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Anchor Analysis of the FPSO Spread Mooring System During Offloading

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***Abstract*— FPSO (Floating Production Storage and Offloading) is a moving floating structure to accommodate petroleum exploration results with a frequently used mooring system, namely spread mooring. To make it easier for the FPSO ship to not be able to rotate or even move when loading and unloading due to environmental influences, a spread mooring mooring system is needed with analysis of the mooring stress and anchor lifting force that occurs on the FPSO ship. To determine the anchor lifting power and tension on the mooring, the RAO formula is needed using the Jonswap method, which will give RAO results in response to environmental influences. In this case, the Jonswap method is used to determine matters related to the RAO response to environmental factors by analyzing the FPSO ship model from Maxsurf software, then continuing the analysis using Ansys software. From the RAO response we get the mooring tension and anchor lifting power to the influence of environmental forces. The results of the mooring spread analysis obtained the highest stress value of 6.141 x 10^5 N, with an anchor lifting force of 4.717 x 10^3 N..**

Keywords— Anchor, Anchor Tension,ANSYS, FPSO Ship, Spread Mooring.

I. INTRODUCTION

Indonesia is a relatively large oil and natural gas producing region. This creates exploration activities which not only require offshore but also require other supporting facilities for exploration activities such as a floating structure in the form of a Floating Production Storage and Offloading FPSO.[i]functions to receive, process, store and distribute oil which is permanently connected to the operating location but can also be moved if necessary [1]. Because an FPSO is a floating structure that carries out storage and offloading duties in waters of a certain depth, it does not rule out the possibility that in carrying out its role there will often be movement on the FPSO ship which results in a shift in position from its original point. Movements that occur in FPSOs during loading and offloading are caused by environmental loads (currents, waves and wind). To maintain the position of the FPSO so that it remains stable in its position, a mooring system is needed which functions to tie the FPSO in place [2]. FPSO itself has several mooring systems. One of the mooring systems that is often used is the Spread Mooring System. This Spread Mooring mooring system can be applied by determining the position between the FPSO ship, oil well, shuttle tanker and supply vessel first, to later be used in determining the mooring deployment route without disturbing the route for loading or offloading activities.

*Spread Mooring System*It is considered the simplest mooring system when using an FPSO because it does not allow the FPSO ship to turn or even if the ship moves due to environmental effects (waves, currents and wind), the possibility is relatively small but in this case it causes a large environmental burden. FPSO ships that move due to environmental factors cause stress and tension between the mooring and anchor. The weight of the anchor also determines the ability of the anchor to grip the bottom of the water so that the FPSO ship can maintain its position against the influence of environmental factors. The number of moorings and mooring spread also play an important role in the anchor's ability to obtain low environmental load values and make the mooring spread in an optimal position. After obtaining the optimal mooring spread results for environmental loads, the degree of mooring angle calculated from the ship's center line is also obtained.

All the problems above are reasons for analyzing the mooring spread on FPSO ships. The method that will be used in this case is the Jonswap calculation method with Times Domain analysis type as well as several ABS and DNV rules regarding mooring and anchor standards. The Jonswap calculation itself is used to find out things related to how mooring with an FPSO ship responds to environmental factors which will later be analyzed using Ansys software by modeling the FPSO ship, which then results in the form of the FPSO ship's movement towards the environment, anchor tension and tension, anchor weight and the number, position and degree of moorings measured from the ship's center line with the lowest environmental load value parameters.

II. METHOD

The process for this analysis begins with collecting data and literature regarding Spread Mooring on FPSOs. After obtaining data and literature, initial modeling is carried out and validated according to existing data, so that it matches actual conditions. The next step is to find the RAO of the structure in full and light conditions for the FPSO. Then an FPSO simulation was carried out using a spread mooring mooring system according to existing environmental data to determine the RAO of the structure and the greatest tension in the chains and anchors. The system simulation results in moored conditions produce the greatest tension and RAO response which will later produce a response to the ship's motion mode.

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TABLE 1.
FPSO

Description	Units	Ballast	Full Loaded
Deadweight	Tons	52,222	
LOAs	m	181.61	
B	m	30	
H	m	18.14	
Q	m	11.77	
LCG From AP	m	93,313	91.12
VCG From Keel	m	12,328	11,983
TCG From CL	m	-0.017	-0.16

TABLE 2.
ENVIRONMENTAL FACTORS

Parameter	Value	Units
Water Depth	150	m
Wave Height (Hs)	6	m
Current Speed (Vs)	0.5	m/s
Max Wind Speed (1 Year)	20.4	m/s
Types of Seabed Conditions	Sandy loam.	

The data that has been obtained is used for structural modeling, both the FPSO structure and the mooring spread used. The data that has been obtained is used for modeling the structure used. Structural modeling is carried out with the help of software.

After the modeling is complete, movement behavior analysis is carried out. To determine the movement characteristics of structures in the deep sea, RAO analysis is carried out on these structures.

After the modeling is complete, movement behavior analysis is carried out. To determine the movement characteristics of structures in the deep sea, RAO analysis is carried out on these structures, namely by considering the following RAO equation.

The tension and equivalent stress results are based on the codes used, namely American Bureau of Shipping [3] and API-RP2SK [4].

2.1 Data

In this research the data used includes

RAO translational movement (surge, sway & heave)

$$\text{RAO} = \frac{\zeta_{k0}}{\zeta_0} \quad (1)$$

It is a direct comparison between the amplitude of the movement compared to the amplitude of the wave.

RAO rotational movement (roll, pitch & yaw)

$$\text{RAO} = \frac{\zeta_{k0}}{k_w \zeta_0} = \frac{\zeta_{k0}}{(\omega^2/g)\zeta_0} \quad (2)$$

It is the ratio between the amplitude of the rotational movement and the slope of the wave.

After knowing the RAO, the voltage calculation is carried out. Before determining the voltage, the safety factor on the mooring is first calculated. The safety factor criteria are based on rules [3] as shows in Table 3.

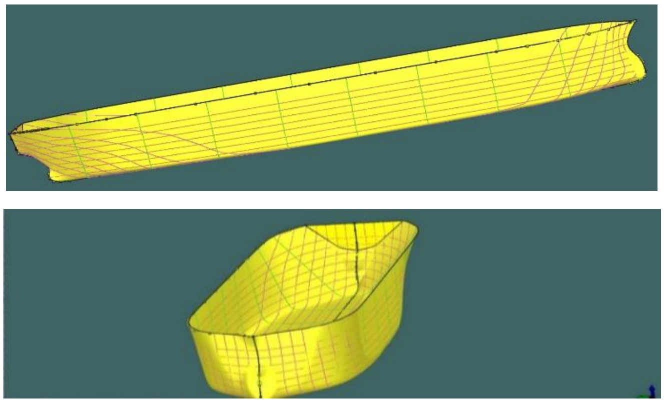

Figure 1. FPSO Modelling

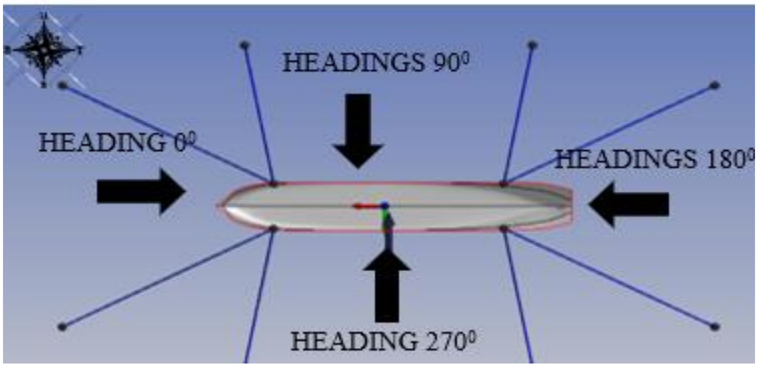

Figure 2. FPSO modeling with mooring

TABLE 3. SAFETY FACTORS

Condition	Safety Factor
Intact (ULS)	>1.67
Damaged (ALS)	>1.25

To determine the size of the chain used, you must use the Equipment Number (EN). In ABS regulations.[4] are:

$$EN = k\Delta^{2/3} + mBh + nA \quad (3)$$

Stress is an internal force that acts on the area of an object consisting of magnitude and direction. The voltage formula is as follows.[5]:
where : F : style
A :cross-sectional area

$$\sigma = \frac{\Delta F}{\Delta A} \quad (4)$$

Meanwhile, according to API RP 2K (2005) [4] Calculation of maximum ship chain tension as follows:

$$Safety\ Factor = \frac{Minimum\ Breaking\ Load}{Maximum\ Tension} \quad (5)$$

Meanwhile, this mooring spread system model is a combination of wire and chain materials.[5] The formula for stress on an FPSO ship is as follows: The stress that occurs on the mooring line is formulated. where: TH= T Cos α

TABLE 4.RESULT RAO FPSO FULL LOAD

Mode Motion	Units	RAO Max		
		0°	90°	180°
		Translation		
Surge	m/m	2,493	0.430	1,824
Sway	m/m	0.279	0.621	0.061
Heave	m/m	2,163	1,501	0.535
		Rotation		
Roll	Deg/m	0.298	2,944	0.582
Pitch	Deg/m	2,503	2,807	2,816
Yow	Deg/m	0.440	2,573	2,013

Table 5 Equipment Number

Equipment Numbers	**Equipment Letter**			**Weight / Anchor (kg)**
	L.R	ABS	DNV	
2530-2699	K+	U37	K	7800

Table 6. Chain Specifications by Type

Ø Diameter (cm)	**Weight Studless**	
	Kg/m	Kg/Link
92	169	69

Table 7. Chain Specifications Based on Type

Ø Diameter (cm)	**Weight R4**	
	Proof Load (kN)	Break Load (kN)
92	6699	8497

$$T = \sqrt{(Th^2 - Tv^2)} \tag{6}$$

Strain is the elongation per unit area. Which is a quantity that has no dimensions, but is usually given the dimensions meters per meter or m/m. Ordinary strain is also given as a percent. The Strain Formula is as follows:[6]

$$\varepsilon = \frac{\Delta}{L} \tag{7}$$

Where Δ: total length
L: initial length

rotational motion, the maximum roll at heading 90° is 2.944 (deg/m).

From the calculation above, the FPSO ship equipment number is 2549,631. The following is a table of equipment numbers which approximate the calculation results contained in ABS (American Bureau of Shipping) Part 3 Chapter 5 Sec 1 [3]
With the safety factor equation according to API RP 2SK [4] the calculation is as follows:

- For ULS (Ultimate Limit State) conditions

$$1{,}67 = \frac{6694000\ N}{Maximum\ Tension}$$

$Maximum\ Tension$ = 4008383.233 N

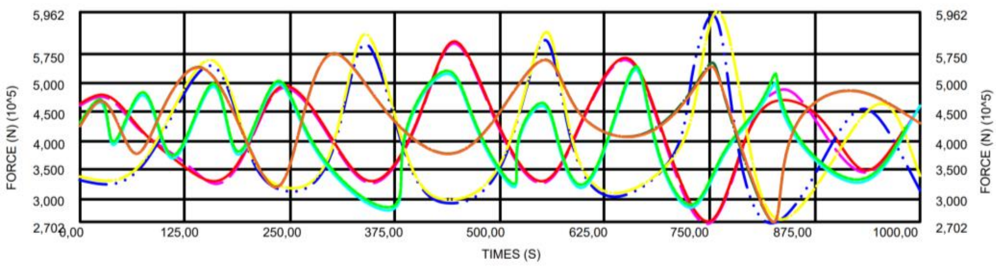

Figure 3. Tension 8 Mooring when heading 0^0

III. RESULTS AND DISCUSSION

This simulation analysis was carried out using ANSYS AQWA software. The analysis results obtained RAO (Response Amplitude Operator) with loading directions of 0°, 90°, 180°, 270° and 360° in six translational and rotational degrees of freedom: surge, sway, heave, roll, pitch and yaw. The results of the analysis show that the maximum RAO of the FPSO is in Full Load condition with mooring.
Based on the graph and table above, it can be seen that the highest surge is 2.493 (m/m), namely at heading 0°, the highest sway at heading 90° is 0.621 (m/m), and the highest heave is 2.163 (m/m) at heading 0°. For

The image above is a calculation for 8 mooring stresses based on heading 0^0. Heading 0^0 refers to the sea conditions in December-February with the direction of environmental factors coming from the west or from the
The maximum pitch is 2.816 (deg/m) at heading 180^0, and the maximum yaw is 2.573 (deg/m) at heading 90°.
The anchor weight and chain size are calculated according to the Equipment Number formula to obtain the results as below.

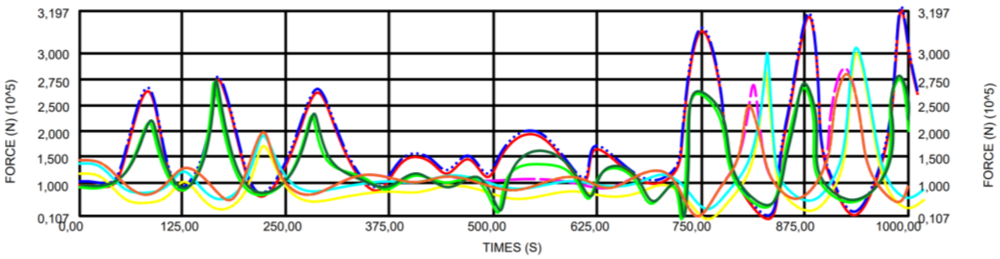

Figure 4. Tension 8 Mooring when heading 90^0

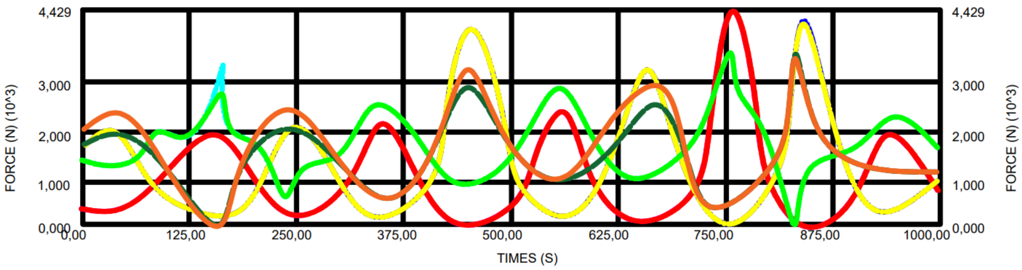

Figure 5. Tension 8 Mooring when heading 180^0

- For ALS (Accidental Limit State) conditions

$$1{,}25 = \frac{6694000\ N}{Maximum\ Tension}$$

Maximum Tension= 5355200 N

After obtaining the safety factor results, mooring stress calculations are carried out using software. This analysis is based on the actual conditions of sea waters over a period of 1 full year with the average environmental factors used in the analysis, namely extreme conditions.

The image above is a calculation for 8 mooring stresses based on heading 180^0. Heading 1800 refers to the sea conditions in June-August with the direction of environmental factors coming from the east or from the

The image above is a calculation for 8 mooring stresses based on heading 270^0. Heading 270^0 refers to sea conditions in

September-November with the direction of

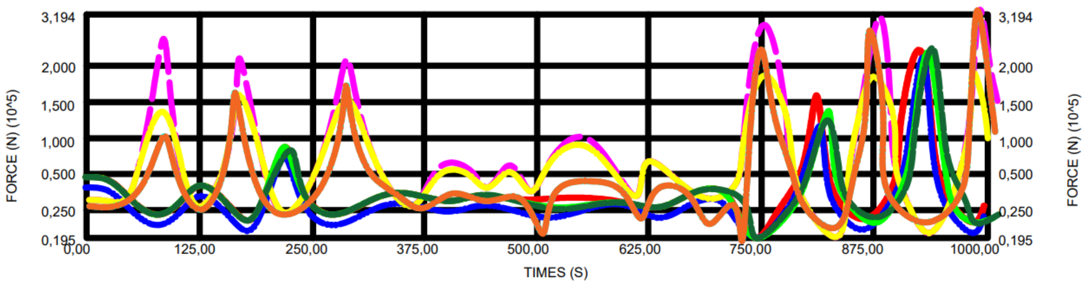

Figure 6. Tension 8 Mooring when heading 270^0

front of the FPSO ship. With the highest voltage value occurring at the 750th second with a tension value of 5.962 x 105 N.

The image above is a calculation for 8 mooring stresses based on heading 900. Heading 90^0 refers to the sea conditions in March-May with the direction of environmental factors coming from the north or from the

environmental factors coming from the south or from the portside of the FPSO ship. With the highest voltage value occurring at the 980th second with a tension value of 3.194×10^5 N. After obtaining the results of the motion mode and tension on the mooring, we also obtained the results of the anchor lift and other anchor and mooring lengths for the FPSO ship when exposed to environmental factors.

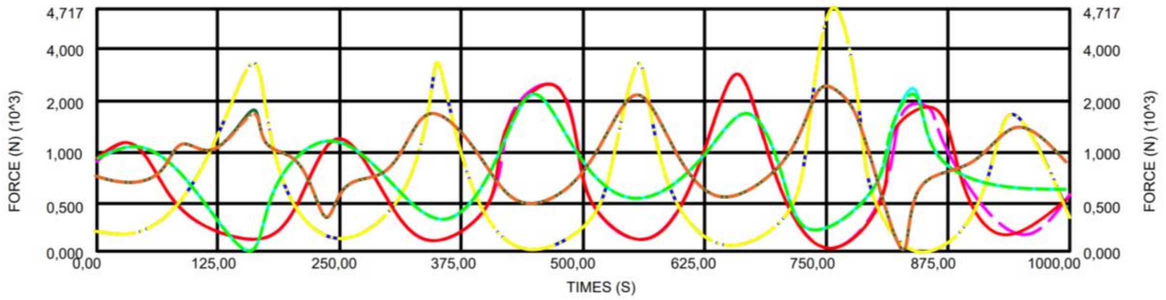

Figure 7. Anchor Lift 8 Mooring at heading 0^0

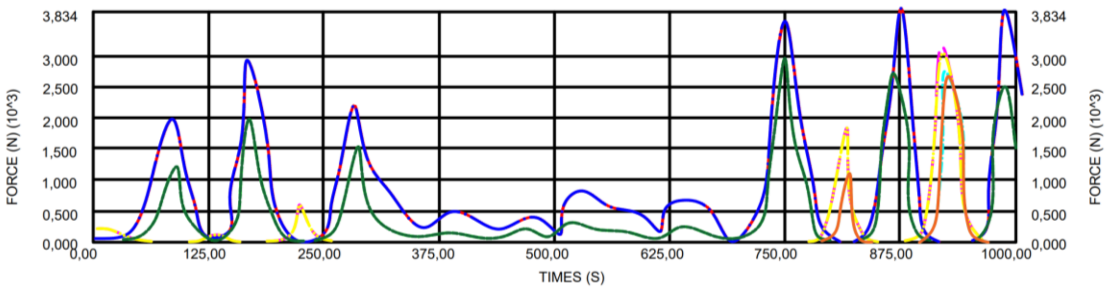

Figure 8. Anchor Lift 8 Mooring when heading 90^0

starboard of the FPSO ship. With the highest tension value occurring at the 980th second with a tension value of 3.197 x 105 N. Stern of the FPSO ship. With the highest tension value occurring at the 780th second with a tension value of 4.429 x 10^5 N.

*Anchor lifts*occurs when the mooring is exposed to wave and current factors. The anchor lift value is based on the heading or direction the environmental factor originates from.

highest point is because the anchor is the one that accepts the environmental factors the most and this results in the *Headings* 90^0 indicates environmental factors occurring from the direction of the ship's starboard and The highest Headings180^0 shows environmental factors occurring from the stern of the ship and with the highest anchor lift value of the anchor's grip strength being greater. With the highest anchor lift value occurring at the 760th second with an anchor lift value of 4.717 x103 N.

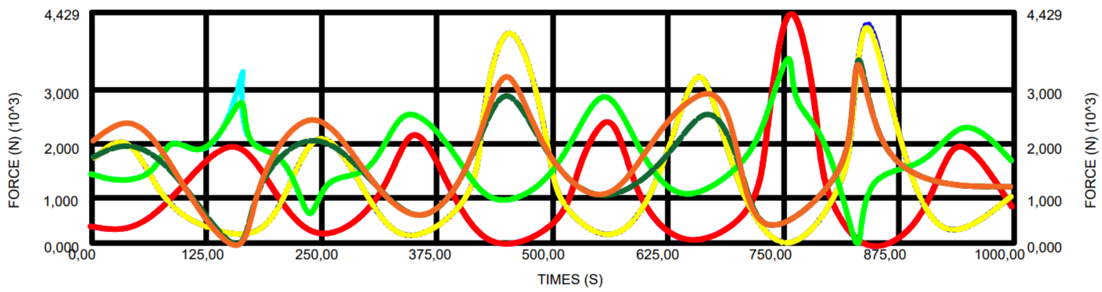

Figure 9. Anchor Lift 8 Mooring when heading 180^0

*Anchor lifts t*his contains the value of the anchor lifting force when gripping the sea bed when exposed to environmental factors. The greater the anchor lift value, the smaller the anchor's ability to grip the sea bed and the smaller the anchor's power to maintain its position, which can result in the anchor and FPSO ship shifting.

The value of the anchor lift when conditions reach its

Anchor lift value occurring at the 875th and 980th seconds with an anchor lift value of 3.834 x 10^3 N. Value occurring at the 760th second with an anchor lift value of 4.429 x103 N.

Headings270^0 shows environmental factors occurring from the portside of the ship. With the highest anchor lift value occurring at the 875th and 980th seconds with an

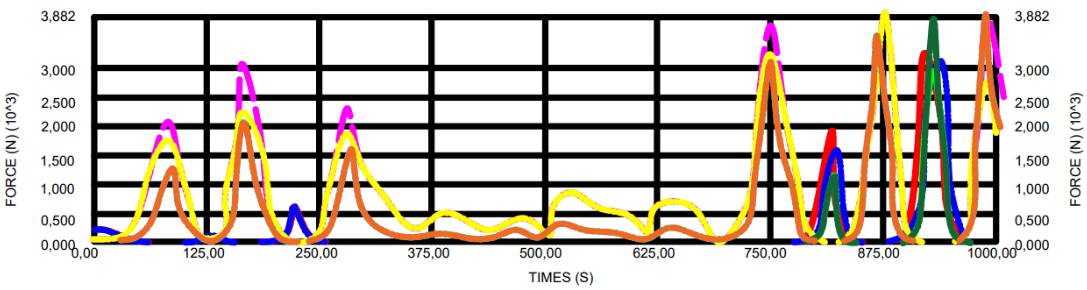

Figure 10. Anchor Lift 8 Mooring when heading 270^0

anchor lift value of 3.882 x 10^3 N.

Laid length is the length of the distance measured from the FPSO ship to the anchor position when exposed to forces from environmental factors. Laid length occurs when environmental factors exert a force on the mooring and FPSO ship which results in stress on the mooring and a shift in position on the FPSO ship.

The image above shows the value of laid length that occurs when heading 0^0. Heading 0^0 shows environmental factors from the front of the ship.

The image above shows the value of laid length that occurs at heading 90^0. Heading 900 shows environmental factors from the direction of the ship's starboard.

Laid length is assessed as the position of the anchor spread when exposed to forces from environmental factors. The degree chosen for each mooring spread is chosen based on data on the degrees most frequently used in FPSO ships.

The smaller the laid length value, the faster the mooring will experience maximum stress. The faster a mooring experiences maximum stress, the greater the risk of the mooring breaking.

The highest anchor lift value occurring at the 150th and 800th seconds with a laid length value of 497,630 m.

With the highest anchor lift value occurring at the 750th

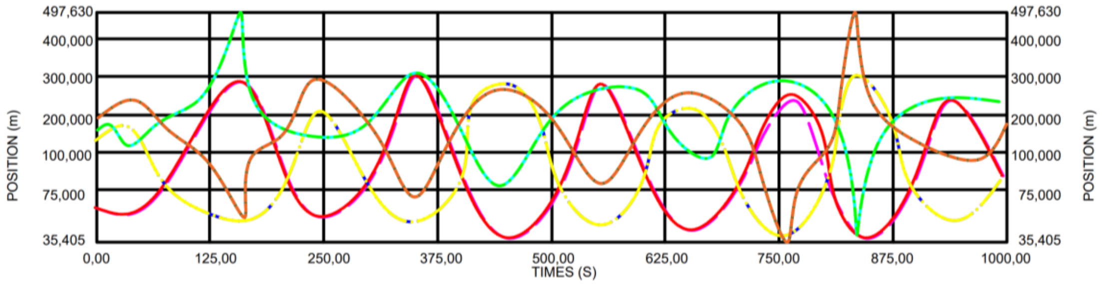

Figure 11. Laid Length 8 Mooring at heading 0^0

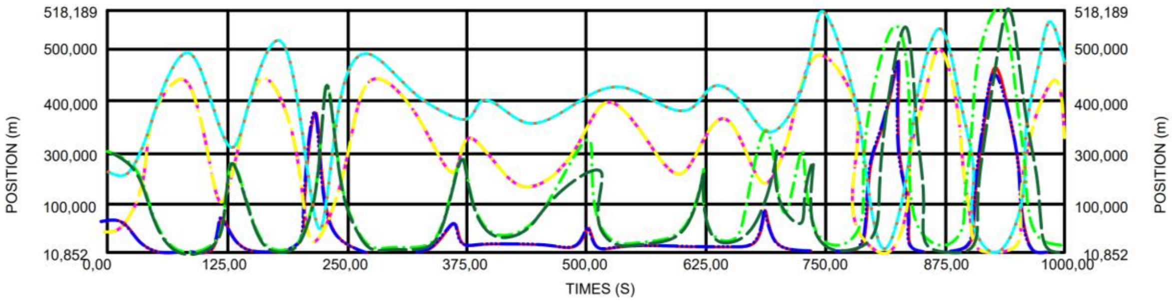

Figure 12. Laid Length 8 Mooring When Heading 90^0

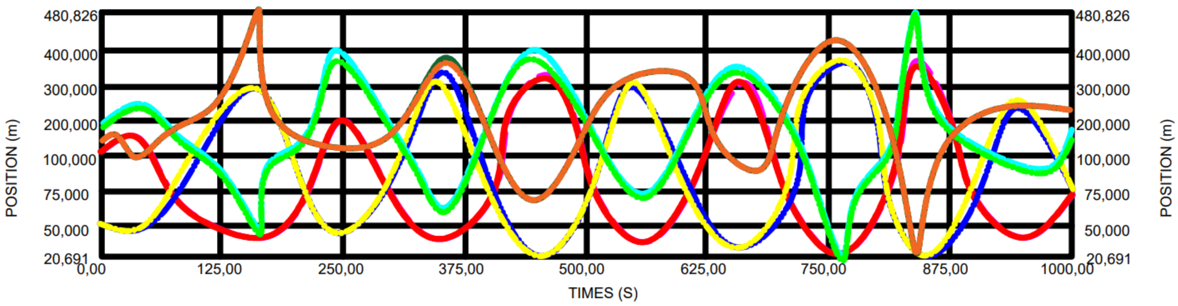

Figure 13. Laid Length 8 Mooring When Heading 180^0

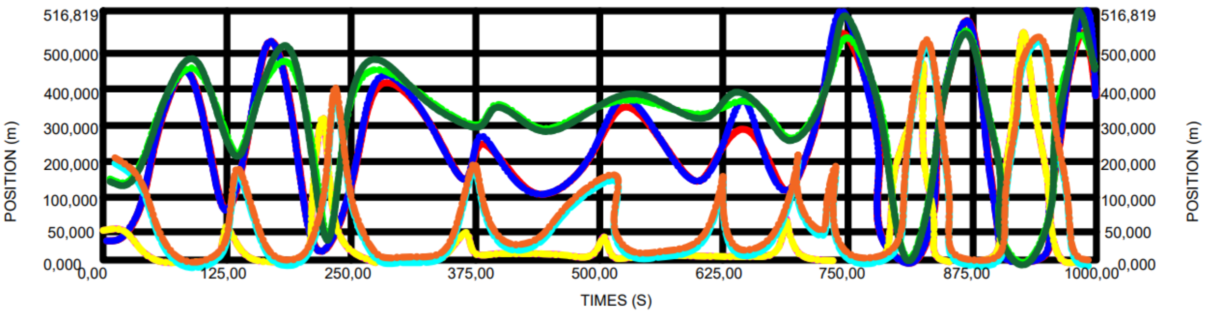

Figure 14. Laid Length 8 Mooring when heading 270^0

and 900th seconds with a laid length value of 518.189 m.
The image above shows the value of laid length that occurs when heading 180^0. Heading 180^0 shows environmental factors from the ship's stern direction.
The image above shows the value of laid length that occurs at heading 270^0. Heading 270^0 shows environmental factors in the direction of the ship's starboard. With the highest anchor lift value occurring at the 750th and 900th seconds with a laid length value of 516,819 m.

IV. CONCLUSION

From the results of the research above, it was concluded that by using 8 anchors, each anchor had dimensions of anchor weight of 8000 kg/pcs, mooring diameter of 92 cm, mooring length of 635 m with weight per link (chain) of 169 kg/m. In accordance with the results above, an analysis was carried out on each anchor, mooring and chain using calculations in the Ansys software. The calculations are carried out according to the provisions so that they can be validated. The main results obtained are in accordance with the problem formulation in this research. Maximum tension and lifting power are one of the problem formulations in this research. The results obtained below are adjusted to the results of the analysis in the previous chapter.

- Max Tension Value: 6.141 x 10^5N
- Max Anchor Lift: 4,717 x 10^3N

With the highest anchor lift value occurring at the 150th and 800th seconds with a laid length value of 480.826 m.

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