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The Study of Mooring Buoy Operability to Support Offloading Operation of Shuttle Tankers with Various Capacities

Moch. Afif Zahiru Fajar[a,*], Eko Budi Djatmiko[a] and Murdjito[a]

[a)] Undergraduate Student, Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
*Corresponding author: mafifzahirufajar02@gmail.com

ABSTRACT

This study was conducted to analyse of the operability of mooring buoy initially designed for offloading operation of 35,000 DWT shuttle tankers enhanced to serve the offloading operations of shuttle tankers with 50,000 DWT, 75,000 DWT, and 111,000 DWT capacities. Operability is reviewed in term of mooring line tensions induced by each new variation of tanker capacity under environmental conditions of 1-year, 10-year, and 100-year recurrence. The governing criteria is that the safety factor should meet the appropriate limit as stated in the API RP2SK. Tension on the mooring line increases in parallel with the increasing of tanker capacity. For the case of 35,000 DWT and 50,000 DWT shuttle tankers the operation can be performed in all environmental conditions. For the case of 75,000 DWT shuttle tanker with full load and 67% DWT capacity can fully operate in all environmental conditions, but with 47% DWT capacity could not be operated in the 100-year environmental condition with significant wave height 3.31 m for the direction of inline-L1, inline-L2, and between line-L1&L4. For the case of 111,000 DWT shuttle tanker at all capacity conditions can fully operate in the 1-year environmental condition with significant wave height up to 1.48 m.

Keywords: *operability, offloading operation, buoy, shuttle tanker.*

1. INTRODUCTION

As we know, the current source of oil and gas in onshore is reduced increasingly, the exploration and production are growing to offshore as the source there not yet utilized. Obtaining oil and gas in offshore needs facilities that support the exploration and operation with some considerations [1].

A tanker is one of the facilities to transport oil and gas products from an offshore production facility to land-based production facilities [2]. Distributing oil from an offshore production facility to tankers is not automatically done, the distribution process is called offloading operation. In this process, the tanker requires a mooring system to keep the tanker in its position [3]. The mooring system commonly used in offloading operation is single Buoy Mooring system [4]. The mooring system must survive in the environmental conditions (winds, waves, and currents). The environmental load causes motion in vessel structure during offloading operation and induces tension in the mooring system [5].

An offloading system is a coupled dynamic system where the response to each component is influenced by the combination of the first-order wave load and the second-order wave load [6]. The dynamic load on the mooring and resultant system of damping force have a significant effect on the buoy motion [7].

Excessive tension due to vessel motion and environmental load may fail in offloading operation [8]. In this study, the initial design of mooring buoy made for a tanker with 35,000 DWT. Because the requirement for offloading operation and the availability of 35,000 DWT ships are limited, so the previous mooring system is scaled up to bigger ships in dimension and capacity considering the capability of mooring system to the scaled-up buoy. Operability will be reviewed on mooring tension on any variation tankers capacity by considering the limitations of environmental conditions allowing shuttle tankers to operate.

2. METHOD AND MATERIALS

The procedure of this study is conducted as follow. The first step is conducting a literature study in researches with similar topics, local and international journals, codes/standard literature as well as books relating to the topic discussed.

2.1 Data Collection

The next step is collecting data that supports the research. The data structures used are tankers with a capacity of 35,000 DWT, 50,000 DWT, 75,000 DWT, and 111,000 DWT, the main dimension of mooring buoy, property and configuration of the mooring systems, and local environmental data that is the North Sea Java region of Semarang Regency, Central Java Province.

2.2 Modelling using Maxsurf

The modelling of shuttle tanker is done with Maxsurf software to derive the hydrostatic properties of the vessel. This is further to be validated against the main data that made before. The Hydrostatic properties then validate referring to the main and ABS Rules for Building and Classing MODU.

2.3 Modelling and Analysis using MOSES

The outputs of the modelled structure on Maxsurf are offset coordinates that will be used for input in MOSES. Analyses were conducted to tankers and mooring buoy with regular waves using frequency domain on stand-alone in free-floating conditions to obtain the characteristic motion of structure and hydrodynamic characteristics of RAO, wave drift force, a matrix of added mass, etc. The characteristic of the motion structures in the regular wave in free-floating conditions was carried out using the MOSES software with the direction of 0^0, 45^0, 90^0, 135^0, and 180^0 which are outlined in six degrees of freedom of surge, sway, heave, roll, pitch, and yaw motion.

2.4 Modelling and Mooring Analysis

Modelling the mooring systems on a buoy in stand-alone and offloading operation condition with the shuttle tankers were carried out using the Orcaflex software. Modelling was done by inputting the main dimensions of the structure on the Orcaflex. Modelling using the OrcaFlex require inputs from MOSES for the RAO property, added mass matrix, and damping. The modelling mooring systems in mooring buoy use the mooring system configuration by inserting the properties of the rope or chain used, the coordinates of the fairlead and anchor of the mooring systems. Modelling done on each shuttle tanker for each capacity variation and each analysis scenario (*inline* and *between line*).

The analysis of mooring tension in buoy is done using Orcaflex software which is obtained maximum tension on each mooring line for each wave, currents and wind loading conditions (1-year, 10-year, and 100-year). Mooring tension analysis was done by following each analysis scenario. Dynamic analysis of the mooring system is done with a simulated duration of 1800 seconds (30 minutes) in each environmental condition.

2.5 Operability Analysis

Operability analysis is done to buoy that have the initial design to the offloading operation with 35.000 DWT tanker. Then, enhanced to the offloading operation with bigger capacity tankers. Operability in mooring buoy is reviewed on the ability of mooring buoy to operate a tandem offloading operation with a shuttle tanker. Based on mooring tension analysis, operability is reviewed on the ability of mooring buoy operations in 1-year, 10-year, and 100-year environmental conditions that have a safety factor value above of the limit requirements set by API RP2SK for the intact condition which is 1.67.

3. RESULTS AND DISCUSSIONS

3.1 Structure Modelling

The modelling of the floating structure is established by referring to the 35.000 DWT, 50.000 DWT, 75.000 DWT, and 111.000 DWT shuttle tankers and mooring buoy. The main dimensions of the tanker can be seen in Table 1 below:

Table 1. The Principal Dimension of Shuttle Tankers

Parameter	Unit	Tanker 35.000 DWT	Tanker 50.000 DWT	Tanker 75.000 DWT	Tanker 111.000 DWT
LoA	m	179.70	183.3	228.50	252.8
Lpp	m	174.00	176	220.00	244.2
B	m	30.03	32.26	32.24	44
D	m	12.07	18.8	20.45	20.8
Ts	m	10.06	13.3	14.18	15
DWT	Ton	34999	50000	74998	111000
Δ	Ton	42681.7	59523.8	89283.3	13373.9

Each tanker is variated by the capacity of the tanker to full load capacity. Tanker with 35,000 DWT made a variation for full load capacity with draft 10.06 m, 71% DWT with draft 7.94 m, and 43% DWT with draft 5.72 m. On 50,000 DWT tanker made a variation for full load capacity with draft 13.3 m, 70% DWT with draft 10.39 m, 50% DWT with draft 8.3 m. On 75,000 DWT tanker made a variation full load capacity with draft 14.18 m, 67% DWT with draft 10.45 m, and 47% DWT with draft 8.11 m. At the 111,000 DWT tanker carried a variation of full load capacity with a draft of 15 m, 45% DWT with a draft 8.69 m, and 32% DWT with draft 7.06 m. The main dimensions of buoy mooring can be seen in Table 2 below:

Table 2**.** The Principal Dimension of a mooring buoy

Parameter	Symbol	Value	Unit
Outside Diameter	Od	8	m
Inside Diameter	Id	1.15	m
Skirt Diameter	Sd	11.24	m
Buoy Height	H	3.7	m
Draft	T	1.8	m

Once the required principal dimension data obtained then continue modelling of the tanker structure and mooring buoy using Maxsurf and MOSES software. After modelling, it is followed by validation of structures that have been modelled with the main data. The tanker hull model then analyzed in further hydrodynamic as shown in Figure 1, Figure 2, and Figure 3

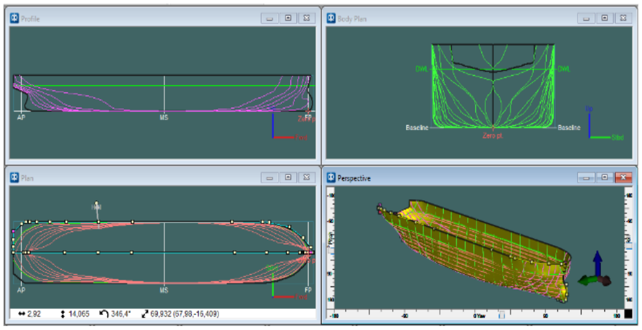
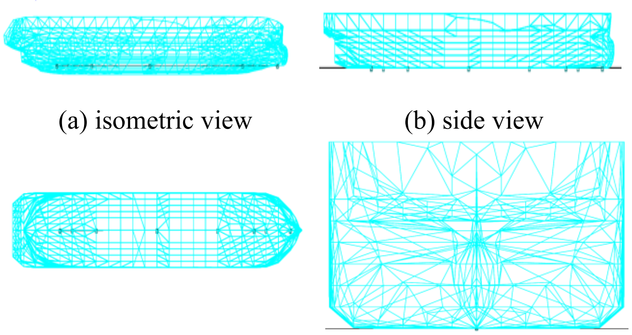


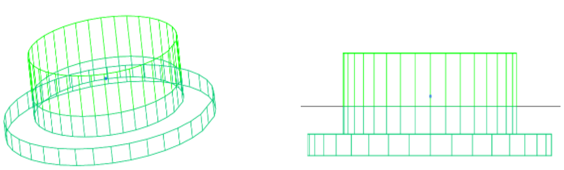
Figure 1. Hull modelling of the shuttle tanker using Maxsurf



(a) isometric view (b) side view

(c) top view (d) bow view

Figure 2. Hull modelliing of the shuttle tanker using MOSES



(a) isometric view (b) side view

Figure 3. Modelling of the buoy using MOSES

3.2 Hull Model Validation

Validation was done from the modelling data with the main data of the tanker. Validation criteria based on ABS Rules for Building and Classing Mobile Offshore Drilling Units MODU 1998, the error value displacement should not exceed 2% while other provisions should not exceed 1% [9].

Table 3. Validation of modelling data shuttle tanker 35.000 DWT.

Parameter	Unit	Full load Capacity (35.000 DWT)			
		Data	Model	Error (%)	Note
Δ	Ton	42681.71	42359.00	0.76	OK
B	m	30.03	30.03	0.00	OK
T	m	10.06	10.06	0.00	OK
Cb		0.79	0.78	0.26	OK
Cm		0.99	0.98	0.99	OK

Table 4. Validation of modelling data shuttle tanker 50.000 DWT.

Parameter	Unit	Full load Capacity (50.000 DWT)			
		Data	Model	Error (%)	Note
Δ	Ton	59523.81	59771.00	0.41	OK
B	m	32.26	32.26	0.00	OK
T	m	13.30	13.30	0.00	OK
Cb		0.77	0.77	0.74	OK
Cm		0.99	0.98	0.81	OK

Table 5. Validation of modelling data shuttle tanker 75.000 DWT.

Parameter	Unit	Full load Capacity (75.000 DWT)			
		Data	Model	Error (%)	Note
Δ	Ton	89283.33	89388.00	0.12	OK
B	m	32.24	32.24	0.00	OK
T	m	14.18	14.18	0.00	OK
Cb		0.77	0.78	0.83	OK
Cm		0.99	0.98	0.80	OK

Table 6. Validation of modelling data shuttle tanker 111.000 DWT.

Parameter	Unit	Full load Capacity (111.000 DWT)			
		Data	Model	Error (%)	Note
Δ	Ton	133735	133867.0	0.10	OK
B	m	44.00	44.00	0.00	OK
T	m	15.00	15.00	0.00	OK
Cb		0.84	0.84	0.10	OK
Cm		1.00	0.99	0.15	OK

Table 7. Validation of modelling data mooring buoy.

Parameter	Unit	*Buoy*			
		Data	Model	Koreksi (%)	Ket.
Δ	Ton	131.2	130.55	0.495	OK
∇	m^3	128.00	127.37	0.495	OK
Draft	m	1.8	1.8	0.000	OK

The result of the validation indicates that the model of the structure is feasible for the motion characteristic in the regular wave. The motion characteristic analysis was done in the frequency domain. The analysis was carried out on the condition of free-floating structures without the mooring system.

3.3 Mooring Configuration and Environmental Loads

Tension on the mooring line was analyzed on a mooring buoy in an offloading operation with tanker capacity of 35.000 DWT to 111.000 DWT. Analysis for an offloading operation carried out on each variations vessel capacity. The environmental loading scenario was performed inline and between line environmental load directions with the collinear loading direction where waves, winds, and currents come from the same direction. Illustrations of the analysis scenario are illustrated in Figure 4.

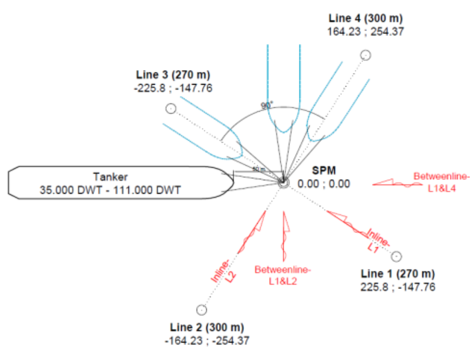


Figure 4. Configuration of offloading operations and environmental load direction scenarios

The mooring line and hawser line property data can be seen in Table 8 as follows:

Table 8. Mooring line and hawser line property data

Equipment	Value	Unit
Mooring Chain		
Type	Studless - Chain	
Grade	R4	
Diameter	82.5	mm
Length	300	m (for line 2 & line 4)
	270	m (for line 1 & line 3)
Minimum Breaking Load (MBL)	6974.773	kN
	699.997	Tons
Hawser Line		
Type	Rope	
Grade	Polypropiylene	
Length	60	m
Circumference	9	inch
	228.6	mm
MBL	573.885	kN
	58.5	Tons

Dynamic analysis of the mooring system was done with the duration of the loading simulation of 1800 seconds (30 minutes) in each environmental condition. Dynamic analysis was conducted on each tanker with for each capacity variation in 1-year, 10-year, and 100-year environmental conditions. In this study, the wave spectrum used was the JONSWAP spectrum where it was able to accommodate the characteristics for closed water or islands, which were suitable for the design and analysis of offshore waterways in Indonesian waters.

The environmental data on the buoy operation waters with a depth of 20 m is shown in Table 9 as follows:

Table 9. Environmental data for operation waters

Parameter	Return Period (years)				
Item	**Notation**	**Unit**	**1**	**10**	**100**
Wind					
1-minute mean	U_1	m/s	5.58	8.14	12.16
Wave					
Significant wave height	Hs	m	1.48	2.38	3.31
Significant wave period	Ts	s	4.71	6.12	7.52
Spectrum	Jonswap				
Current					
Current Speed	V_0	m/s	0.77	1.69	2.36

3.4 Motion Characteristics of Structure in Free-floating Condition

To know the motion characteristic of structure in the regular wave, we need to know RAO (Response Amplitude Operator) as the operator function. The RAO structure for the translational motion mode (surge, sway, and heave) is obtained through the following equation [10]:

$$\text{RAO}\ (\omega) = \left(\frac{\zeta_s}{\zeta_w}\right)\ (\text{m/m}) \qquad (1)$$

The RAO for the rotational motion mode (roll, pitch, and yaw) is obtained through the following equation:

$$\text{RAO}\ (\omega) = \left(\frac{\zeta_s}{k_w.\zeta_w}\right) = \left(\frac{\zeta_s}{(\omega^2/g).\zeta_w}\right)\ (\text{rad/rad}) \qquad (2)$$

The motion characteristic of structures in the regular wave in free-floating conditions was carried out using the MOSES software with the direction of 0^0, 45^0, 90^0, 135^0, and 180^0 which are in six degrees of freedom of surge, sway, heave, roll, pitch, and yaw.

Characteristics of motion for tanker 35.000 DWT with scenario for full load capacity condition, capacity 71% DWT (25.000 DWT), and capacity 43% DWT (15.000 DWT). The motion characteristics for tanker 35.000 DWT can be seen in Table 10 below.

Table 10. Maximum RAO for 35.000 DWT

Motion Mode	Direction				
	0^0	**45^0**	**90^0**	**135^0**	**180^0**
	Capacity 100% (*full load*)				
Surge (m/m)	0.96	0.679	0.001	0.679	0.96
Sway (m/m)	0	0.7	0.991	0.7	0
Heave (m/m)	0.999	1	1.212	1	0.999
Roll (deg/m)	0.02	1.639	6.617	1.752	0.021
Pitch (deg/m)	1.01	1.089	0.279	1.101	1.108
Yaw (deg/m)	0.001	0.417	0.094	0.451	0.001
	Capacity 71% DWT (25.000 DWT)				
Surge (m/m)	0.966	0.683	0.001	0.683	0.966
Sway (m/m)	0.001	0.7	0.991	0.7	0
Heave (m/m)	0.999	0.999	1.333	0.999	0.999
Roll (deg/m)	0.02	1.989	6.815	1.33	0.012
Pitch (deg/m)	1.02	1.079	0.279	1.17	1.086
Yaw (deg/m)	0.001	0.429	0.119	0.453	0.001
	Capacity 43% DWT (15.000 DWT)				
Surge (m/m)	0.971	0.687	0	0.687	0.971
Sway (m/m)	0	0.7	0.991	0.7	0
Heave (m/m)	0.997	0.997	1.418	0.997	0.997
Roll (deg/m)	0.01	1.988	6.838	1.347	0.032
Pitch (deg/m)	1.056	1.097	0.176	1.172	1.11
Yaw (deg/m)	0.001	0.432	0.122	0.458	0.001

Characteristics of motion for tanker 50.000 DWT with scenario for full load capacity, 70% DWT capacity (35.000 DWT), and 50% DWT capacity (25.000 DWT) for each motion mode can be seen in Table 11.

Table 11. Maximum RAO for 50.000 DWT

Motion Mode	Direction				
	0^0	**45^0**	**90^0**	**135^0**	**180^0**
	Capacity 100% (*full load*)				
Surge (m/m)	0.95	0.672	0.002	0.672	0.95
Sway (m/m)	0.001	0.698	0.988	0.698	0
Heave (m/m)	0.999	0.999	1.335	0.999	0.999
Roll (deg/m)	0.001	2.069	3.246	2.008	0.001
Pitch (deg/m)	1.059	1.166	0.256	1.172	1.076
Yaw (deg/m)	0	0.385	0.032	0.391	0
	Capacity 70% DWT (35.000 DWT)				
Surge (m/m)	0.95	0.67	0	0.67	0.95
Sway (m/m)	0	0.69	0.989	0.699	0
Heave (m/m)	0.998	0.999	1.34	0.999	0.998
Roll (deg/m)	0.003	2.383	5.441	2.424	0.002
Pitch (deg/m)	1.099	1.191	0.079	1.179	1.095
Yaw (deg/m)	0.001	0.393	0.019	0.396	0.001
	Capacity 50% DWT (25.000 DWT)				
Surge (m/m)	0.963	0.681	0	0.681	0.963
Sway (m/m)	0.001	0.7	0.99	0.7	0.002
Heave (m/m)	0.998	0.998	1.424	0.998	0.998
Roll (deg/m)	0.026	3.348	5.639	3.36	0.026
Pitch (deg/m)	1.126	1.214	0.043	1.202	1.121
Yaw (deg/m)	0	0.394	0.017	0.399	0

Characteristics of motion for tanker 75.000 DWT with scenario for full load capacity, 67% DWT capacity (50.000 DWT), and 47% DWT capacity (35.000 DWT) for each motion mode can be seen in Table 12.

Table 12. Maximum RAO for 75.000 DWT

Motion Mode	Direction				
	0^0	**45^0**	**90^0**	**135^0**	**180^0**
	Capacity 100% (*full load*)				
Surge (m/m)	0.948	0.671	0.002	0.671	0.948
Sway (m/m)	0	0.698	0.987	0.698	0
Heave (m/m)	0.998	0.998	1.438	0.998	0.998
Roll (deg/m)	0.001	1.165	1.749	1.157	0.001
Pitch (deg/m)	0.768	0.892	0.279	0.929	0.812
Yaw (deg/m)	0	0.359	0.017	0.363	0
	Capacity 67% DWT (50.000 DWT)				
Surge (m/m)	0.959	0.678	0.001	0.678	0.959
Sway (m/m)	0	0.7	0.99	0.7	0
Heave (m/m)	0.996	0.997	1.453	0.997	0.996
Roll (deg/m)	0.003	1.696	4.664	1.715	0.001
Pitch (deg/m)	0.858	0.989	0.178	0.977	0.863
Yaw (deg/m)	0	0.369	0.034	0.376	0
	Capacity 47% DWT (35.000 DWT)				
Surge (m/m)	0.965	0.683	0	0.683	0.966
Sway (m/m)	0	0.701	0.991	0.701	0
Heave (m/m)	0.996	0.997	1.616	0.997	0.996
Roll (deg/m)	0.003	1.775	5.244	1.863	0.002
Pitch (deg/m)	0.839	0.913	0.089	0.992	0.848
Yaw (deg/m)	0	0.369	0.03	0.381	0

Characteristics of motion for tanker 111.000 DWT with scenario for full load capacity, 45% DWT capacity (50.000 DWT), and 32% DWT capacity (35.000 DWT) for each motion mode can be seen in Table 13.

Table 13. Maximum RAO for 111.000 DWT

Motion Mode	Direction 0^0	45^0	90^0	135^0	180^0
	Capacity 100% (*full load*)				
Surge (m/m)	0.955	0.676	0.002	0.676	0.955
Sway (m/m)	0	0.698	0.989	0.698	0
Heave (m/m)	0.998	0.999	1.431	0.999	0.998
Roll (deg/m)	0.005	1.618	3.75	1.6	0.002
Pitch (deg/m)	0.737	0.845	0.235	0.837	0.739
Yaw (deg/m)	0	0.28	0.038	0.308	0
	Capacity 67% DWT (50.000 DWT)				
Surge (m/m)	0.972	0.688	0	0.688	0.972
Sway (m/m)	0	0.701	0.992	0.701	0
Heave (m/m)	0.997	0.998	1.471	0.998	0.997
Roll (deg/m)	0.003	1.022	4.777	0.952	0.005
Pitch (deg/m)	0.727	0.875	0.063	0.883	0.732
Yaw (deg/m)	0	0.31	0.019	0.311	0
	Capacity 47% DWT (35.000 DWT)				
Surge (m/m)	0.976	0.69	0	0.69	0.976
Sway (m/m)	0	0.7	0.996	0.7	0
Heave (m/m)	0.998	0.999	1.853	0.999	0.998
Roll (deg/m)	0.003	1.08	5.517	1.082	0.004
Pitch (deg/m)	0.729	0.882	0.039	0.894	0.732
Yaw (deg/m)	0	0.309	0.013	0.312	0

Since the buoy structure has a symmetrical shape, the buoy motion characteristic analysis was done for head seas direction. In general, the trend of the RAO curve for symmetrical buoy free-floating conditions with circular shapes has the same characteristic on surge and sway motion mode. Thus, each direction and motion indicate the same pattern except for the perpendicular direction of the structure. Characteristics of motion for buoy can be seen in Figure 5 to Figure 6.

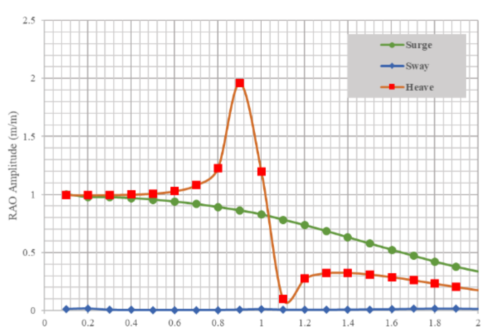


Figure 5. RAO graph translational motion mode buoy structure free-floating conditions.

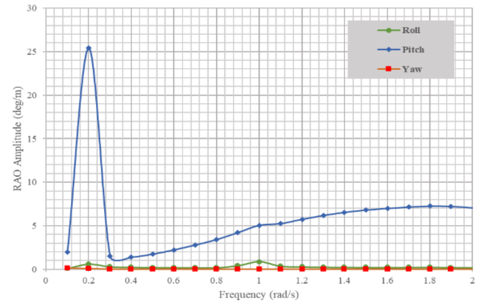


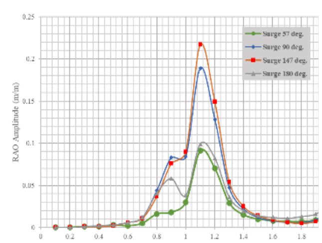
Figure 6. RAO graph rotational motion mode buoy structure free-floating conditions.

Table 14. Maximum RAO for buoy

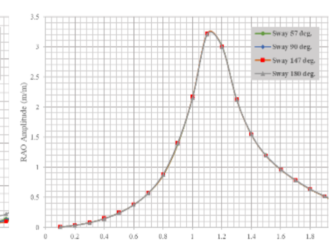
Motion Mode	Maximum RAO
Surge (m/m)	**1.001**
Sway (m/m)	0.019
Heave (m/m)	1.964
Roll (deg/m)	0.845
Pitch (deg/m)	25.403
Yaw (deg/m)	0.106

3.5 Motion Characteristics of Structure in Moored Condition

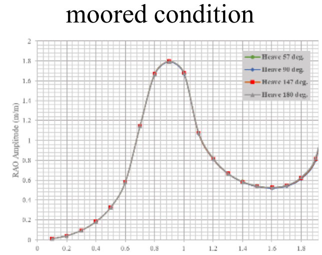
For buoy in moored conditions, the chosen RAO was the maximum loading direction in accordance the scenario of environmental loading in dynamic analysis with the loading direction of inline-L1 (147^0), inline-L2 (57^0), Between line-L1 & L2 (90^0), and Between line-L1 & L4 (180^0). Moored buoy RAO can be seen in the image below:



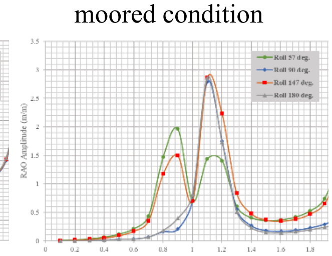
(a) RAO surge motion moored condition



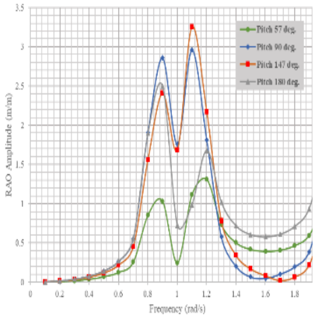
(b) RAO sway motion moored condition



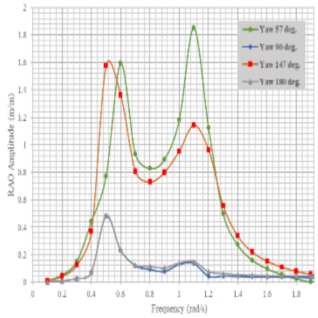
(c) RAO heave motion moored condition



(d) RAO roll motion moored condition



(e) RAO pitch motion moored condition



(f) RAO yaw motion moored condition

Figure 7. RAO graph for moored buoy

Table 15. Maximum RAO for moored buoy

Motion Mode	Direction (degree) 57^0	90^0	147^0	180^0
Surge (m/m)	0.091	0.189	0.217	0.099
Sway (m/m)	3.207	3.207	3.222	3.208
Heave (m/m)	1.792	1.793	1.797	1.794
Roll (deg/m)	1.962	2.79	2.861	2.864
Pitch (deg/m)	1.31	2.959	3.252	2.493
Yaw (deg/m)	1.851	0.482	1.576	0.484

3.6 Mooring Tension Analysis

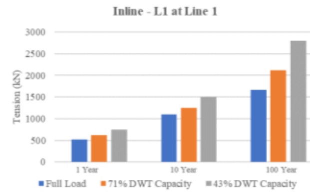
Mooring tension analysis on a buoy in the offloading conditions was done by doing variations on the capacity of each tanker. The maximum tension value that not exceed the appropriate criteria in the API RP2SK for the intact condition is as follows:

$$\text{Safety Factor} = \frac{\text{Minimum Breaking Load (MBL)}}{\text{Maximum Tension}}$$

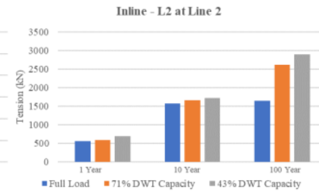
$$1.67 = \frac{6974.773 \text{ kN}}{\text{Maximum Tension}}$$

$$\text{Maximum Tension} = 4176.51 \text{ kN}$$

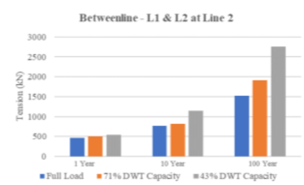
Maximum tension on mooring line during offloading operation moored with 35.000 DWT tanker on each capacity variation for each environmental condition shown in the diagram in Figure 8 below:



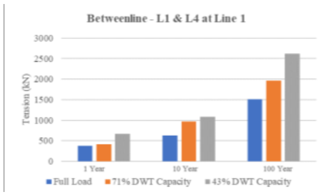
a) Mooring tension diagram for Inline-L1 environmental direction



(b) Mooring tension diagram for Inline-L2 environmental direction



(c) Mooring tension diagram for Between line-L1&L2 environmental direction



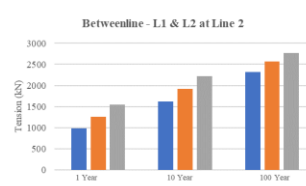
(d) Mooring tension diagram for Between line-L1&L4 environmental direction

Figure 8. Maximum mooring tension diagram for 35.000 DWT during the offloading condition

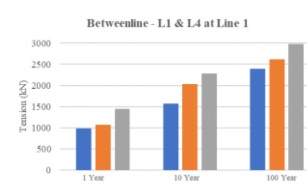
Maximum tension on mooring line during the offloading operation moored with 50.000 DWT tanker on each capacity variation for each environmental condition shown in the diagram in figure 9:

(a) Mooring tension diagram for Inline-L1 environmental direction

(b) Mooring tension diagram for Inline-L2 environmental direction



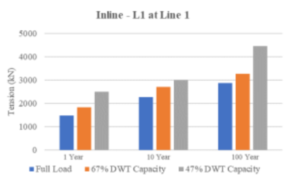
(c) Mooring tension diagram for Between line-L1&L2 environmental direction



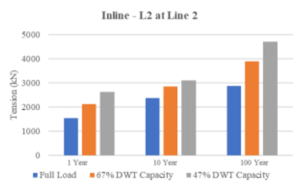
(d) Mooring tension diagram for Between line-L1&L4 environmental direction

Figure 9. Maximum mooring tension diagram for 50.000 DWT during the offloading condition

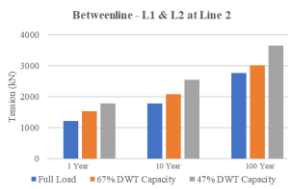
Maximum tension on mooring line during offloading operation moored with 75.000 DWT tanker on each capacity variation shown in diagram on figure 10 below:



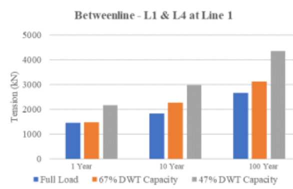
(a) Mooring tension diagram for Inline-L1 environmental direction



(b) Mooring tension diagram for Inline-L2 environmental direction



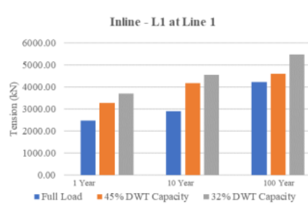
(c) Mooring tension diagram for Between line-L1&L2 environmental direction



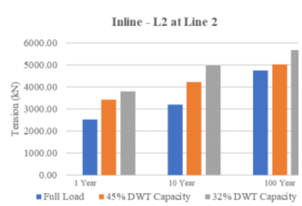
(d) Mooring tension diagram for Between line-L1&L4 environmental direction

Figure 10. Maximum mooring tension diagram for 75.000 DWT during the offloading condition

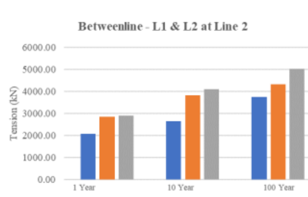
Maximum tension on mooring line during the offloading operation moored with 111.000 DWT tanker on each capacity variation for each environmental condition shown in Figure 11 below:



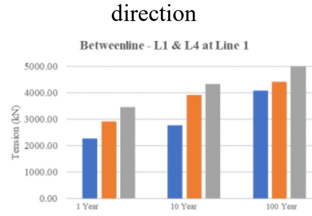
(a) Mooring tension diagram for Inline-L1 environmental direction



(b) Mooring tension diagram for Inline-L2 environmental direction



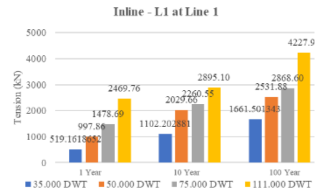
(c) Mooring tension diagram for Between line-L1&L2 environmental direction



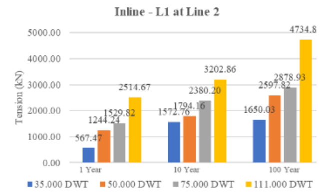
(d) Mooring tension diagram for Between line-L1&L4 environmental direction

Figure 11. Maximum mooring tension diagram for 75.000 DWT during the offloading condition.

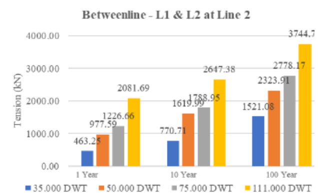
The diagram in Figure 12 below shows tension comparison on the mooring line on different tanker dimensions on full load capacity conditions.



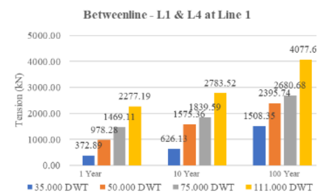
(a) Mooring tension diagram for Inline-L1 environmental direction



(b) Mooring tension diagram for Inline-L2 environmental direction L2



(c) Mooring tension diagram for Between line-L1&L2 environmental direction



(d) Mooring tension diagram for Between line-L1&L4 environmental direction

Figure 12**.** Maximum mooring tension comparison on the mooring line on different tanker dimensions on full load capacity conditions

3.7 Operability Analysis

Operability in mooring buoy was analyzed on the ability to operate a tandem offloading operation with the shuttle tankers. Based on the previous analysis, operability is reviewed on the ability to mooring buoy operations in the 1-year, 10-year, and 100-year environmental conditions that have the safety factor value above from the limit requirement set by API RP2SK which is 1.67. The safety factor of mooring line can be seen in Figure 13-16.

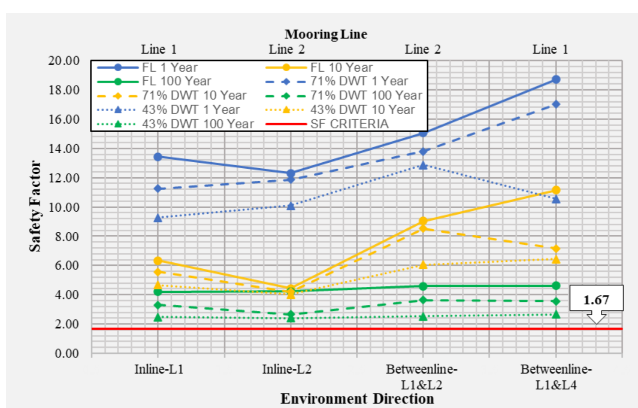


Figure 13. Resume the value of safety factor mooring line at offloading tanker 35.000 DWT

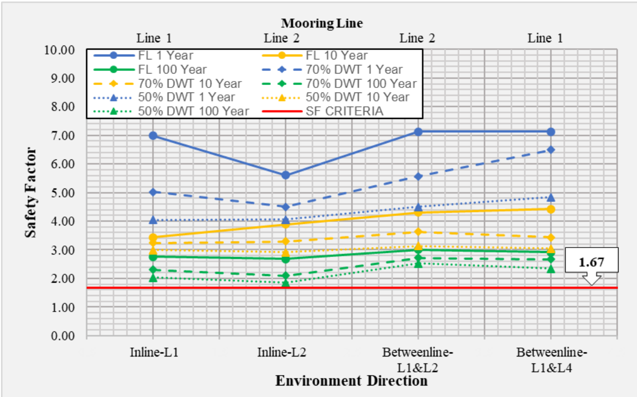


Figure 14. Resume the value of safety factor mooring line at offloading tanker 50.000 DWT

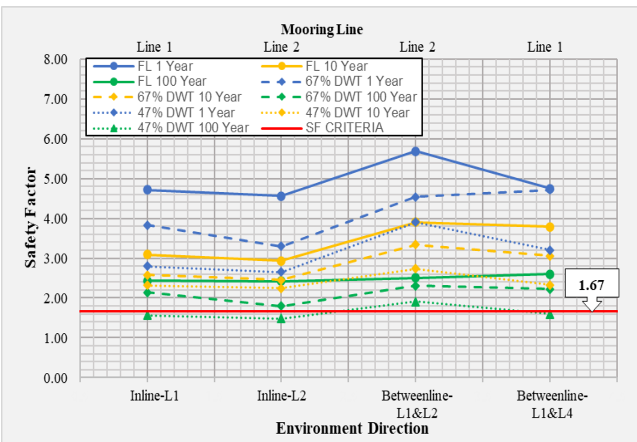


Figure 15. Resume the value of safety factor mooring line at offloading tanker 75.000 DWT

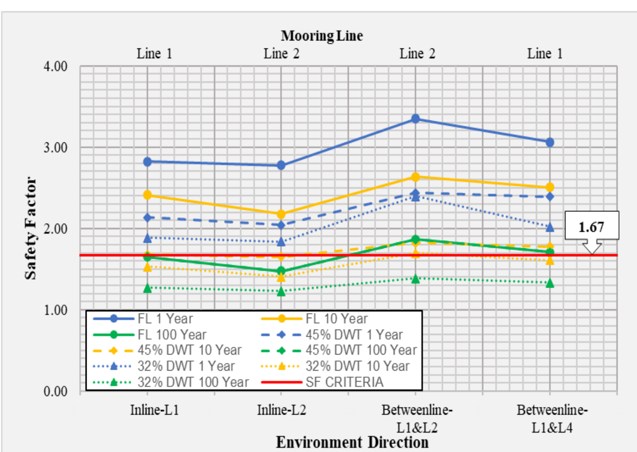


Table 16. Resume the value of safety factor mooring line at offloading tanker 111.000 DWT

Operability that was reviewed based on safety factor resulted above the safety factor of 1.67 in 1-year, 10-year, and 100-year environmental condition for 35.000 DWT and 50.000 DWT in every load capacity. It is also above the safety factor in full load 75.000 DWT and 67% load of 50.000 DWT tankers with the same environmental conditions.

4. CONCLUSIONS

In the present study, the operability of mooring buoy designed for offloading operation with 35.000 DWT tanker was analyzed to be with a bigger capacity of tankers. The main contributions of the present study are listed as follows:

- The motion characteristics of the mooring buoy acquired RAO for the surge motion mode was 0.217 m/m, 3.222 m/m in sway motion mode, 1.797 m/m in heave motion mode, 2,864 deg/m in roll motion mode, 3,252 deg/m in pitch motion mode, and 1,851 deg/m in yaw motion mode.
- Tension on the mooring line increases on tankers with larger dimensions and also increases in lower tanker capacity conditions.
- On 35.000 DWT and 50.000 DWT shuttle tankers with all capacity conditions can fully operate in all environmental conditions. On 75.000 DWT shuttle tanker with full load and 67% DWT capacity can fully operate in all environmental conditions but the 47% DWT capacity can not operate in the 100-year environmental condition with significant wave height 3.31 m for the direction of inline-L1, inline-L2, and between line-L1&L4. On 111.000 DWT shuttle tanker in all capacity conditions can fully operate in 1-year environmental condition with significant wave height 1.48 m.

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