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Numerical Studies Fatigue Damage From Material Variations Catenary Mooring System FPSO Al Zaafarana

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Abstract

When operating, the FPSO receives environmental loads in the form of currents, wind and waves so mooring ropes are required (mooring line). Mooring line is a way to dampen the movement of the Al Zaafarana FPSO which allows it to move freely in the direction of the load. However, several cases of mooring rope accidents occurred including material fatigue of 20%, deployment 17%, and corrosion 11%. So the aim of this research is to analyze motion trajectory (surge and sway), mooring line stress, and deterministic fatigue on mooring line so you get it fatigue damage material catenary mooring line for FPSO Al Zaafarana. Thus, it is hoped that this research can make a scientific contribution in improving the quality and safety of materials mooring line for the Al Zaafarana FPSO, as well as increasing the efficiency of the oil drilling process. This research method uses a numerical study approach as a secondary data source with modeling and simulation using software as well as literature analysis that will support the numerical simulation results. From the results of numerical studies obtained fatigue damage The highest is the material type chain for FPSO Al Zaafarana. 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 is needed or an increase in the number of ropes. In addition, the numerical study simulation only uses 100 seconds so that the movement process only reaches movement transient namely temporary changes that occur in the transition phase before reaching a stable condition.

Keywords: Fatigue Damage; Material; Mooring System.

1. Introduction

The Ministry of Energy and Mineral Resources stated that Indonesia's oil and gas exploration was shifting from onshore (mainland) to offshore (off/deep sea) due to decreased production results due to the old age of the well. Moreover, around 70% of oil and gas reserves are in waters. In this case it is used floating platform in the form of an FPSO (Floating Production Storage and Offloading) Al Zaafarana because of its advantages, namely good operations in deep sea drilling, receiving and processing oil and gas from wells or from fixed platform, and economical because the FPSO can be used at another location when production time has run out [1]. When operating, the FPSO receives environmental loads in the form of currents, wind and waves so mooring ropes are required (mooring line) [2].

Mooring line is a way to reduce the movement of the Al Zaafarana FPSO which allows it to move freely in the direction of environmental loads and mooring line help the process weathervaning so that the operation can be carried out safely. But in reality it failed mooring system quite high, Drori (2015) noted that from 1997 to 2012, there were 107 mooring rope accidents at 73 facilities from all industries. According to a survey conducted by Carra et al (2015),

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several causes of mooring rope accidents, including material fatigue 20%,deployment 17%, and corrosion 11% [3].

To maintain the operational reliability of the Al Zaafarana FPSO and reduce the risk of accidents in the deep sea, fatigue damage material mooring line is very important because it experiences dynamic loads continuously, causing the material to become fatigued which can reduce service life and increase the risk of operational failure [4].

Therefore, knowledge of types is required fatigue damage material mooring line for FPSO Al Zaafarana. So the aim of this research is to analyse motion trajectory (surge and sway), mooring line stress, and deterministic fatigue on mooring line so you get it fatigue damage material catenary mooring line for FPSO Al Zaafarana. Thus, it is hoped that this research can make a scientific contribution in improving the quality and safety of materials mooring line for the Al Zaafarana FPSO, as well as increasing the efficiency of the oil drilling process.

2. Research Methods

The research method used is a numerical study approach as a secondary data source with modeling and simulation using software. The first step is to choose 5 types of material mooring line for the Al Zaafarana FPSO, which was modeled using software to determine the material response to various dynamic load conditions. Apart from the numerical study approach, literature analysis was also carried out by accessing relevant library documents, scientific articles, books and research reports. This literature study will support the results of numerical simulations. This combination of methods will make it easier to determine the best material for the Al Zaafarana FPSO, with the aim of increasing the operational reliability of the FPSO and reducing the risk of failure.

3. Results

Fig. 1. FPSO Al Zaafarana

The Al Zafarana FPSO is one of the FPSOs used in the exploitation of oil and gas in deep waters, so maintaining its operational reliability is very important. FPSO Al Zaafarana is located off the coast of Egypt in the Red Sea and is operated by Gemsa Petroleum Company (Gempetco). The dimensions of the Al Zaafarana FPSO are in table 1.

Table 1. Al Zaafarana FPSO dimensions

No	Dimensions
IMO	6906866
Displacement	222,133 t
LOA	275 m
B	45 m
H	35 m
T	20.42 m

The type of mooring FPSO Al Zaafarana uses catenary mooring system widely used in shallow water to deep water where the system catenary influenced by horizontal forces. Catenary moored at both ends, one on the seabed and the other at FPSO Al Zaafarana. This is due to the weight of the rope, which causes the stretch of the floating rope from the floating structure (FPSO) to the anchor (seabed) not tense but tense. In this research, focusing on the type of material catenary mooring system then the number of mooring ropes used is 4 ropes with an angle of 45^0 and a rope length of 3000 m at a depth of 1000 m as shown in Figure 2.

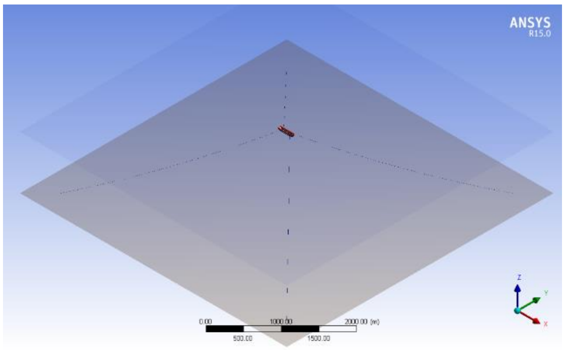


Fig. 2. FPSO Al Zaafarana.

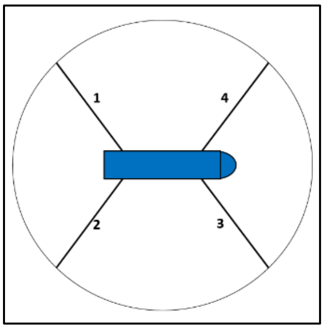


Fig. 3. FPSO Al Zaafarana Mooring Rope Numbering.

On FPSO Al Zaafarana need coordinates fixed point namely the coordinates of the mooring lines on the ship and connection point namely the coordinates of the mooring ropes on the seabed for each cable in the x, y and z directions as in table 2. In addition, 5 types of materials are used in table 3 to find out the best type of material to be used by the Al Zaafarana FPSO based on operational material reliability.

Table 2. Mooring Coordinates

Mooring Line		Fixed Point		Connection Point
	X	-2121.32	X	-80
Rear Left (1)	Y	2121.320	Y	22.500
	Z	-1000	Z	0
	X	-2121.32	X	-80
Rear Right (2)	Y	-2121.320	Y	-22.500
	Z	-1000	Z	0
	X	2121.32	X	80
Front Right (3)	Y	-2121.320	Y	-22.500
	Z	-1000	Z	0
	X	2121.32	X	80
Front Left (4)	Y	2121.320	Y	22.500
	Z	-1000	Z	0

Table 3. Material Catenary Mooring System

Properti Penambatan	Chain on Fairlead	Chain on Anchor	Chain	Chain Segment	Wire Segment
Mass/Unit Length (kg/m)	438.9	438.9	876	264	43
Cross-Sectional Area (m^2)	0.019806	0.019806	0.0314	0.0104	0.0064
Stiffness (N)	1,842,397,800	1,842,397,800	4,040,000,000	1,060,000,000	764,000,000
Maximum Stress (N)	19,563,300	19,563,300	24,980,000	10,300,000	8,380,000
Rope Diameter (m)	0.025	0.1588	0.2	0.115	0.09

3.1 Analysis Response Amplitude Operator (RAO)

The movement of a structure on regular waves is known as Response Amplitude Operator (RAO). RAO movement response to translational movement viz surge and sway is the ratio between the amplitude of the incident wave and the amplitude. Response Amplitude Operator as a response function that occurs when waves hit a structure in a frequency range that functions to transfer external loads in the form of a dynamic response of the structure [5].

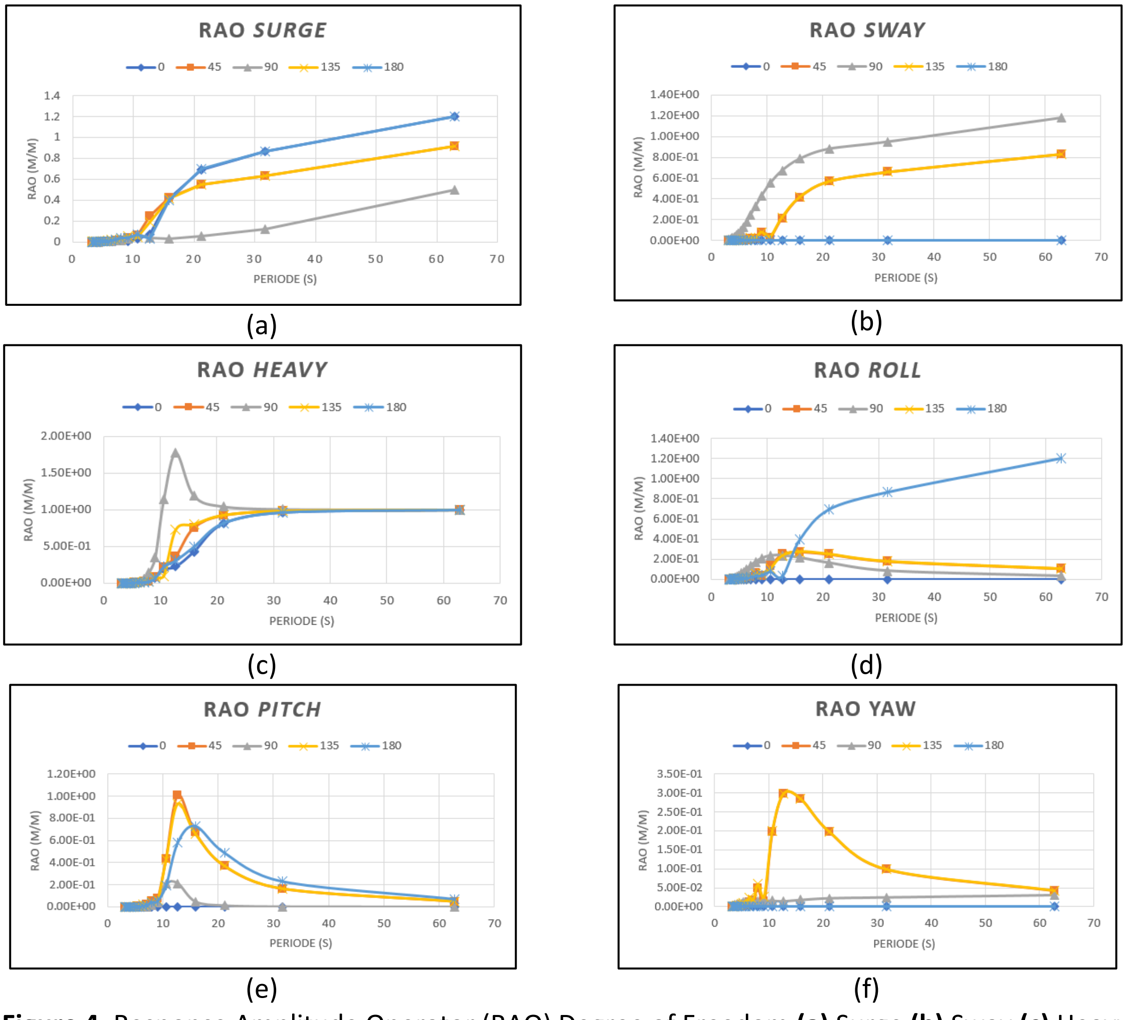


Figure 4. Response Amplitude Operator (RAO) Degree of Freedom **(a)** Surge **(b)** Sway **(c)** Heavy **(d)** Roll **(e)** Pitch **(f)** Yaw.

Table 4. Degree of Freedom

DOF	Satuan	Tn	0^0	Tn	45^0	Tn	90^0	Tn	135^0	Tn	180^0
Surge	m/m	62.832	1.200	62.832	0.920	62.832	0.498	62.832	0.920	62.832	1.200
Sway	m/m	62.832	0.000	62.832	0.832	62.832	1.178	62.832	0.832	62.832	0.000
Heavy	m/m	62.832	0.997	62.832	0.999	12.736	1.772	62.832	0.999	62.832	0.997
Roll	deg/m	62.832	0.000	15.906	0.271	12.736	0.235	15.906	0.273	62.832	0.000
Pitch	deg/m	15.906	0.734	12.736	1.008	12.736	0.210	12.736	0.928	15.906	0.729

DOF	Satuan	Tn	0^0	Tn	45^0	Tn	90^0	Tn	135^0	Tn	180^0
Yaw	deg/m	5.317	0.000	12.736	0.299	62.832	0.031	12.736	0.299	5.317	0.000

3.2 Motion Trajectory

In research Degree of Freedom which is used is surge and sway. Surge is the movement of the ship on the X-axis translation, namely movement along the longitudinal axis of the ship where the ship moves forward (forward) or backward (backwards). Where as, sway is the movement of the ship on the Y-axis translation, namely the lateral movement of the ship where the ship moves to the side (left or right) [6] as seen in Figure 3.

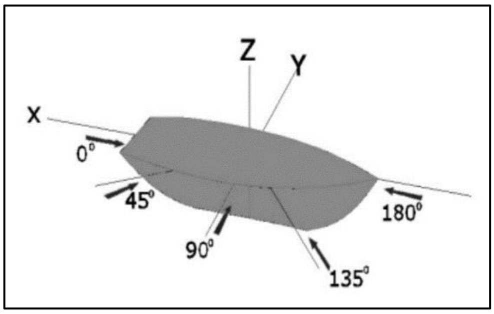
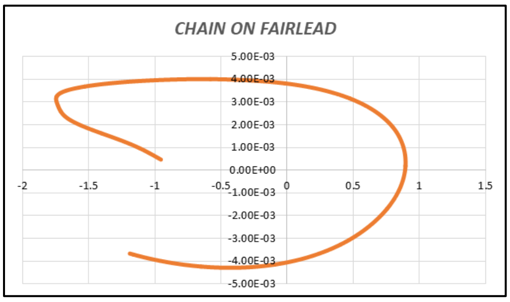
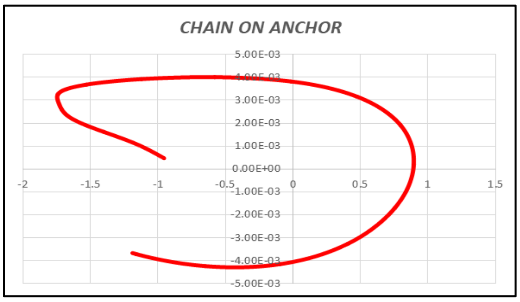


Fig. 5. Heading Direction on Software Ansys.

The angle of incidence of the wave (wave heading) is the direction of the wave arrival measured from 0^0 at the bow of the ship to 180^0 at the stern of the ship. In this study, 5 directions were used which represent the direction of the wave coming towards the Al Zaafarana FPSO. For waves in a direction parallel or perpendicular to the longitudinal axis, it is wave 0^0 known by the term following seas/waves namely waves at the stern, for waves of 180^0 known by the term head seas namely waves on the bow, and waves 90^0 known by the term beam seas namely the left side wave (portside). Meanwhile, waves that are oblique or diagonal to the longitudinal axis are waves in the 45 direction^0 known by the term stern quartering seas namely a quarter wave at the stern and a wave direction of 135^0 known by the term bow quartering seas namely a quarter wave on the bow [7].



(a)



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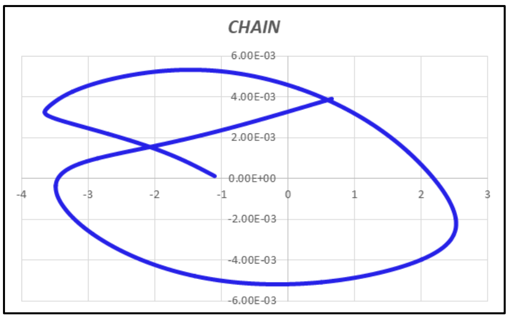

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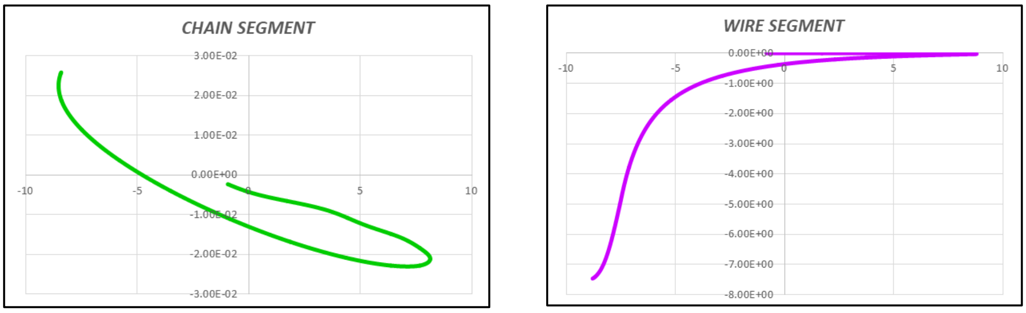

(d) (e)

Fig. 6. Motion Trajectory Tiap Material **(a)** Chain on Fairlead **(b)** Chain on Anchor **(c)** Chain **(d)** Chain Segment **(e)** Wire Segment.

Table 5. Maximum and Minimum Values Motion Trajectory

Motion Trajectory	Chain on Fairlead	Chain on Anchor	Chain	Chain Segment	Wire Segment
Maximum	0.896	0.896	2.522	8.139	8.802
Minimum	-1.747	-1.747	-3.655	-8.524	-8.796

Based on the table above it can be seen that the material wire segment have movement surge and sway largest while material chain on fairlead and chain on anchor have movement surge and sway smallest. This is influenced by the parameters in table 3, namely the mass of the rope (the greater the mass of the mooring rope, the greater the inertial force produced by the mooring rope when the ship is moving), rope diameter (the greater the diameter of the mooring rope, the stronger and stiffer the rope. the mooring), the cross-sectional area of the rope (the larger the cross-sectional area of the mooring rope, the stronger and stiffer the mooring rope), the stiffness of the rope (a mooring rope that is too stiff can limit the movement of the ship and require a more elastic mooring rope), and the tension of the rope (rope Moorings that are too tight can limit the movement of the vessel and require looser mooring lines).

3.3 Mooring Line Stress

Mooring line stress caused by an external force which causes a pull on the mooring rope [8]. Stress is divided into two types, namely static stress and dynamic stress. Static tension is the weight of the mooring rope itself and the wet weight of the mooring rope. Meanwhile, dynamic stress arises as a result of dynamic loads (wind, current and waves). Additionally, resistance to fatigue and changing environmental conditions is another thing to consider when analyzing mooring rope tension. Therefore, to prevent failure, it is necessary to select the right material to ensure safety, stability and reliability during the mooring process. So, the calculation is carried out mooring line stress for each material to get the best material used by FPSO Al Zaafarana.

Probability of a Specific Wave (Pi)

Hydrooceanographic data used in the Masela Block which is located in West Southeast Maluku is as in table 6 and table 7 below:

Table 6. Masela Block Wave Distribution Data

		Hs (m)					Total
		0.1-1	1.1-2	2.1-3	3.1-4	4.1-5	
Tp (s)	0.1-2	0	0	0	0	0	0
	2.1-4	0.58	0	0	0	0	0.58
	4.1-6	9.51	4.43	0	0	0	13.94
	6.1-8	5.12	6.9	4.74	0.03	0	16.79
	8.1-10	8.2	3.5	5.6	0.78	0.04	18.12
	10.1-12	10.8	**20.8**	0.15	0.01	0.01	31.77
	12.1-14	9.3	2.68	0.02	0	0	12
	14.1-16	2.93	2.46	0.04	0	0	5.43
	16.1-18	0.42	0.77	0.03	0	0	1.22
	18.1-20	0.05	0.09	0	0	0	0.146

Total	46.91	41.636	10.58	0.82	0.05	100.0
Cumulative	49.9	88.5	99.1	99.9	100.0	

Source : FUGRO,2012

Table 7. Masela Block Wind and Current Data

Parameter	**Speed (m/s)**
Wind	16.91
Current	0.5

Source : Mahdarreza, 2020

2. Dynamic Amplification Factor (DAF)

An important parameter in structural analysis is the dynamic strengthening factor (DAF) which is used to determine the dynamic response of a structure due to dynamic loads. This is important because the structure can provide a much greater response when considering only static loads. So by calculating DAF, mooring ropes can be designed to withstand dynamic loads that may occur during operation by identifying the areas most vulnerable to these dynamic responses. The data used in the DAF calculation is in table 4 and table 6. To make things easier for readers, the data used is presented in the following table:

Table 8. DAF Calculation Data

Data	**Value**	**Unit**
Tn	62.832	s
T	12	s
β	20%	

Source : FUGRO,2012

$$\mathbf{DAF} = \frac{1}{\sqrt{\left(1-\left(\frac{T_n}{T}\right)^2\right)^2 + 2\beta\left(\frac{T_n}{T}\right)^2}} \quad (1)$$

$$\mathbf{DAF = 0.03}$$

Where :
Tn : period natural structure (s)
T : wave period (s)
b : damping ratio (20%) based on API RP2A

3. Hot Spot Stress (HSS)

Hot spot stress used to identify critical areas on mooring ropes that experience high stress or high fatigue. This area is the starting point for fatigue which can cause the mooring rope to break. Calculation hot spot stress mooring ropes help in proper material optimization. In calculation shot spot stress used data cable force at time 0 seconds to 100 seconds from the simulation results for each material and the diameter of each material is also needed to get the cross-sectional area of each material which is presented in table 9.

Table 9. Cross-sectional Area (A)

Data	**Chain on Fairlead**	**Chain on Anchor**	**Chain**	**Chain Segment**	**Wire Segment**
Diameter (m)	0.025	0.090	0.159	0.115	0.200
Cross-Sectional Area (m^2)	0.02	0.025	0.079	0.042	0.126

$$\mathbf{HSS} = \frac{\mathbf{F}}{\mathbf{A}} \quad (2)$$

Where :
F : pulling force (N)
A : cross-sectional area (m^2)

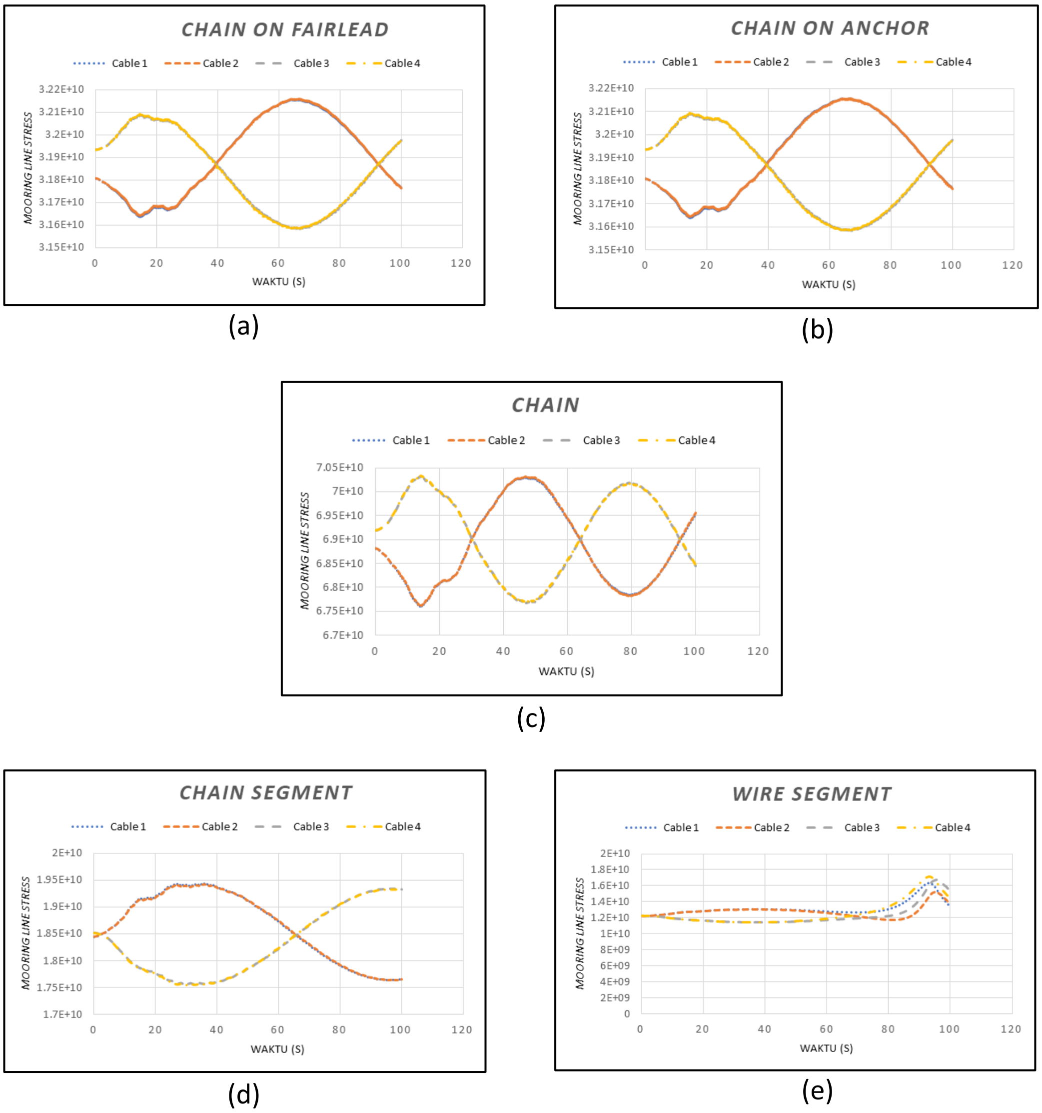

Fig. 7. Mooring Line Stress **(a)** Chain on Fairlead **(b)** Chain on Anchor **(c)** Chain **(d)** Chain Segment **(e)** Wire Segment.

From the calculation result shot spot stress from 0 seconds to 100 seconds on 4 strings of each material, a graph is obtained hot spot stress for each type of mooring rope material as in Figure 5 above. Next, look for the maximum value for each mooring rope in 5 types of material which can be seen in table 10.

Table 10. Maximum Value Mooring Line Stress

Place the Rope	Chain on Fairlead	Chain on Anchor	Chain	Chain Segment	Wire Segment
Rear Left	32,156,381,791	32,156,381,791	70,303,194,702	19,433,449,060	16,341,326,728
Rear Right	32,157,467,609	32,157,467,609	70,308,287,660	19,419,058,397	15,205,410,652
Front Right	32,088,769,715	32,088,769,715	70,311,343,435	19,337,644,405	16,771,001,275
Front Left	32,092,473,314	32,092,473,314	70,327,640,901	19,326,472,492	17,154,625,294

3.4 Deterministic Fatigue on Mooring Lines

After knowing mooring line stress, calculation fatigue life can continue with the calculation stress range and the number of wave events of each stress range mooring rope on each material.

1. Stress Range (S)

In mooring rope fatigue analysis, stress range (S) is an important parameter that gives an idea of how much stress variation the material will experience during a particular load cycle. Therefore, calculations need to be made stress range to reduce the risk of mooring rope fatigue. Data used in calculations stress range is value mooring line stress in table 10 and the DAF values that have been obtained.

$$\mathbf{S = MLS \times DAF} \quad (3)$$

Where :
MLS : mooring line stress
DAF : dynamic amplification factor

Table 11. Stress Range (S)

Place the Rope	Chain on Fairlead	Chain on Anchor	Chain	Chain Segment	Wire Segment
Rear Left	860,210,899	860,210,899	1,880,670,987	519,861,494	437,144,559
Rear Right	860,210,899	860,239,945	1,880,807,228	519,476,531	406,757,826
Front Right	858,402,217	858,402,217	1,880,888,973	517,298,637	448,638,723
Front Left	858,501,292	858,501,292	1,881,324,944	516,999,779	458.900,996

2. Number of Wave Events Each Stress Range (Ni)

After getting the value stress range for 5 types of material, the next step is to calculate the wave incidence for each stress range. Each material has an S-N parameter fatigue curve different ones as in table 11. Next, divide the S-N value fatigue curve with stress range on each material.

Table 12. S-N Fatigue Curve

Mooring Types	a_D	m
Stud Chain	$\mathbf{1.2 \cdot 10^{11}}$	3.0
Studless Chain (Open Link)	$\mathbf{6.0 \cdot 10^{10}}$	3.0
Standed Rope	$\mathbf{3.4 \cdot 10^{14}}$	4.0
Spiral Rope	$\mathbf{1.7 \cdot 10^{17}}$	4.8

$$\mathbf{Ni = \frac{a_D}{S^3}} \quad (4)$$

Where :
a_D : parameter S-N fatigue curve
S : stress range

Table 13. Number of Wave Events EachStress Range (S)

Place the Rope	Chain on Fairlead	Chain on Anchor	Chain	Chain Segment	Wire Segment
Rear Left	$1.89 \cdot 10^{-16}$	$1.88 \cdot 10^{-16}$	$1.80 \cdot 10^{-16}$	$1.54 \cdot 10^{-16}$	$4.07 \cdot 10^{-16}$
Rear Right	$1.89 \cdot 10^{-16}$	$1.89 \cdot 10^{-16}$	$1.80 \cdot 10^{-16}$	$1.56 \cdot 10^{-16}$	$5.05 \cdot 10^{-16}$
Front Right	$1.90 \cdot 10^{-16}$	$1.90 \cdot 10^{-16}$	$1.80 \cdot 10^{-16}$	$1.67 \cdot 10^{-16}$	$3.76 \cdot 10^{-16}$
Front Left	$1.89 \cdot 10^{-16}$	$1.89 \cdot 10^{-16}$	$1.80 \cdot 10^{-16}$	$1.68 \cdot 10^{-16}$	$3.51 \cdot 10^{-16}$

3. Fatigue Damage

Fatigue damage is the main factor in reducing the service life of mooring ropes. Where fatigue damage is damage that occurs to the mooring rope material as a result of repeated stress that continuously occurs so that the material will experience fatigue [9].

$$\mathbf{D = \frac{P_i}{N_i \cdot T_i}} \quad (5)$$

Cyclic stress changes cause small cracks in the mooring rope material that can develop into more severe damage if not repaired. To ensure that mooring ropes operate safely and reliably, calculations are made fatigue damage very important. Following are the calculations fatigue life for 5 types of material.

Table 14. Fatigue Damage

Place the Rope	Chain on Fairlead	Chain on Anchor	Chain	Chain Segment	Wire Segment
Rear Left	$9.19 \cdot 10^{13}$	$9.19 \cdot 10^{13}$	$9.61 \cdot 10^{14}$	$2.03 \cdot 10^{13}$	4,258,713,307
Rear Right	$9.20 \cdot 10^{13}$	$9.20 \cdot 10^{13}$	$9.61 \cdot 10^{14}$	$2.02 \cdot 10^{13}$	3,430,922,638
Front Right	$9.14 \cdot 10^{13}$	$9.14 \cdot 10^{13}$	$9.61 \cdot 10^{14}$	$2.00 \cdot 10^{13}$	4,603,556,107
Front Left	$9.14 \cdot 10^{13}$	$9.14 \cdot 10^{13}$	$9.62 \cdot 10^{14}$	$2.00 \cdot 10^{13}$	4,926,746,009

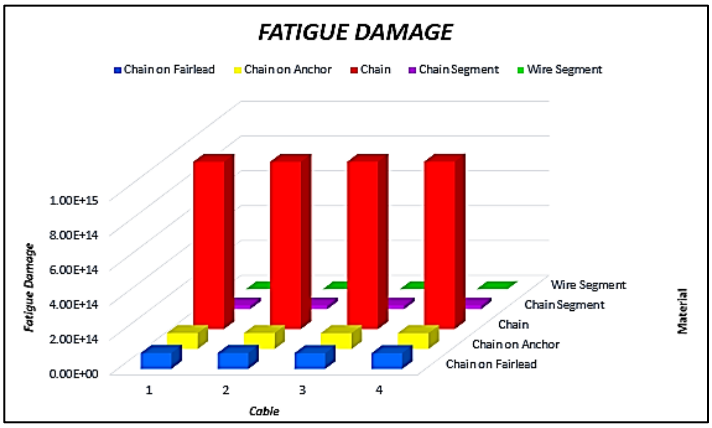

Fig. 8. Fatigue Damage

4. Discussion

From the results of numerical studies obtained fatigue damage the highest is chain for FPSO Al Zaafarana. 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 is needed or an increase in the number of ropes. In addition, the numerical study simulation only uses 100 seconds so that the movement process only reaches movement transient namely temporary changes that occur in the transition phase before reaching a stable condition. It is hoped that the next researcher will carry out a numerical study simulation for 10,800 seconds or until movement is reached steady which is a stable state [10].

5. Conclusions

In operational processes catenary mooring system The Al Zaafarana FPSO experiences static loads and dynamic loads continuously, causing material damage which can reduce service life and increase the risk of operational failure. After carrying out numerical studies on several types of materials with calculations motion trajectory (surge and sway), mooring line stress, and deterministic fatigue on mooring line so you get it fatigue damage the highest is chain for the FPSO Al Zaafarana which is caused by the mass of the rope not being proportional to the ship's displacement and the numerical study simulation has only achieved the movement transient at 100 seconds so it has not yet reached a stable condition.

References

[1] Arifin, "Numerical Prediction of FPSO Instability Moored at Buoy Due to Failure of Mooring Line". ITS Engineering Journal, vol. 1, no. 1, 2012.

[2] B.S. Prasodjo, W.D. Aristanto, and D.F. Ashyar, "Long Optimization Study Mooring Line Tipe Spread Mooring on F(P)SO", JournalWave, vol. 5, no. 1, hlm. 13-19, 2011.

[3] N.D. Aditia, "Analytical, Numerical and Experimental Study of SPAR Structure Movement and Tension Dynamics of Link Type Mooring Systems in Mooring Rope Failure Conditions". Department of Ocean Engineering. Faculty of Marine Technology. Sepuluh Nopember Institute of Technology. 2017

[4] A. Sadat, and M.N. Misbah, "Fatigue Life Analysis (Fatigue Life) Scantling Support Structure Module FSO Cinta Natomas", ITS Engineering Journal, vol. 1, no. 1, pp. 307-310, 2012.

[5] A.R.Jurais, "Motion and Mooring Analysis in Planning Floating Breakwater Structure In Nagan Raya, Aceh". Department of Marine Engineering. Faculty of Marine

Technology. Sepuluh Nopember Institute of Technology. 2018.
[6] I.A.I. Ismail, "Strength Analysis Anchor Crown Shackle At FPU Madura Straightt With Angle VariationsMooring Line". Department of Marine Engineering. Faculty of Engineering. Hasanuddin University. 2021.
[7] F. M. Assidiq, D. Paroka, M.Z. Muis, dan S. Klara, "Fatigue Analysis of Catenary Mooring System due to Harsh Environment in Head Seas", AND International Journal of Engineering, vol. 1, no. 1, hlm. 30-38, 2018.
[8] J.R. Thalita, "Tandem Performance and Operability Study Offloading "With Variations in the Mooring System on the SSP Type FPSO". Department of Marine Engineering. Faculty of Marine Technology. Institut Teknologi Sepuluh Nopember. 2017.
[9] Sumardiono, "Estimation of Fatigue Life (Fatigue Life) FSO Construction (Floating Storage and Offloading) with MethodSpectral-Based Fatigue Analysis". Field of Marine Building Design Engineering Expertise. Faculty of Marine Technology. Sepuluh Nopember Institute of Technology. 2015.
[10] B. Hariyanto, "Stress AnalysisMooring Line OnSingle Point Mooring Calm Bouy Cilaca". Department of Marine Engineering. Faculty of Marine Technology. Sepuluh Nopember Institute of Technology. 2018.