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Analysis of the Pretension Angle of Mooring Lines SPM and Its Effect on the Tension and Strength of Subsea Marine Hose

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ABSTRACT

The industry of oil and gas industry have developed along with advances in technology, so does the mooring system. Mooring system is a series that functions to keep the ship station or floating platform at all water depths. Currently, there are many types of moorings that can be used, one of which is Single Point Mooring (SPM). SPM itself consists of various types of mooring legs, as well as other supporting components such as subsea hose or riser. Subsea hose and mooring lines are closely related because in the application, the length of the mooring lines also determines the offset or limitation of motion of the SPM, while the subsea hose also has a maximum limit of pull caused by the movement of the SPM. In addition to the length of the mooring lines, another factor is the pretension angle. Therefore, in this study, an analysis was carried out by varying the pretension angle (45°, 50°, 55°, 60°) under extreme conditions and inline loading by reviewing the tensile forces on the mooring lines and risers. The larger the angle, the smaller the tensile force, so the offset would be larger, and vice versa. The results of this study indicate that the pretension angle applied must be appropriate so that the tensile force on the mooring lines that occurs can also be appropriate.

Keywords: *Offset, Mooring Line Tension, Pretension Angle, SPM , Subsea Hose.*

1. INTRODUCTION

Along with technology development, the demand and need for oil and gas is also growing. This, of course, triggers the increasing discovery of large oil/gas fields offshore, increasing the popularity of floating structures built as a means of exploration, exploitation and production rapidly. An activity that is no less important than the oil and gas industry is storing and transferring oil and gas products. So far, tankers have carried out this activity because they have a large capacity and can send oil and gas products to land domestically and abroad at an economical cost [1]. This is because fixed-type offshore structures, such as fixed-jacket platforms widely used in the oil and gas industry, have proven inefficient use in the deep sea [2].

Examples of floating structures used in the oil and gas industry are FPSO (floating production storage and offloading), semi-submersible, SPAR, TLP (tension-leg platform), FLNG (floating liquefied natural gas), and so on. These floating offshore structures have their respective functions and use, adjusting to the conditions and needs of the related fields. When operating, the floating building must be able to maintain its position so that it does not move beyond a specific limit. For this reason, the floating building must be moored with a series of mooring systems.

One of the mooring systems that is often used is single point mooring (SPM) which has various supporting components, one of which is a mooring rope. The number of these mooring ropes varies, depending on the needs. The installation of this mooring rope needs to pay attention to several aspects, such as the installation angle, namely the pretension angle. This angle is measured vertically from the SPM and its value also varies, as it can affect the offset or motion of the SPM itself.

Another component that is also present in the SPM is the configuration of the subsea marine hose or riser, which is a tool that helps transfer crude oil from subsea pipelines to vessels. The mooring system and subsea hose configuration are arranged so oil can be moved following applicable regulations. During the operation period, it is necessary to check and repair components that are not good, for example, installing new mooring lines or increasing the length of mooring lines. Repairing mooring lines can change the pretension angle, whether it is getting bigger or smaller. This angle change can affect the offset of the SPM. When viewed from the vertical side of the SPM, the greater the pretension angle, the greater the tension on the mooring line, which will cause the offset of the floating building to be smaller. On the other hand, when the pretension angle is smaller, the riser is more likely to suffer damage or even failure due to an offset value that is too large.

2. BASIC THEORY

2.1 Study of Literature

According to [3], offshore platform construction can be broadly divided into three main groups: Mobile Offshore Drilling Unit (MODU or Floating Production Platform), Fixed Offshore Platform and Compliant Structure Platform.

The selection of the structure concept is an early stage that is very important for the success of the bridge structure in carrying out its functions [3]. In certain waters, oil and natural gas sources usually have small to medium volumes and are located in scattered locations, so the operation of fixed platforms becomes uneconomical. Therefore, a floating platform is the most appropriate choice.

A floating platform is a platform that has the character of moving following the wave motion. This type of platform is often connected to the seabed using mechanical equipment such as cables or chains (mooring). For this type of platform, the main thing is its mobility and ability to anticipate movements due to waves and ocean currents [4]. Floating buildings moored in the sea will be affected by the forces that tend to cause the ship to move from its original position, which is influenced by the geometry of the building itself, the mooring system, and external forces acting on the structure [5]. Generally, there are two types of mooring systems: conventional spread mooring and single point mooring (SPM) [6]. Single-point mooring is a system in which vessels are moored with several mooring lines to maintain or limit the vessel's movement. Several types of SPM include SALM (Single Anchor Leg Mooring), CALM (Catenary Anchor Leg Mooring), and turret mooring [7]. In addition to being a mooring system for vessels, SPM also has a subsea hose configuration or it can also be called a riser, which helps transport oil from a series of subsea pipelines to the vessel. The riser has a variety of configurations, which in its use, can adapt to environmental conditions and industrial needs.

Several previous studies that have analyzed flexible risers, such as those completed by [8] with the title "Study of the Effect of Motion of Semi-Submersible Drilling Rig with Variation of Pre-Tension Mooring Line on Drilling Riser Safety", then by [9] with the title "Study of the Effect of CALM Buoy Motion on the Brotojoyo FPSO Mooring System with Variation of Pre-Tension Mooring Lines on Lazy-S Riser Safety". In addition to these two studies, there is also a study entitled "Time-Domain Analysis of the Effect of Spread Mooring with Variations in Number of Lines on Tension on Flexible Riser" conducted by [10]. Some of the analyses above become a reference for the author to analyze the strength of the flexible riser by varying the pretension angle.

2.2 Single Point Mooring

Single point mooring is a mooring system often used for ship-shaped vessels because it allows the ship to be able to weathervane so it could help minimize the environmental load on the ship by facing the weather that allows it. The SPM is tethered to the seabed with such a mooring arrangement, including anchors, anchor chains, chain stoppers, and so on [11]. In this study, the SPM used is the CALM buoy type. This type of SPM consists of a single large enough buoy that supports several catenary chain legs attached to the seabed. The riser configuration or flow lines that emerge from the seabed are installed at the bottom of the CALM buoy.

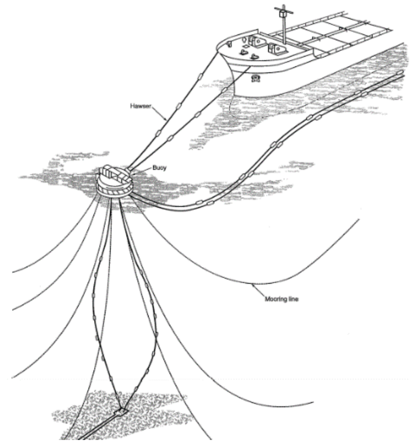


Figure 1. Vessel moored to a CALM buoy

2.3 Subsea Marine Hose

The riser system is basically a conductor pipe that connects the buoy on the surface and the wellhead on the seabed. Basically, there are two kinds of risers, namely rigid risers and flexible risers [12]. The hybrid riser is a combination of the two. The riser helps deliver fluid from the seabed to the vessel, and is one of the major design constraints for the mooring system. The riser system often imposes an allowable offset on the vessel [7]. Basically, the feasibility of a subsea marine hose can be viewed from various aspects, but one of them that is quite commonly used is the Minimum Bending Radius (MBR), which is the minimum bend limitation for a hose. Another parameter that can be used to determine failure is tension. [13] include in their research that to determine the allowable maximum tension of a riser or hose, the following equation can be used, based on [7]

$$T_E = \sigma_y \pi (OD - t) t$$

where

T_E = allowable tension
σ_y = minimum yield strength
t = pipe thickness (OD - ID)
OD = outer diameter

2.4 Mooring System Analysis

Analysis of the mooring system can be carried out based on design criteria classified into 3 state limits [14], namely:

1. ULS (Ultimate Limit State) conditions
   Analysis in this condition usually uses the load at this top/extreme condition with a return period of 100 years. This is comparable to the statement [7], which states that the maximum design condition is a combination of wind, wave, and current under extreme environmental loads over a 100-year return period.
2. ALS (Accidental Limit State) conditions
   This analysis is carried out to ensure that the mooring system can withstand the failure of one mooring line, one

thruster failure, or one thruster control failure. This failure is caused by an unexpected thing (accidental).

3. FLS (Fatigue Limit State) conditions
   This analysis is carried out to ensure that each mooring line can withstand repeated (cyclic load) loads. This analysis usually uses the one-year return period load.

3. MODELING AND VALIDATION

3.1 Properties of the Component

The following are some parameters in this study.

Table 1. Properties of SPM

Properties	Size	Unit
Displacement	132.89	ton
Outer Diameter Buoy	8	m
Outer Diameter Skirt	11.24	m
Height	3.7	m
Draught	1.8	m
Vertical Center of Gravity	2.22	m
Kxx	2.586	m
Kyy	2.586	m
Kzz	3.574	m

Table 2. Properties of Mooring Line

Properties	Size	Unit
Type	Studless Chain	-
Grade	R4	-
Diameter	58	mm
Weight in Water	0.058	te/m
Minimum Breaking Load (MBL)	3627.95	kN

Table 3. Properties of Subsea Marine Hose

Properties	Size	Unit
Diameter	300	mm
Length	10.7	m
Unit	4	pieces
Configuration	Lazy S	

The data on the tables above are then used as input for modelling on the MOSES. The output will then function as the input in another software, Orcaflex.

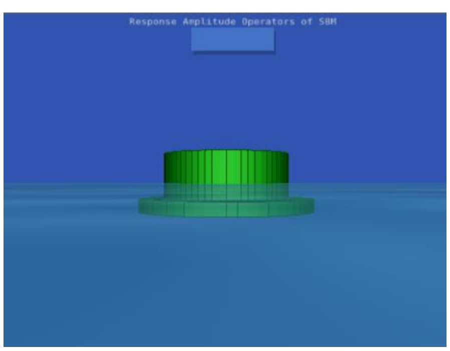


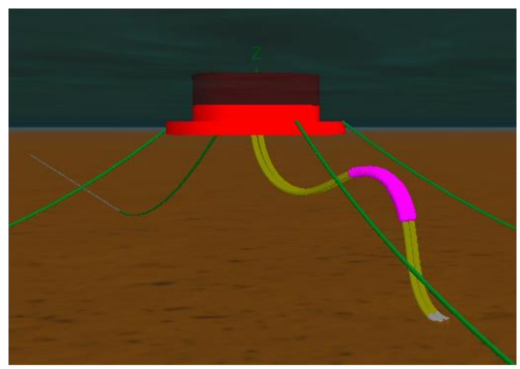
Figure 2. SPM modelling on MOSES

The model will then be checked based on the tolerance of the error value according to [15], which is 2%. If the error value exceeds the limit, it can be said that the model cannot represent the SPM.

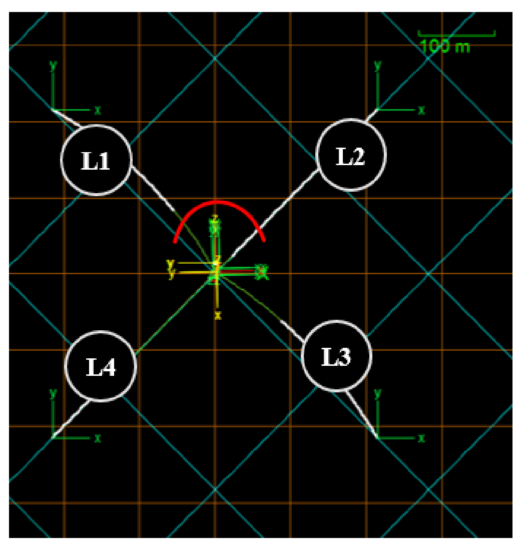
Table 4. Result of validation software MOSES

Description	Data	MOSES	Unit	Error
Displacement	132.89	132.35	ton	0.40%
Outer Diameter Buoy	8	8	m	0.00%
Outer Diameter Skirt	11.24	11.24	m	0.00%
Height	3.7	3.7	m	0.00%
Draught	1.8	1.8	m	0.00%
Vertical Center of Gravity	2.22	2.22	m	0.00%

The table above shows that the model is in accordance with the specified error criteria. This means that the research could be conducted to the next step, which is modeling on the Orcaflex according to the initial data along with the subsea marine hose.



(a)



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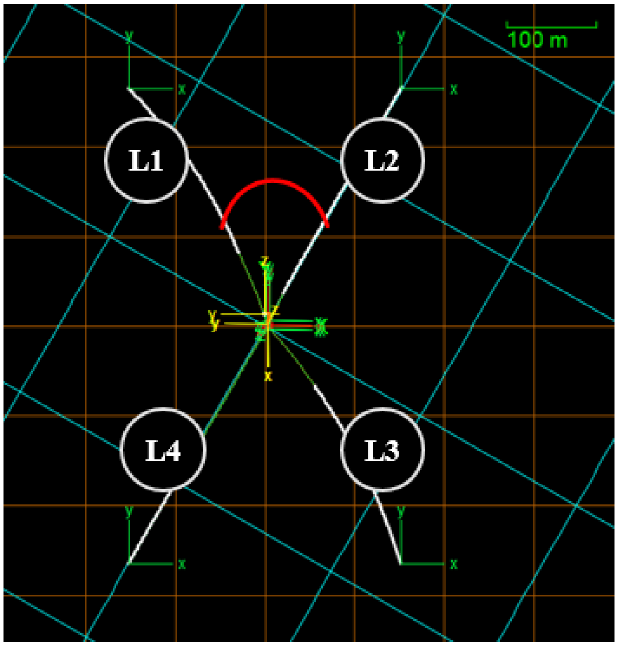


(c)

Figure 3. Modelling of SPM configuration on Orcaflex, (a) isometric view, (b) symmetrical top view and (c) asymmetrical top view

3.2 Length of The Mooring Line

One of the most influential parameters in this study is the length of the mooring chain which Orcaflex successfully generated. The longer the rope, the greater the pretension angle. The following table shows the length of mooring lines in both symmetrical and asymmetrical configurations at each declination.

Table 5. Mooring chain length on each case scenario

Declination (deg)	45	50	55	60
		SYMMETRICAL		
L1 (m)	302.09	302.81	303.68	304.96
L2 (m)	301.35	301.90	302.58	303.45
L3 (m)	302.09	302.81	303.68	304.96
L4 (m)	300.97	301.36	301.77	302.20
		ASYMMETRICAL		
L1 (m)	302.09	302.81	303.68	304.96
L2 (m)	301.35	301.90	302.58	303.45
L3 (m)	302.09	302.81	303.68	304.96
L4 (m)	300.97	301.36	301.77	302.20

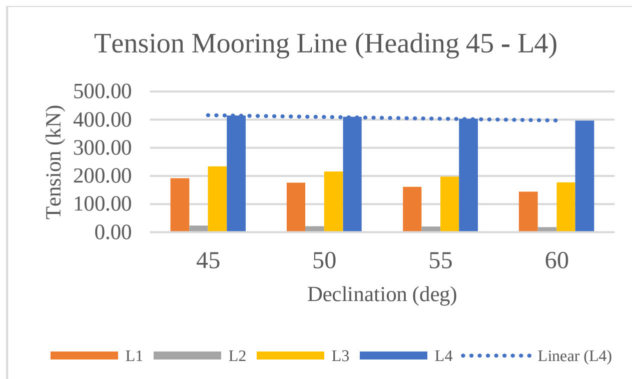
Specifically, on heading 135° and 315° at a pretension angle of 60 degrees, there is an anomaly of the rope length result generated by Orcaflex.

4. RESULT

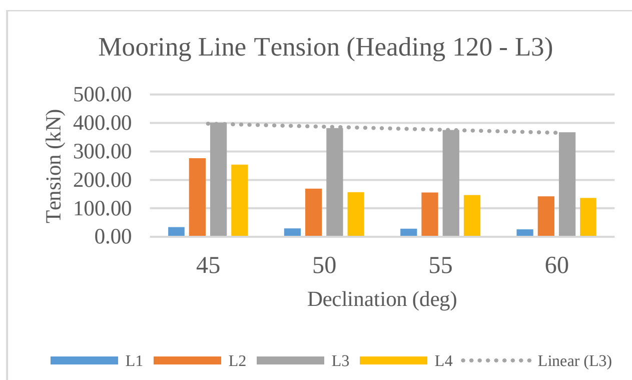
4.1 Mooring Line Tension Result

Dynamic analysis is carried out with variations in the angle of spread (symmetric and asymmetric), as well as modelling the riser for the entire configuration. The study was conducted with SPM and four mooring lines arranged, with variations in the pretension angle (45°, 50°, 55°, 60°). There are two configurations considered in this analysis, namely symmetrical conditions where the angle of spread is evenly distributed (90°), and the angle of spread is 60° in two kinds of load conditions which are ULS (intact) and ALS (damaged) load. Environmental load is headed inline on each mooring line. From all these configurations, the highest significant tension for ULS conditions occurs at heading 45 (L4) with the result 415.39 kN, while for asymmetric configurations, it occurs at heading 120 (L3) with the result 400.75 kN.

From these two scenarios, a graph is obtained that can describe the decrease in tension as the rope length increases, as shown in Figure 4 below.



(a)



(b)

Figure 4. Graph of mooring line tension on each declination, (a) symmetrical, (b) asymmetrical – ULS

The analysis on ALS condition is carried out with the same loading direction, and the tension results were obtained as shown in the following table.

Table 6. Tension result on analysis (ALS condition)

MOORING CHAIN	TENSION (kN)			
	SYMMETRICAL (Heading 45°)		ASYMMETRICAL (Heading 120°)	
	Stage 1	Stage 2	Stage 1	Stage 2
L1	120.56	193.92	82.50	62.30
L2	124.34	187.01	148.28	295.61
L3	154.56	345.88	377.53	0.62
L4	401.64	0.63	146.84	548.16

In the table above, it can be seen that for symmetrical conditions, when one mooring chain is released, all other mooring lines experience an increase in tension from stage 1 to stage 2. In contrast to the asymmetrical condition, the tension of line 1 decreases from the original 82.50 kN. to 62.30 kN when one of the lines is removed.

4.2 Hose Tension Result

The strength of the subsea marine hose (riser) in this study is viewed from two aspects: the value of the Minimum Bending Radius (MBR) and the amount of tension that occurs. In contrast to mooring lines, hose tension analysis does not use significant tension. The following is a graph of the results of the hose tension.

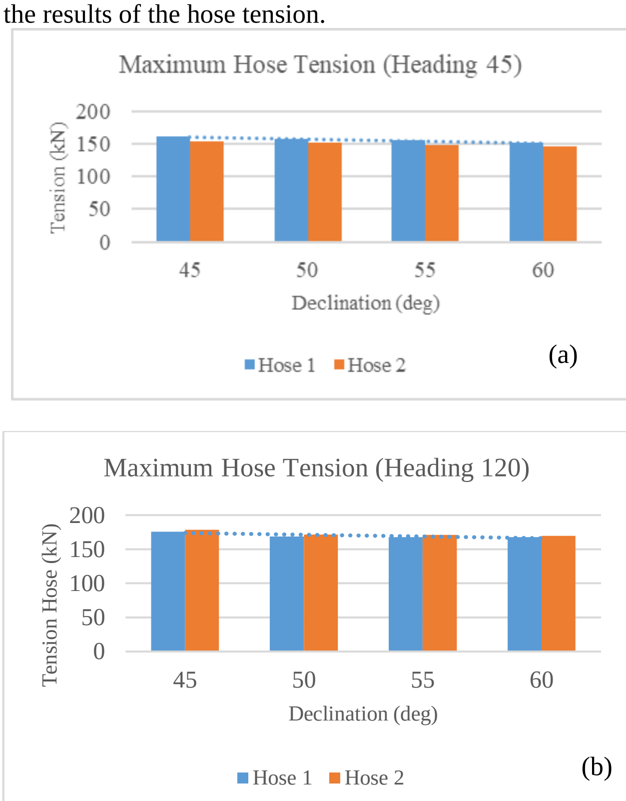


Figure 5. Graph of subsea marine hose tension on each declination, (a) symmetrical, (b) asymmetrical – ULS

While in ALS conditions, the results of the subsea hose tension can be seen in the table below.

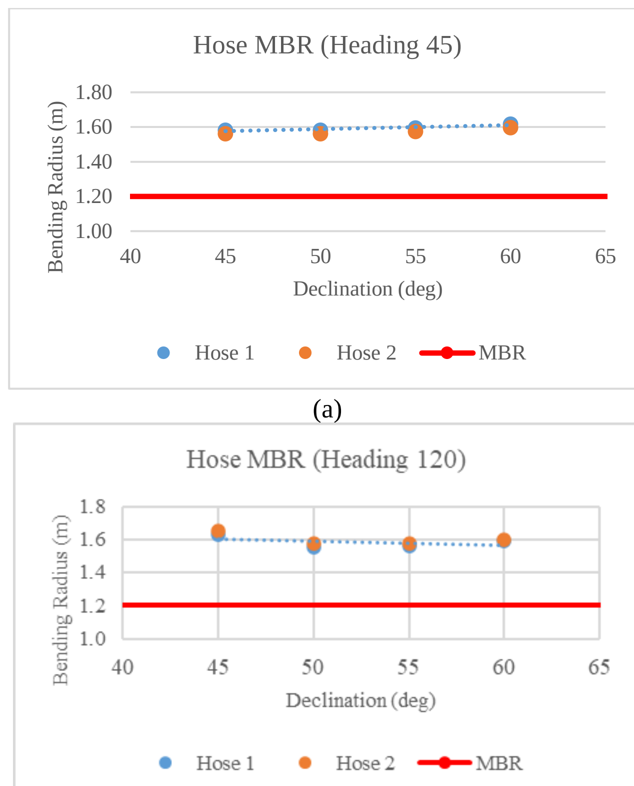
Table 7. Result of Maximum Hose Tension – ALS

SUBSEA HOSE	TENSION (kN)			
	SYMMETRICAL (Heading 45°)		ASYMMETRICAL (Heading 120°)	
	Stage 1	Stage 2	Stage 1	Stage 2
Hose 1	70.19	359.86	79.65	286.51
Hose 2	69.01	327.42	80.32	306.96

The table above shows that the hose's maximum tension has increased significantly when it is on stage 2. This is because at stage 2, the condition of one of the mooring lines on the SPM has been cut off, resulting in the tensile force that occurs in the hose.

4.3 Hose Minimum Bending Radius Result

Minimum Bending Radius (MBR) is one of the parameters that must be considered on the hose or riser. The allowable MBR value in this study is 1.2 m. if the MBR value is less than that, the hose is considered unfit to operate under the specified conditions. MBR results can be seen in the following graph.



(b)

Figure 6. Graph of subsea marine hose MBR on each declination, (a) symmetrical, (b) asymmetrical – ULS

The smallest MBR value in the symmetrical condition is 1.56 m, while for the asymmetrical condition, the smallest MBR value is 1.55 m. Both values are still above the minimum limit of 1.2 m, so a subsea hose is considered suitable for use.

In contrast to the MBR value in the ALS condition, the smallest MBR value occurs when the condition is symmetrical compared to the asymmetric condition. MBR results for ALS analysis can be seen in the following table.

Table 8. Result of Hose MBR – ALS

SUBSEA HOSE	HOSE MBR (m)			
	SYMMETRICAL (Heading 45°)		ASYMMETRICAL (Heading 120°)	
	Stage 1	Stage 2	Stage 1	Stage 2
Hose 1	1.79	2.28	1.79	2.11
Hose 2	1.79	2.28	1.80	2.11

The MBR value is still within the safe operating limit as described in both symmetric and asymmetric configurations on both stages.

4.4 SPM Offset Result

The movement of the SPM in this study is viewed from the direction of the X and Y axes, where the greater the declination, the wider the range of the SPM movement. An illustration of SPM movement can be seen in the following graph.

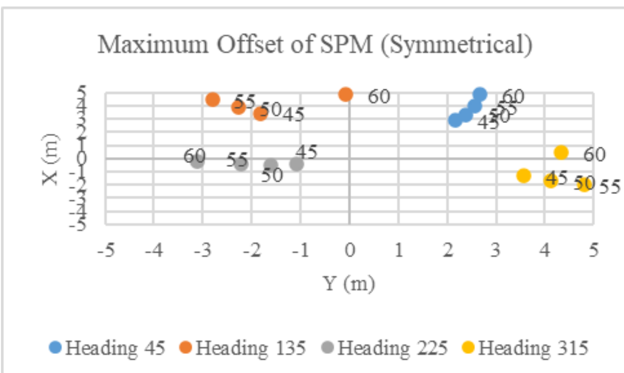


Figure 7. Maximum Offset of SPM – Symmetrical

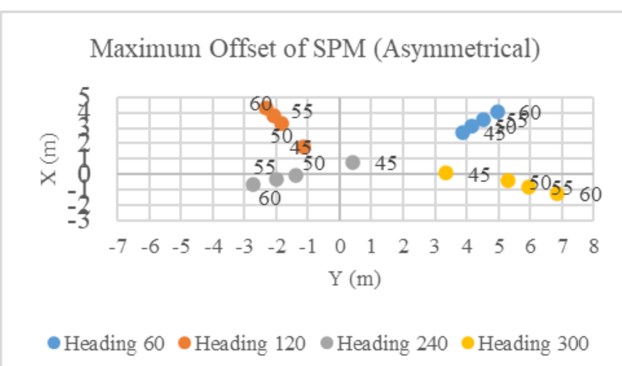


Figure 8. Maximum Offset of SPM – Asymmetrical

The maximum offset results for symmetrical conditions show that the SPM movement is getting farther as the rope length increases and the pretension angle increases. For headings at 135° and 315°, at a declination of 60 degrees, there is a pattern that does not show the SPM movement getting further away because the length of the rope that changes is not following the proper increase.

Unlike the ALS conditions, the maximum offset results are as shown in the following graph.

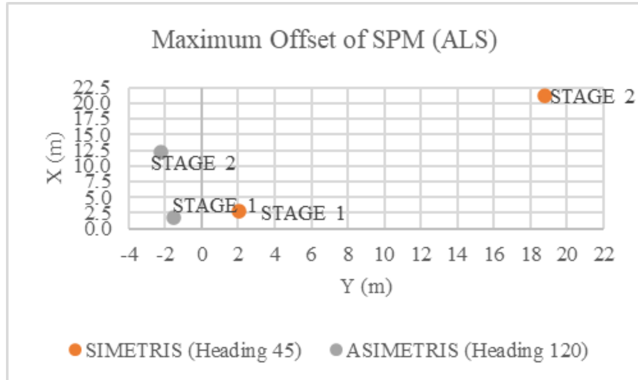


Figure 9. Maximum Offset of SPM – ALS

In ALS condition, it can be seen that in stage 2 (one of the ropes is broken), the maximum offset motion on the Y axis reaches 21.22 m in symmetrical conditions, while for asymmetrical conditions, the farthest offset motion is up to 12.16 m.

CONCLUSIONS

From the research that has been done above, several conclusions can be drawn, including:

1. The greater the pretension angle, the lower the tension on the mooring line. In the asymmetric configuration, the largest increase in rope length is 0.54%, with a decrease in tension of 8.28%. while in the symmetrical configuration the largest increase in rope length is 0.41%, with a decrease in tension of 4.49%.
2. The highest significant tension mooring lines in the symmetrical configuration occurs at heading 45 (L4) of 415.39 kN, while for the asymmetric configuration occurs at heading 120 (L3) of 400.75 kN.
3. The maximum offset that occurs in the ULS analysis is (4.79 m; 4.85 m) for symmetrical conditions and (4.33 m; 6.86 m) for asymmetrical conditions, indicating that the movement of SPM in symmetrical configurations is more stable than asymmetrical. As for the ALS condition, the maximum SPM movement occurs on the Y axis, as far as 21.22 m.
4. The declination angle or pretension angle affects the mooring line tension, as well as the tension and Minimum Bending Radius of the hose.

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