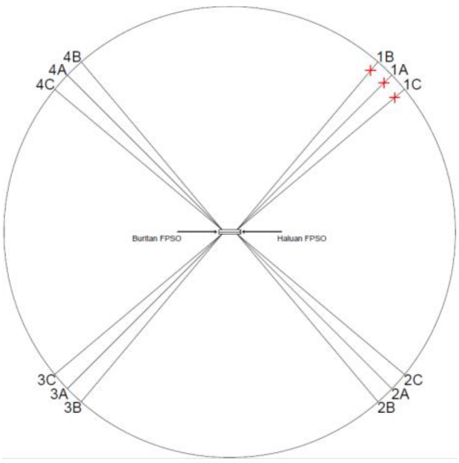


Figure 3. Variations of 3 Mooring Lines with Broken Rope 1A, Rope 1B and Rope 1C

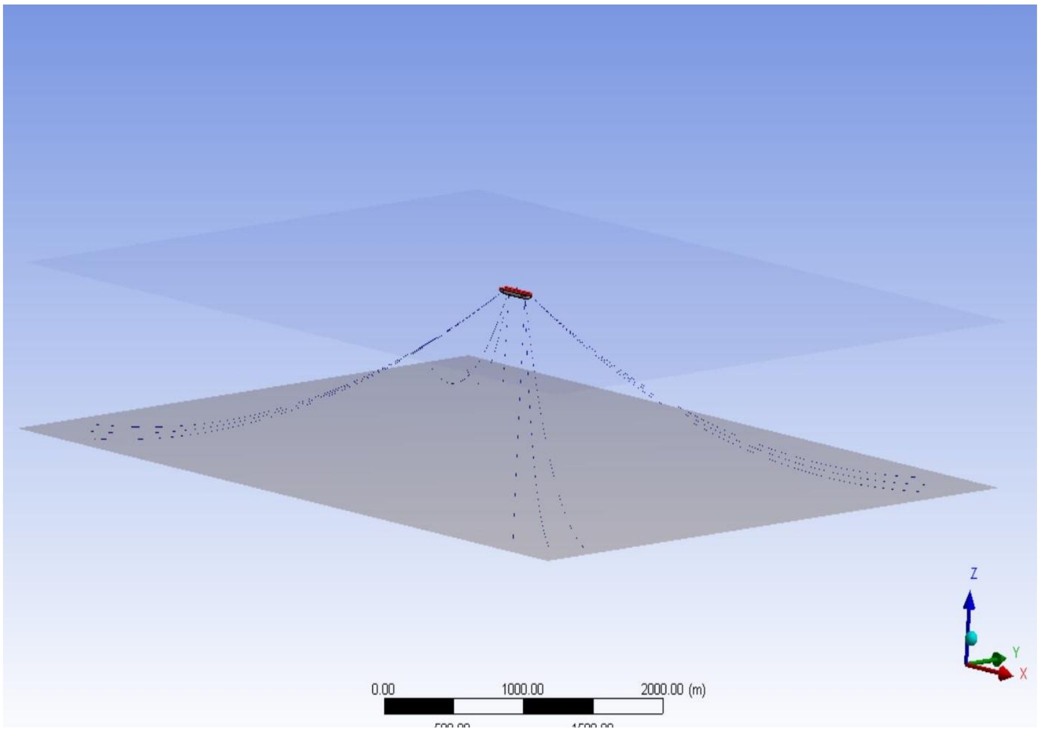


Figure 4. Catenary Mooring of an FPSO Ship with a Depth of 1000 Meters

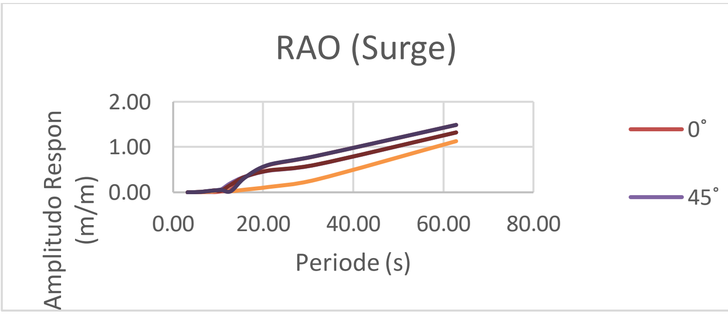


Figure 5. RAO Surge Free Floating Analysis

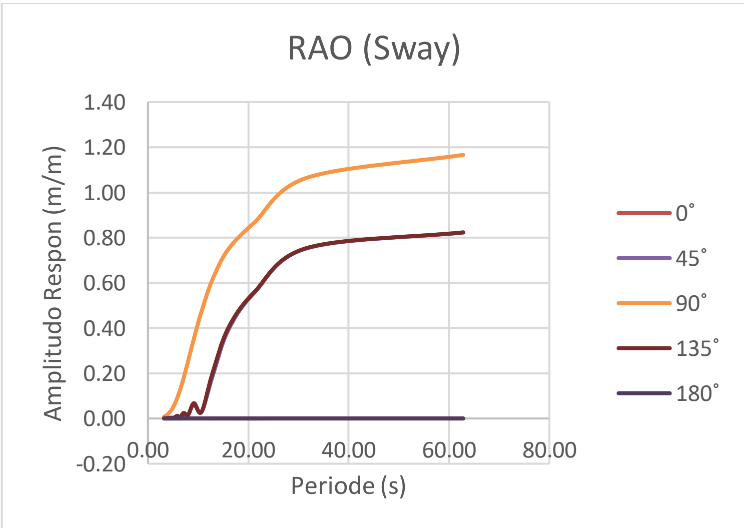


Figure 6. RAO Sway Free Floating Analysis

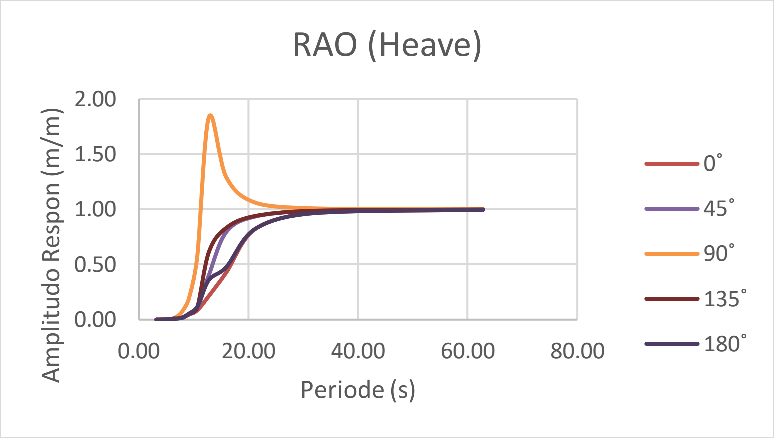


Figure 7. Heave Free Floating RAO Analysis

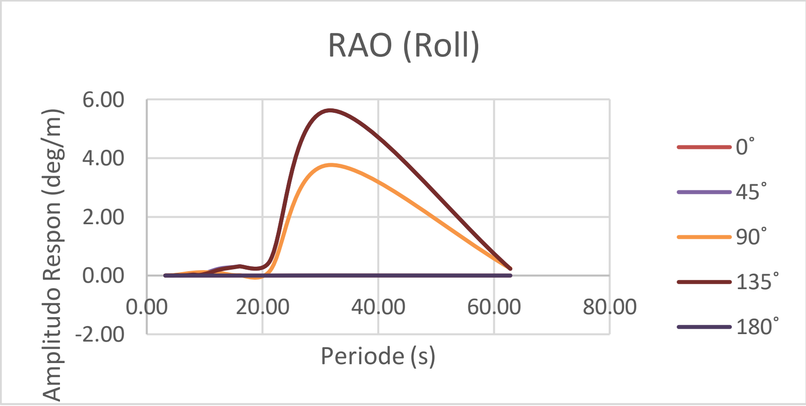


Figure 8. RAO Roll Free Floating Analysis

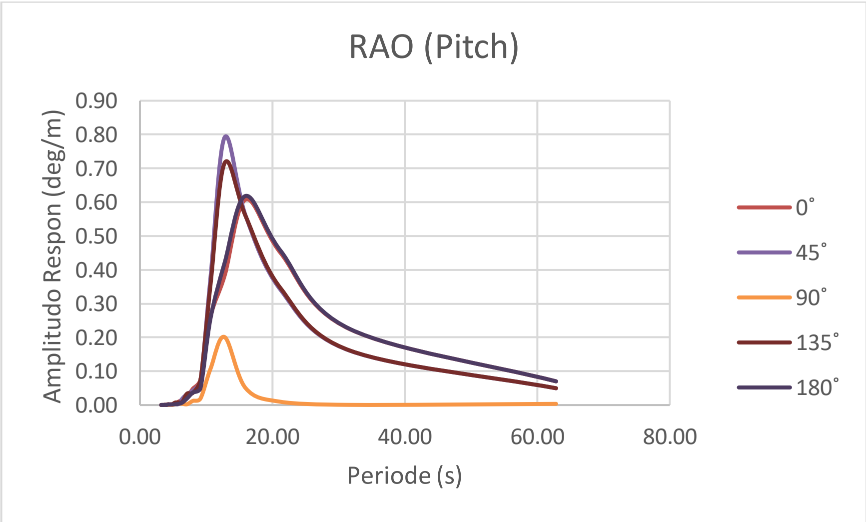


Figure 9. Free Floating Pitch RAO Analysis

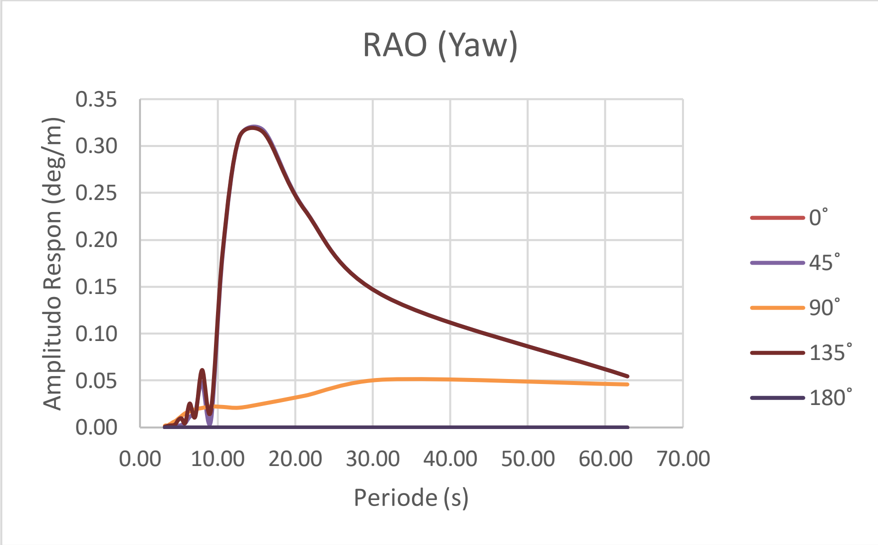


Figure 10. Free Floating Pitch RAO Analysis

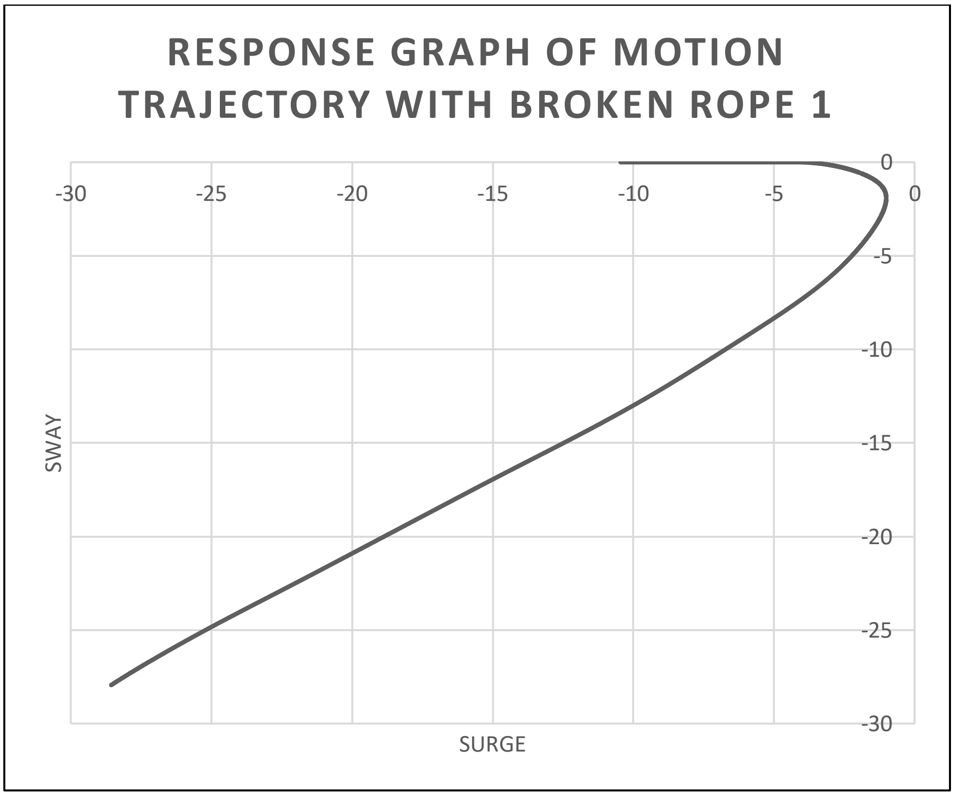
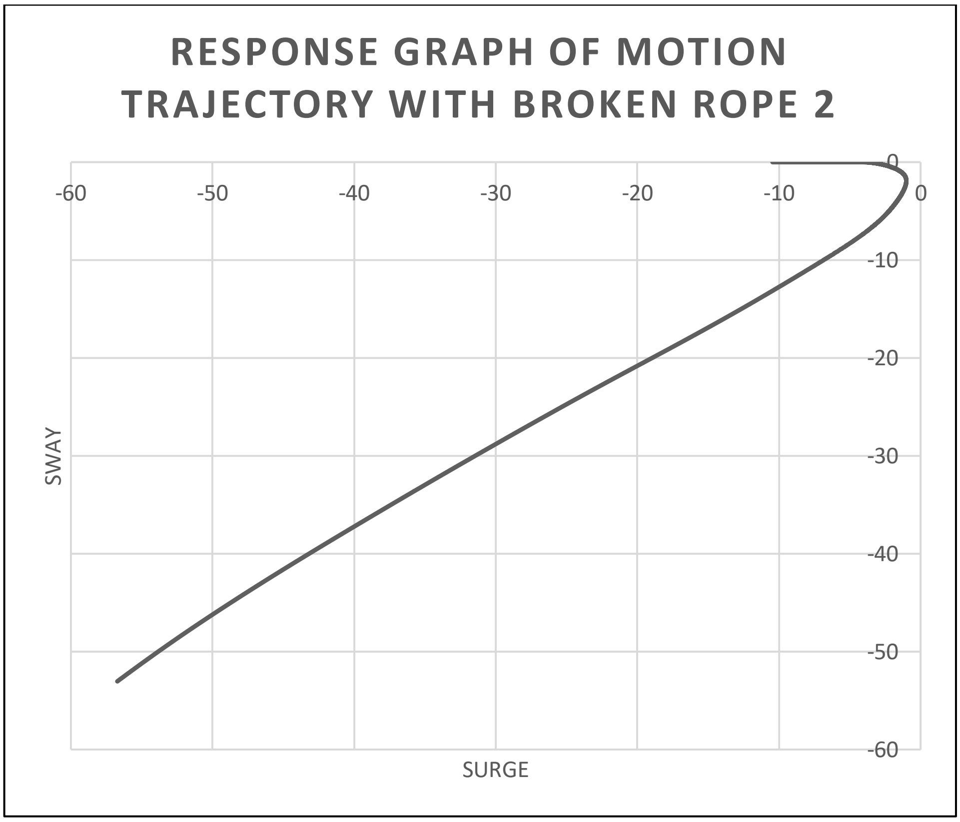


Figure 11. Motion Trajectory Variation 1



Gambar 12. Motion Trajectory Variasi 2

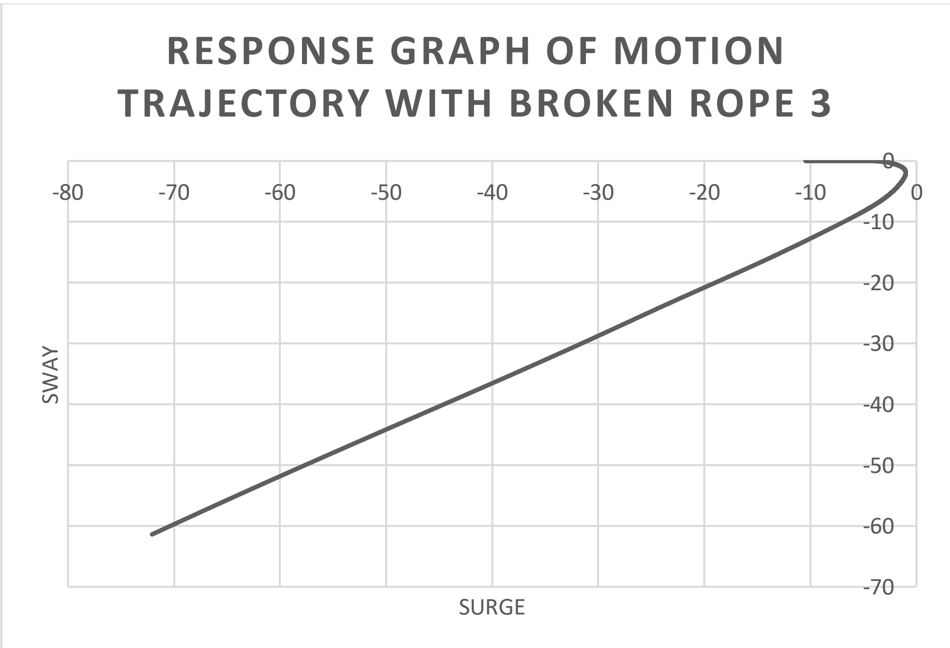


Figure 13. Motion Trajectory Variation 3

4. CONCLUSION

After carrying out this analysis, we used software on the FPSO ship which was modeled with free floating and catenary type mooring system modeling where there were mooring rope failures. The conditions on the FPSO ship can be described as quite good because the maximum RAO obtained is below the wave height value, although on the Roll RAO there is a maximum value that exceeds the wave height value. In the motion trajectory of the FPSO ship which had a failure in the mooring rope system of each variation experienced significant displacement where when the rope broke 1 the surge displacement was -28.566353

meters, when the rope broke 2 the surge displacement was -56.720108 meters and when the rope broke 3 the surge displacement was -72.062843 meters.
With the catenary type mooring system from the software, the stress range value is obtained which shows that the higher the maximum rope tension value, it will be directly proportional to the stress range on each mooring rope, while the fatigue damage ratio shows that the higher the failure cycle value, the inversely proportional to the fatigue value. damage ratio on each mooring rope.

THANK-YOU NOTE

In this chapter, I as the author realize that without support, assistance, cooperation and guidance from various parties, the preparation of this research would never be completed. Therefore, I would like to express my deepest thanks to:
1.Mr. Fuad Mahfud Assidiq, ST., MT., as Lecturer in Marine Engineering, Hasanuddin University
2. Muhammad Mustafa Algifari, as a Bachelor of Marine Engineering student at Hasanuddin University
3. Fadhil Julyardiansyah, as an undergraduate student in Marine Engineering at Hasanuddin University
4. Adhitya Arya Prayudha Kurniawan, as a Bachelor's Degree Student in Marine Engineering, Hasanuddin University
5. Sulkifli, as a Bachelor's Degree Student in Marine Engineering at Hasanuddin University
May Allah SWT give a double reward to everyone who has helped in carrying out this research. The author hopes that this research can provide benefits for readers and the author himself.

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