Analysis on the Effect of Subsea Buoy to the Tension of Spread Mooring System

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Keywords: FSO, Spread Mooring, Subsea Buoy, Tension.

Abstract: The problem that might occur in floating structures with mooring systems is clashing between mooring lines with subsea equipment, for example pipelines. Addition of subsea buoys on the mooring line can lift the mooring line so that it can avoid clashing. The addition of the subsea buoy can affect tension on the mooring line. This research discusses the effects of subsea buoy to the tension of mooring line with a variation position of subsea buoy. Variations on the position of one subsea buoy is arranged at the distance of 605 m, 577.5 m, 550 m, 522.5 m from anchor and two subsea buoys at the distance 605 m and 467.5 m from the anchor. The analysis was carried out on stand alone and offloading conditions with wave directions 0°, 45°, 90°, 135°, 180°. The results after the addition of subsea buoys it has a smaller tension on the mooring line. The result of the variation of subsea buoy position, the optimum position to get the smallest tension value is when the variation of two subsea buoys with a distance of 605 m and 467.5 m from the anchor. From the results of the analysis there is also no clashing between the mooring line and pipeline.

1 INTRODUCTION

Natuna is an area at the northern end of the Karimata Strait. This area is one of the largest oil and gas reserves in the world. Natuna is an area where there are many offshore structure for oil and gas exploration, either fix structure or floating structure. At present, the development of offshore structure design technology is continuing to explore oil and gas in the Natuna area. One of them is the construction of Floating Storage and Offloading (FSO).

Floating Storage Offloading (FSO) is a floating structure in the form of a ship which serves to store hydrocarbons and transfer to vessels or barges. In its operation the FSO structure is movement caused by environmental loads, such as waves, wind and currents. So that the mooring system is needed on the FSO structure. The purpose of this mooring system is to limit movement and keep the FSO in place.

One type of mooring system that is usually used is spread mooring. The mooring system consists of several mooring lines that spread and are moored to the seabed using anchors. This system does not allow the ship to move or spin to reach a position where environmental effects such as wind, current, and waves are relatively small.

The construction of mooring systems there are many factors that must be considered, one of the distance between the mooring line and the mooring line or with other subsea equipment. Clashing between the mooring line and the pipe is one of the problems that can be found. The addition of the subsea buoy on the mooring line can avoid clashing between the mooring line and the pipe, because the subsea buoy can lift the mooring line so that clashing does not occur. Addition of the subsea buoy can affect the tension on the mooring line. This research discusses the effect of adding subsea buoys to the tension of mooring line with a variation of one subsea buoy with four variations of position and two subsea buoys.

2 LITERATURE REVIEW

Many studies and research analyze variations in mooring system designs, such as subsea buoy analysis on mooring systems. Examples of numerical analysis on hybrid mooring systems with clump weights and buoys by Yuan Z.M. et al. (2014) which analyzed the type of new mooring line, hybrid mooring system with clump weigth and buoys (HMSWB). In this study Yuan Z.M only analyzed the

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effect of buoys on (HMSWB) because previously the influence of the clump weight was discussed by Ji C.Y. et al. (2011). This study concluded that installed buoys can reduce tension on the mooring line.

Sundaravadivelu (1991) has a study that the increase in submerged buoy net bouyancy can reduce the excurce of the buoy. The buoys used in the study were single point subsurface mooring. Fitria, Favi Ainin (2018) conducted a research on adding clump buoys to mooring systems which aimed to see the effect of adding clump buoys to mooring line tension and avoiding the potential for clashing between mooring lines. The results of the study that the addition of a clump buoy on the mooring line can reduce tension and also clashing between the mooring lines. Mavrakos (1997) analyzed the effect of adding submerged buoys in the deep sea and has variations in the number, size, and position of the submerged buoy. The next analysis is the effect of adding submerged buoy to the tension and dry length on a single point mooring mooring system (Suseprasetyo, 2013). This analysis get the results of the submerged buoy displacement in proportion to the amount of dry length and the farther position of the submerged buoy from fairlead has smaller tension.

3 OBJECTIVES AND SCOPE OF STUDY

The objective of this research is to comprehend how the subsea buoy in the mooring system affects the tension of mooring line. The responses which to be analysed are tension of mooring line, maximum offset, and clashing between mooring line and pipeline. The scope of study and boundaries of this research are as follows.

- The mooring system used is spread mooring.
- FSO is analyzed in full load and ballast condition.
- Environmental data uses data in Natuna.
- Collinear environmental loading conditions.
- Variation of one subsea buoy at a distance of 605 m, 577.5 m, 550 m, 522.5 m from the anchor.
- Variation of two subsea buoys at a distance of 605 m and 467.5 m from the anchor.
- The size of the subsea buoy is fixed.
- Dynamic analysis using time domain method.

4 METHODOLOGY

The flow and procedure of this research was conducted in stages as follows.

- Structural data uses Belida FSO data which is a conversion from tankers, shuttle tanker data, & environmental data using data in Natuna.
- Modelling FSO & shuttle tanker
- Model validation is to ensure the modeling is accordance with the original structure. Validation by comparing the hydrostatic data from the software with the original hydrostatic data. Model validation using reference from ABS (2018).
- Mooring system modeling, which uses a spread mooring type with eight mooring lines and 45 ° & 60° angle configurations.
- The mooring line analysis conducted in this study is the analysis of tension, offset, and clereance between the mooring line and pipeline.
- Analyzes were performed without subsea buoys and with subsea buoys.

5 RESULTS AND DISCUSSION

5.1 Structur Modeling

FSO modeling uses software by entering FSO coordinates.

Table 1: FSO Data.

Parameter	Unit	Value	
		Full load	*Ballast*
LOA	m	244.60	244.60
LPP	m	233.00	233.00
Breadth	m	42.20	42.20
Depth	m	22.20	22.20
Draft	m	15.50	7.00
KG	m	13.71	10.08
Displacement	Ton	12588.60	58833.87

Table 2: Shuttle tanker Data.

Parameter	Unit	Value
LOA	m	240.50
LPP	m	230.00
Breadth	m	42.00
Depth	m	21.20
Draft	m	14.85
KG	m	12.48
Displacement	Ton	118643.87

Table 3: Mooring Line Data.

Parameter	Unit	Value
Type	-	Chain, R4 Studless
Length of chain	m	914
Size	mm	87 mm dia
MBL	mT	783.35

Table 4: Mooring Hawser Data.

Parameter	Unit	Value
Type	-	*Rope/Nylon*
Size	mm	96 dia
MBL	mT	154.076

Table 5: Subsea Buoy Data.

Parameter	Unit	Value
Weight	kg	5600
Tinggi	m	4.6
Diameter	m	2.8

Table 6: Environment Data.

Direction	NE	E	SE	S	SW
Wind Speed (m/s)	18	11	10	13	13
Wave Data					
Hs	4.4	2.0	1.8	2.0	2.0
Tp	9.9	8.6	8.5	8.6	8.6
Current Speed (m/s)					
Surface	0.89	0.80	0.62	0.62	0.76
30 m	0.69	0.62	0.48	0.48	0.67
3 m	0.45	0.41	0.35	0.35	0.43

This is modelling of FSO & shuttle tanker.

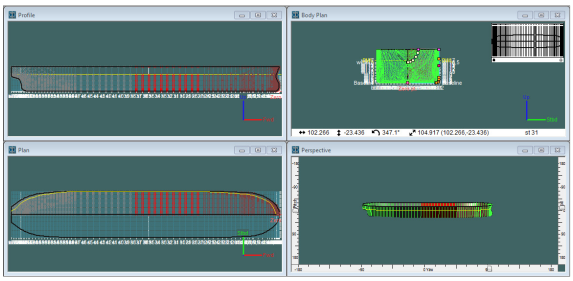

Figure 1: Modeling FSO with Maxsurf.

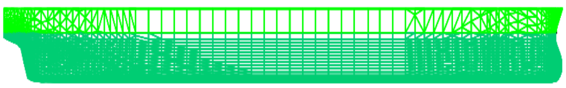

Figure 2: Side view FSO with Moses.

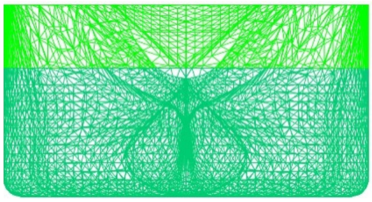

Figure 3: Front view FSO with Moses.

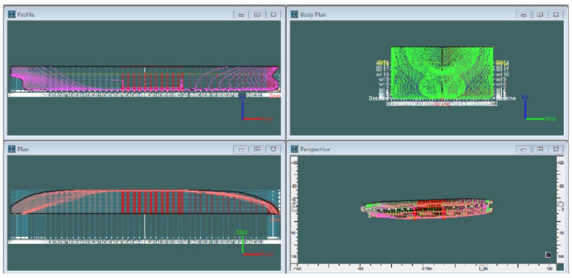

Figure 4: Modeling shuttle tanker with Maxsurf.

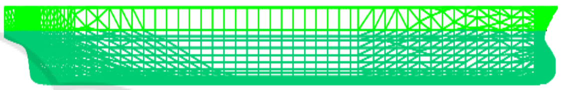

Figure 5: Side view shuttle tanker with Moses.

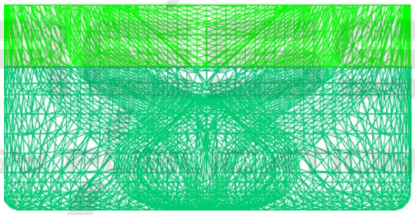

Figure 6: Front view shuttle tanker with Moses.

Mooring systems were modeling by software and modeled in 6 variations in two conditions, stand alone and offloading. The Variations were mooring line without subsea buoy, mooring line with one of subsea buoy at a distance from the anchor 605 m, 557.5 m, 550 m, 522.5 m, and mooring line with two subsea buoy at a distance from the anchor 605 m and 476.5m.

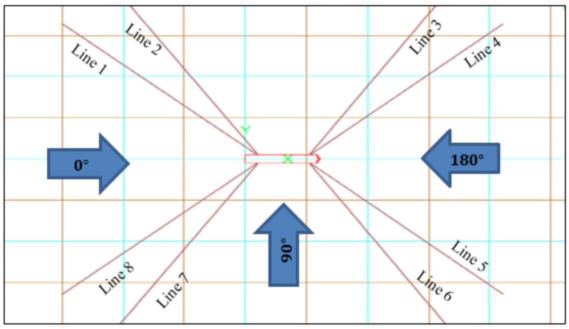

Figure 7: Stand alone conditions.

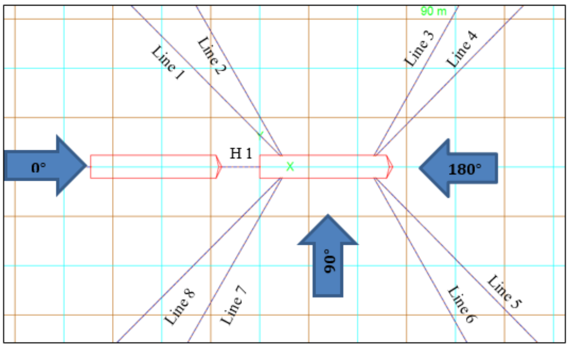

Figure 8: Offloading conditions.

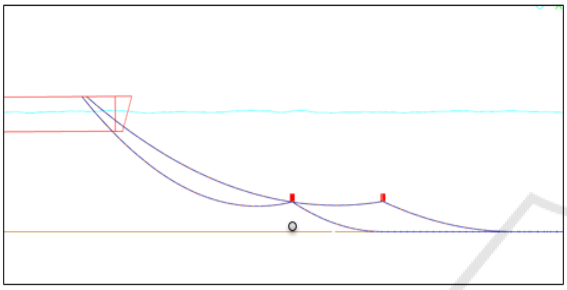

Figure 9: Mooring Line with one Subsea Buoy.

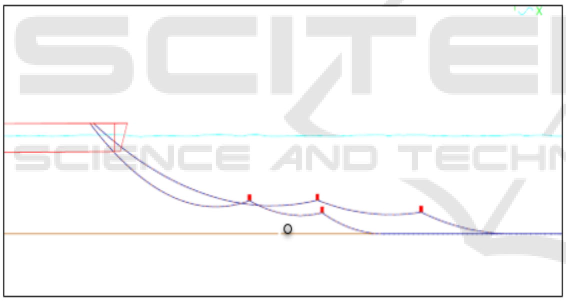

Figure 10: Mooring Line with two Subsea Buoy.

5.2 Model Validation

The model was validated based on the ABS (*American Bureau of Shipping)* MODU (*Mobile Offshore Drilling Unit*) rules, the difference of displacement modeling not exceed 2%.

Table 7: FSO Validation.

Load	Data	MOSES	Validasi
Full Load	128588.6	128561	0.02%
Ballast	58796.11	57589.1	2.00%

Table 8: Shuttle Tanker Validation.

Load	Data	MOSES	Validasi
Full Load	118644	118787	0.12%

5.3 Responses Amplitude Operator Analysis

RAO (Response Amplitude Operator) analysis is performed motion characteristics of FSO and shuttle tanker. This analysis carried out when free floating and moored condition in 6 degrees of freedom, namely surge, sway, heave, roll, pitch and yaw. The following is RAO of FSO and shuttle tanker during full load and ballast conditions.

1. RAOs Free Floating Condition

Table 9: Max. RAO FSO Full Load Condition.

Motion	Unit	RAO Max.				
		0°	45°	90°	135°	180°
Surge	m/m	0.97	0.69	0.00	0.69	0.97
Sway	m/m	0.00	0.70	0.99	0.70	0.00
Heave	m/m	1.00	1.00	1.45	1.00	1.00
Roll	deg/m	0.01	1.60	2.21	1.59	0.01
Pitch	deg/m	0.79	0.97	0.37	0.93	0.79
Yaw	deg/m	0.00	0.30	0.03	0.32	0.00

Table 10: Max. RAO FSO Ballast Condition.

Motion	Unit	RAO Max.				
		0°	45°	90°	135°	180°
Surge	m/m	0.98	0.69	0.00	0.69	0.98
Sway	m/m	0.00	0.70	0.99	0.70	0.00
Heave	m/m	1.00	1.00	1.09	1.00	1.00
Roll	deg/m	0.00	2.20	4.65	2.31	0.00
Pitch	deg/m	0.73	0.78	0.12	0.77	0.73
Yaw	deg/m	0.00	0.32	0.04	0.33	0.00

Table 11: Max. RAO shuttle tanker Full Load Condition.

Motion	Unit	RAO Max.				
		0°	45°	90°	135°	180°
Surge	m/m	0.97	0.68	0.00	0.68	0.97
Sway	m/m	0.00	0.70	0.99	0.70	0.00
Heave	m/m	1.00	1.00	0.45	1.00	1.00
Roll	deg/m	0.01	1.94	2.69	1.92	0.01
Pitch	deg/m	0.85	1.01	0.36	0.88	0.88
Yaw	deg/m	0.00	0.31	0.05	0.32	0.00

5.4 Mooring Line Tension Analysis

Analysis of the mooring line tension was carried out without subsea buoys and with subsea buoys in two conditions, namely stand alone conditions and offloading conditions. Mooring line 6 has the largest tension value compared to the mooring line 3, 4, 5 which has been added to the subsea buoy. So that a comparative analysis of the position of the subsea buoy is carried out on the mooring line 6.

1. Stand Alone Condition

For analysis of tension on the mooring line carried out with conditions without subsea buoy, one subsea buoy with four variations of position and two subsea buoys in five of wave directions, namely, 0 °, 45 °, 90 °, 135 °, 180 °.

a. Wave Direction 0°

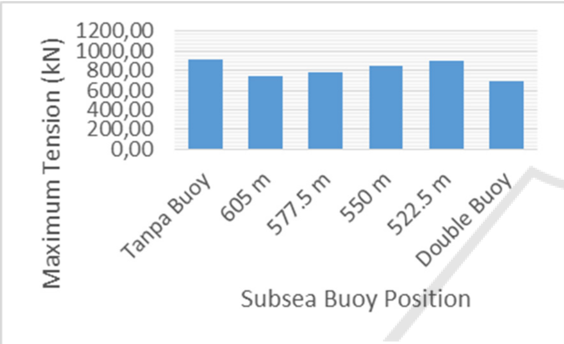

Figure 11: Max. Tension 0°.

b. Wave Direction 45°

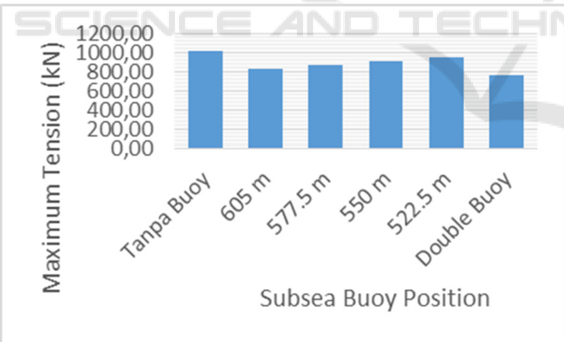

Figure 12: Max. Tension 45°.

c. Wave Direction 90°

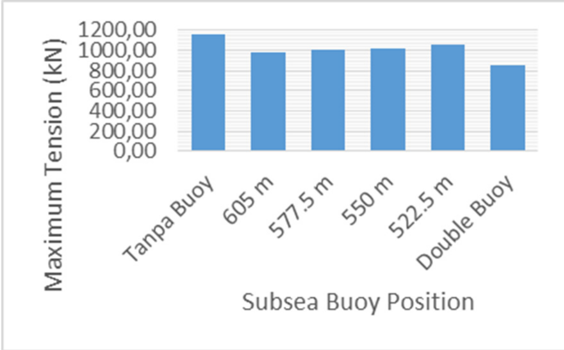

Figure 13: Max. Tension 90°.

d. Wave Direction 135°

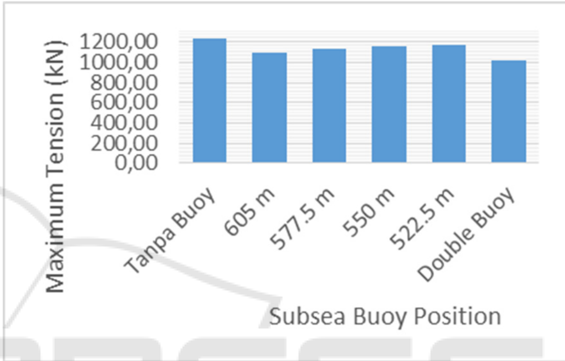

Figure 14: Max. Tension 135°.

e. Wave Direction 180°

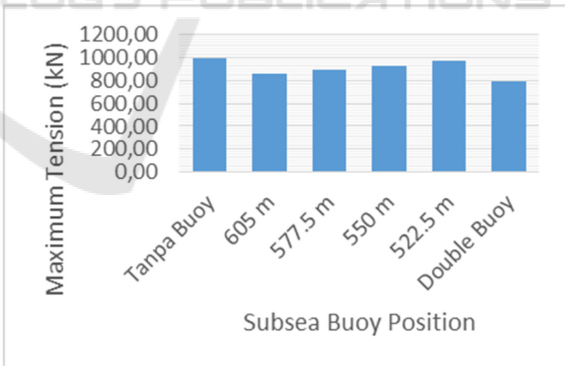

Figure 15: Max. Tension 180°.

From Figure 11 until Figure 15 indicates that the largest mooring line tension on the mooring line without subsea buoys. The mooring line with the subsea buoy from the smallest to the largest is the mooring line with two subsea buoys, the mooring line with one subsea buoy with a distance of 605 m, 577.5 m, 550 m, 522.5 m from the anchor.

2. Offloading Condition

For analysis of tension on the mooring line carried out with conditions without subsea buoy, one subsea buoy with four variations of position and two subsea buoys in five of wave directions, namely, 0 °, 45 °, 90 °, 135 °, 180 °.

a. Wave Direction 0°

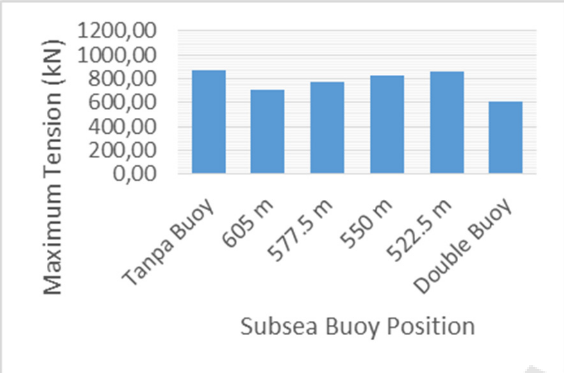

Figure 16: Max. Tension 0°.

b. Wave Direction 45°

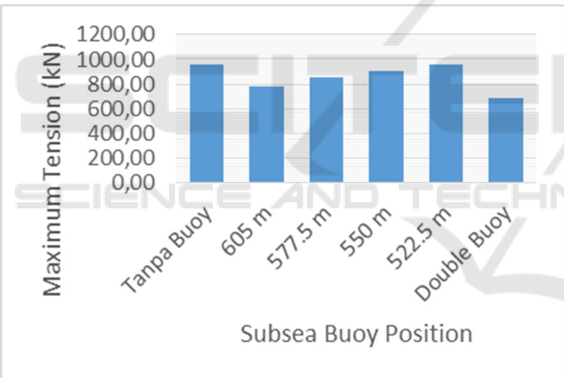

Figure 17: Max. Tension 45°.

c. Wave Direction 90°

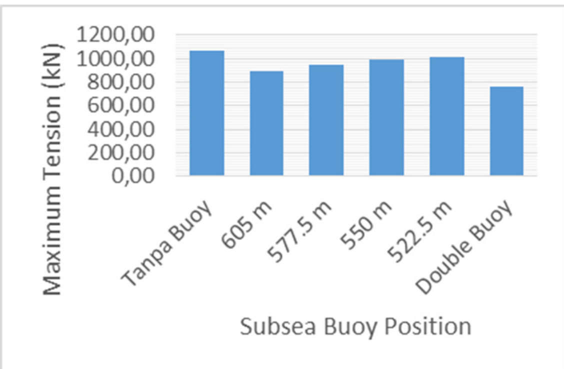

Figure 18: Max. Tension 90°.

d. Wave Direction 135°

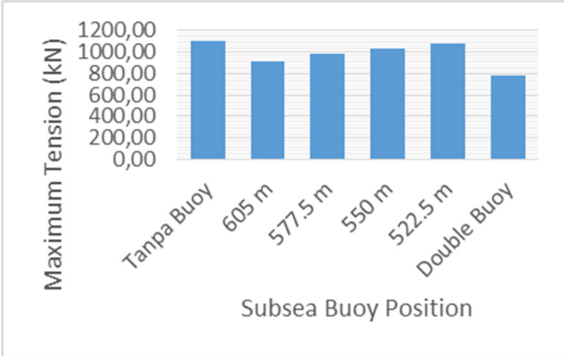

Figure 19: Max. Tension 135°.

e. Wave Direction 180°

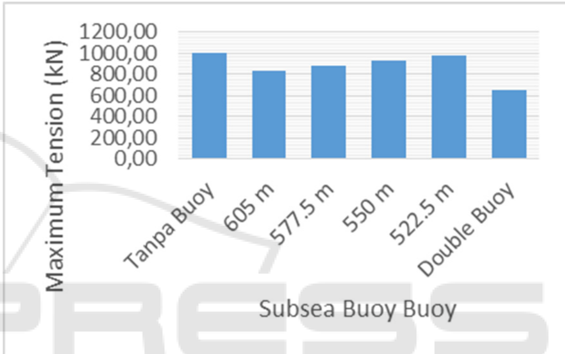

Figure 20: Max. Tension 180°.

From Figure 16 until Figure 20 indicates that the largest mooring line tension on the mooring line without subsea buoys. The mooring line with the subsea buoy from the smallest to the largest is the mooring line with two subsea buoys, the mooring line with one subsea buoy with a distance of 605 m, 577.5 m, 550 m, 522.5 m from the anchor.

5.5 Offset Analysis

Stand alone and offloading condition are used in the analysis.

1. Stand Alone Condition.

This analysis was carried out with 5 load directions include 0°, 45°, 90°, 135° and 180°.

Table 12: Max. Offset Stand Alone Condition.

Wave Directions	*Offset* x & y	*Maximum Offset* (m)		
		Tanpa *Buoy*	605 m	577.5 m
0°	x	0.80	1.67	1.05
	y	0.00	0.00	0.00
45°	x	0.34	2.28	1.67
	y	2.84	3.49	3.49
90°	x	0.41	2.34	1.72
	y	2.69	2.90	2.82
135°	x	0.31	2.06	1.47
	y	1.49	1.57	1.30
180°	x	1.43	2.89	2.24
	y	0.14	0.08	0.08

Table 13: Max. Offset Stand Alone Condition.

Wave Directions	*Offset* x & y	*Maximum Offset* (m)		
		Tanpa *Buoy*	605 m	577.5 m
0°	x	0.50	0.47	2.53
	y	0.00	0.00	0.00
45°	x	1.02	0.57	3.54
	y	3.46	3.44	3.68
90°	x	1.09	0.46	3.53
	y	2.70	2.62	3.45
135°	x	0.86	0.50	3.08
	y	1.28	1.28	2.13
180°	x	1.58	0.90	4.54
	y	0.08	0.08	0.08

2. Offloading Condition.
This analysis was carried out with 5 load directions include 0º, 45º, 90º, 135º and 180º.

Table 14: Max. Offset Offloading condition.

Wave Directions	*Offset* x & y	*Maximum Offset* (m)		
		Tanpa *Buoy*	605 m	577.5 m
0°	x	0.81	1.67	1.56
	y	0.00	0.00	0.00
45°	x	1.75	3.90	3.19
	y	5.19	5.92	5.62
90°	x	2.41	4.78	3.92
	y	6.72	7.75	7.28
135°	x	3.10	5.94	4.90
	y	7.97	8.91	8.77
180°	x	1.44	3.55	2.67
	y	0.14	0.00	0.00

Table 15: Max. Offset Offloading condition.

Wave Directions	*Offset* x & y	*Maximum Offset* (m)		
		Tanpa *Buoy*	605 m	577.5 m
0°	x	1.37	0.66	1.66
	y	0.00	0.00	0.30
45°	x	2.42	1.61	5.18
	y	5.34	5.15	6.40
90°	x	3.14	2.34	6.38
	y	6.84	6.52	8.40
135°	x	4.02	3.19	7.87
	y	8.26	7.85	9.11
180°	x	1.84	1.13	4.89
	y	0.00	0.00	0.00

5.6 Clearance between Mooring Line and Pipeline

Stand alone and offloading condition are used in the analysis.

1. Stand Alone Condition.

Table 16: Clearance between Mooring Line and Pipeline.

Line	*Clearance* (m)		
	No Buoy	605 m	577.5 m
3	0.00	6.51	10.10
4	0.19	17.42	14.41
5	0.19	17.42	14.41
6	0.00	6.51	10.10

Table 17: Clearance between Mooring Line and Pipeline.

Line	*Clearance* (m)		
	550 m	522.5 m	*Double Buoy*
3	12.45	4.77	25.73
4	10.84	3.20	29.90
5	10.84	3.20	29.90
6	12.45	4.77	25.73

From Table 16 and 17 shows that there is no clashing between mooring line and pipeline after the addition of the subsea buoy, but the clearance that matches the criteria of DNV OS E301 which is in the variation of one subsea buoy with a distance of 577.5 m from the anchor, one subsea buoy with a distance of 577.5 m from anchor, and on the condition of two subsea buoys. The biggest clearance occurred in the condition of two subsea buoys, namely on lines 3 and 6 valued at 25.73 m and on lines 4 and 5 worth 29.9m.

2. Offloading Condition.

Table 18: Clearance between Mooring Line and Pipeline.

Line	*Clearance* (m)		
	No Buoy	605 m	577.5 m
3	0.00	6.13	10.04
4	0.19	15.92	12.74
5	0.19	15.92	12.74
6	0.00	6.13	10.04

Table 19: Clearance between Mooring Line and Pipeline.

Line	*Clearance* (m)		
	550 m	522.5 m	*Double Buoy*
3	10.58	5.22	24.88
4	10.11	4.39	27.55
5	10.11	4.39	27.55
6	10.58	5.22	24.88

From Table 18 and 19 shows that there is no clashing between the mooring line and the pipe after the addition of the subsea buoy, but the clearance that matches the criteria of DNV OS E301 which is in the variation of one subsea buoy with a distance of 577.5 m from the anchor, one subsea buoy at 577.5 m from anchor, and on the condition of two subsea buoys. The biggest clearance occurred in the condition of two subsea buoys, namely on lines 3 and 6 valued at 24.88 m and on lines 4 and 5 worth 27.55 m.

6 CONCLUSIONS

The findings of the study could be revealed as follows:

- Mooring line without subsea buoys at stand alone conditions and in all loading directions has the maximum tension. The largest tension from the direction of 45° on line seven with a value of 1503.09 kN. The offloading condition, the mooring line without the addition of subsea buoys in all loading directions also has the maximum tension value. In the direction of 135° on line seven has the largest tension with a value of 1743.05 kN. For all tension it matches the criteria of API RP 2SK, which is a safety factor less than 1.67.
- From the research it is known that the addition of the subsea buoy reduces the tension on the mooring line. On the mooring line with one subsea buoy the further distance from the anchor has smaller tension. At the mooring line with two subsea buoys with a distance of 605 m and 467.5 m has the minimum value. This condition occurs in all of wave directions when stand alone and offloading.
- From the research it is known that the addition of the subsea buoy can affect the offset of the FSO. In stand alone and offloading conditions, the highest offset is on the mooring line with two subsea buoys and a mooring line with one subsea buoy with a distance of 605 m from the anchor. The value of all offsets that occur is in accordance with the API RP 2P criteria.
- From the research it is known that the addition of subsea buoys can avoid clashing between mooring line and pipeline. However, for the clearance between mooring line and pipeline that matches the criteria of DNV OS E301 which is in the variation of one subsea buoy with a distance of 577.5 m from the anchor, one subsea buoy with a distance of 550 m from the anchor, and in the conditions of two subsea buoys. The biggest clearance occurred on the mooring line with two subsea buoys.

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