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Configuration Comparison Catenary Spread Mooring Line On The Movement Characteristics Of Fpso Ships Using Numerical Analysis

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Abstract

FPSO (Floating Storage Production and Offloading) is a floating structure that can be used as a location for production, storage or offloading of offshore oil and gas. Therefore, FPSO plays an important role in the exploration of oil fields in the deep sea. When operating, the FPSO will be exposed to environmental loads that can cause it to operate flexibly. To reduce movement response and maintain the FPSO in position, a mooring system is needed. The aim of this research is to analyze the numerical results of this experiment to find RAO (Response Amplitude Operator) free movement (free floating) as well as motion trajectory (surge & sway), motion characteristics, mooring line stress based on variations in the number of ropes used when moored with the direction of loading (heading) from different directions with time domain 250 seconds for each identification. This comparison analysis uses software Boundary Element Method (BEM) with data on FPSO dimensions, type of rope and mooring system, as well as environmental loads that influence the movement of the FPSO structure. The results of the analysis obtained show that in essence the use of the number of mooring lines will greatly influence the movement characteristics, the trajectory/flow of the floating structure and the tension of the mooring ropes. Where, the fewer the number of ropes used, the greater the movement and tension of the resulting rope and vice versa. Usually due to the mass of mooring line which is influenced by the number of ropes not being the same or smaller than displacement FPSO and is also influenced by environmental forces or loads which have repeated patterns over a certain time so that the amount used mooring line must also consider all aspects of the environment in its planning.

Keywords: FPSO, Mooring Line, Motion, RAO

1. Introduction

Until now, the price of crude oil has continued to soar per barrel in recent years. Along with population growth, crude oil consumption also increases. In these circumstances, significant energy sources are needed, especially those from crude oil reserves. Shifting gas and oil production to deep sea environments requires offshore structures and technology that can support exploration in these environments [1]. Offshore floating structures or FPSOs, are one alternative technology and construction that can be used. FPSO (Floating Production Storage and Offloading) is an alternative floating platform that is starting to be widely used in Indonesia due to the increasingly deeper water depth and the conversion of tankers [2].

When operating, a floating structure will experience movement due to receiving loads from the surrounding environment (currents, wind and waves) [3], so a mooring system is needed (mooring system) in floating structures which function as fasteners so that the structure can remain in position and reduce its

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movement so that it can operate and function safely [4]. The movement of the FPSO causes forces to act on the mooring system, where the forces that act are very dependent on the characteristics of the motion (motion characteristic) and vice versa [5]. Large FPSO/FSO vessels can produce high dynamic loads on the mooring ropes, accompanied by cyclical tensile loads during the movement of the ship, causing the mooring ropes to tire in a short time. The cause of excessive movement not only comes from the large forces acting on the ship but also because of the cyclical component of these forces [3].

2. Materials and Methods

This research applies quantitative methods, namely numerical methods, to model and simulate the Agbami FPSO ship software Boundary Element Method (GOOD)and literature studies are also used by looking for supporting books and scientific publications. The main objective is to determine and analyse the free movement of the ship when it is not moored (free floating) and the effect of the number of mooring ropes used on the specified wind, wave, current and water depth conditions. With the development of computer methods and easy access to computer equipment, numerical methods have become a reliable choice for predicting the performance of ships at anchor in recent years. Predicting the performance and load of a mooring system using mathematical models is often based on a number of assumptions to simplify the calculation steps.

The ship model in this test used the Agbami FPSO ship where the ship model was at its highest water draft. The mooring system used is a system spread mooring with profile catenary mooring. Say Catenary actually comes from the formula used to plan the system. Formula Catenary explains a rope moored at both ends, one to the seabed and the other to the FPSO, causing the shape mooring line the slope is the weight. So it forms a stretch mooring line from the floating structure (FPSO) to the anchor (seabed) not tense but tense. In analysing the moorings of the floating structure, three (3) variations of mooring rope configurations were used in the model, namely three ropes, two ropes, and a mixture of the previous two variations with the materials used chain (Studless R4) as well as polyester. The location of the test environment is in the Masela Block with environmental loads including wave, wind and current data, all of which can be seen in the table below. The length of time each model is used for analysis time domain 250 seconds.

Table 1. Main Dimensions of FPSO

Ship data		
Measurment	**Value**	**Units**
LoA	270	m
Height	30.15	m
Beam	48	m
Draft	24	m
Displacement	280676	t
Volume (displaced)	273830.52	m^3

Table 2. Mooring Material Data

Data Mooring Line						
Item	**Description**	**Diameter (m)**	**Length (m)**	**Weight (kg/m)**	**MBL (Kn)**	**EA (Kn)**
Chain on Feirlead	Studless R4	0.1588	140.208	438.9	19563.3	1842397.8
Polyester	Polyester	0.2699	3596.64	12.5	21351.5	256217.6
Chain on Anchor	Studless R4	0.1588	91.44	438.9	19563.3	1842397.8

Table 3. Masela Block Wave Data

Masela Block Wave Distribution Data							
Data		Hs (m)					Total
		0.1-1	1.1-2	2.1-3	3.1-4	4.1-5	
Tp (s)	0.1-2	0	0	0	0	0	0
	2.1-4	0.58	0	0	0	0	0.58
	4.1-6	9.51	4.43	0	0	0	13.94
	6.1-8	5.12	6.9	4.74	0.03	0	16.79
	8.1-10	8.2	3.5	5.6	0.78	0.04	18.12
	10.1-12	10.8	20.8	0.15	0.01	0.01	31.77
	12.1-14	9.3	2.68	0.02	0	0	12
	14.1-16	2.93	2.46	0.04	0	0	5.43
	16.1-18	0.42	0.77	0.03	0	0	1.22
	18.1-20	0.05	0.096	0	0	0	0.146
Total		46.91	41.636	10.58	0.82	0.05	100
Quantitative		46.9	88.5	99.1	99.9	100	

Source: Fugro, 2012.

Table 4. Masela Block Wind and Wave Distribution Data

Masela Block Wind and Current Data	
Parameter	speed (m/s)
Wind	16.91
Current	0.5

Source: Mahdarreza, 2010.

3. Results and Discussion

3.1 Floating Building Motion

A floating object basically has six degrees of freedom (six degrees of freedom) which is divided into two movements, namely three translational movements and three rotational movements. Translational motion; movement in the same direction as the axis (surge : x-axis, sway : y axis, heave : z axis), while rotational motion; motion at an angle to an axis (roll : x-axis, pitch : y axis, yaw : z axis). Where the direction of movement of the floating building is influenced by wave heading (μ) which is the direction of wave propagation and the direction speed of the structure [6].

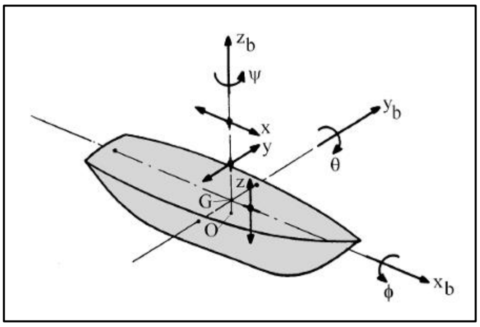


Fig. 1. Floating building movement model [7].

3.2 Numerical Modeling

Structural Modeling of an FPSO (Floating Production Storage and Offloading) created on the app maxsurf where the mooring system model design itself is created using one of the software tools Computer-Aide Design (CAD), namely Autocad and the modeling results are applied to be processed using software Boundary Element Method (BEM). This is to find computational results from data and assumptions that have been processed, starting from hydrostatic data, RAO (Response Amplitude Operator), motion trajectory (surge; sway), mooring line stress, and motion characteristic.

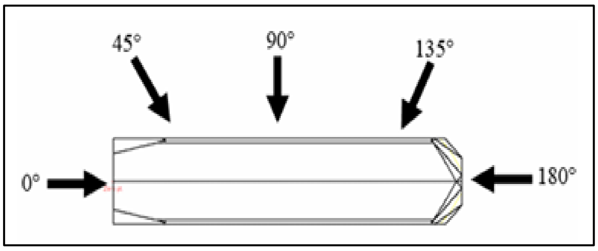


Fig. 2. Direction of loading on the Ansys device [8].

In fig. 2. Direction of loading (heading) that hits the floating structure is in five angles, namely 0° (stern), 45° (stern quartering), 90° (beam), 135° (bow quartering), and 180° (head) [8].

3.3 Hydrostatic

This kind of design will produce data that affects the floating structure. The results obtained in this analysis consider motion heave, roll and pitch from hydrodynamic diffraction where vertical movement (heave, roll, and pitch) as well as horizontal movement (surge ,sway, and yaw) greatly influences the hydrostatic characteristics.

Table 5. Hydrostatic Analysis Results.

Hydrostatic Stiffness						
Centre of Gravity Position :	**X:**	-5.0125027 m	**Y:**	-1.7658e-4 m	**Z:**	0. m
		Z:		**RX:**		**RZ:**
Heave (WITH) :		1,23456e8 N/m		351,84631 N/°		3511209,3 N/°
Roll (RX) :		20159,309 N.m/m		-1.55387e8 N.m/°		979,79968 N.m/°
Pitch (RY) :		2,01177e8 N.m/m		979.79968 N.m/°		1,1366e10 N.m/°
Hydrostatic Displacement Properties						
Actual Volumetric Displacement :		273831,19 m³				
Equivalent Volumetric Displacement :		273831,22 m³				
Centre of Buoyancy Position :	**X:**	-5,0125108 m	**Y:**	-1,7578e-4 m	**Z:**	-11,505103 m
Cut Water Plane Properties						
Cut Water Plane Area :		12282,001 m²				
Small Angle Stability Parameters						
C.O.G. to C.O.B.(BG) :		11,505103 m				
Metacentric Height (GMX/GMY) :		-3,2345209 m		236,46622 m		
COB to Metacentre (BMX/BMY) :		8,2705822 m		247,97131 m		
Restoring Moments/Degree Rotations (MX/MY) :		-2712015,5 N.m/°		1.98267e8 N.m/°		

3.4. RAOs (Response Amplitude Operators)

Response Amplitude Operator (RAO), which is also known as transfer function, is a means of transferring wave forces into the dynamic reactions of structures [9] which serves to describe the response of structures to waves in various frequency ranges (in radians per second). This is a way to understand how waves influence the movement of ocean structures dynamically and the characteristics of these structure movements are represented in graphical form. According to Djatmiko [10], RAO movement responses can be divided into two types, namely:

1. translational movements such as surge, sway, and heave. RAO of this translational movement is a comparison between the

amplitude of the structure's movement and the wave amplitude, which is expressed in equation (1)

$$\mathrm{RAO}(\omega) = \frac{\zeta k0(\omega)}{\zeta 0\ (\omega)} \qquad (1)$$

Information:

ζk0 (ω) = amplitudo struktur (m)

ζ0 (ω) = amplitudo gelombang (m)

2. In the context of rotational movements, e.g roll, pitch, and yaw, RAO of rotational motion describes the comparison between the amplitude of the structure's movement and the inclination angle of the wave. It is calculated by multiplying the wave number by the amplitude of the wave impinging on the structure, as described in equation (2).

$$\mathrm{RAO}(\omega) = \frac{\zeta k0(\omega)}{\mathrm{kw}\ \zeta 0\ (\omega)} = \frac{\zeta k0(\omega)}{(\omega^2/g)\zeta 0} \qquad (2)$$

Table 6. RAO maximum value

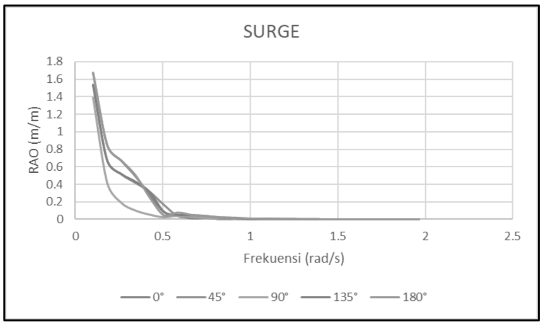
Maximum RAOs (Response Amplitude Operators)

Translation

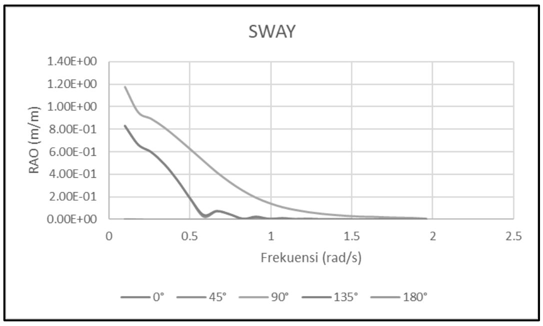
Degrees	Frequency (rad/s)	x	Degrees	Frequency (rad/s)	and	Degrees	Frequency (rad/s)	With
180	0.1	1.6705256	**180**	0.1	2.33E-05	**180**	0.1	9.96E-01
135	0.1	1.5373998	**135**	0.1	8.28E-01	**135**	0.1	9.98E-01
90	0.1	1.3903483	**90**	0.1	1.7E+00	**90**	0.505	2.19E+00
45	0.1	1.5369234	**45**	0.1	8.28E-01	**45**	0.1	9.98E-01
0	0.1	1.6699388	**0**	0.1	2.37E-05	**0**	0.1	9.96E-01

Rotation

Degrees	Frequency (rad/s)	Rx	Degrees	Frequency (rad/s)	Ry	Degrees	Frequency (rad/s)	Rz
180	0.424	1.84E-05	**180**	0.424	9.02E-01	**180**	0.505	7.97E-06
135	0.424	1.96E-01	**135**	0.505	1.18E+00	**135**	0.424	2.98E-01
90	0.505	2.96E-01	**90**	0.424	1.49E-02	**90**	0.829	9.41E-03
45	0.424	1.95E-01	**45**	0.505	1.14E+00	**45**	0.424	2.98E-01
0	0.262	1.65E-05	**0**	0.424	8.68E-01	**0**	0.99	6.78E-06



(a)



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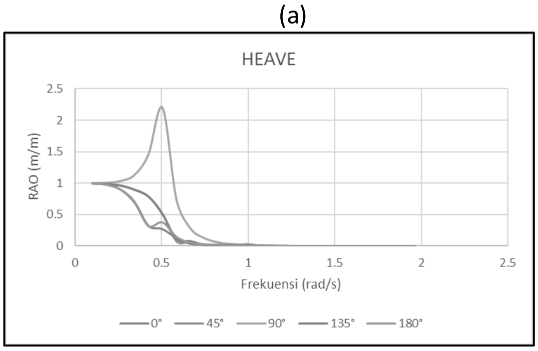

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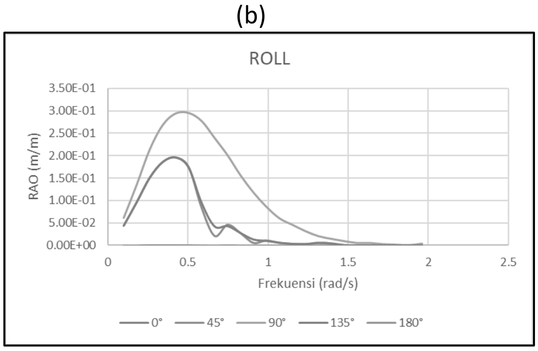

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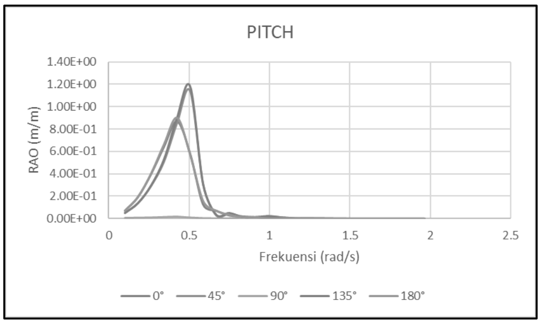
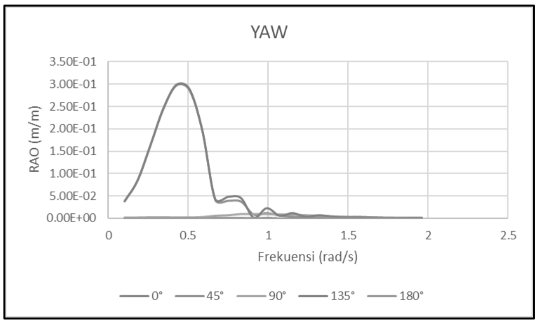




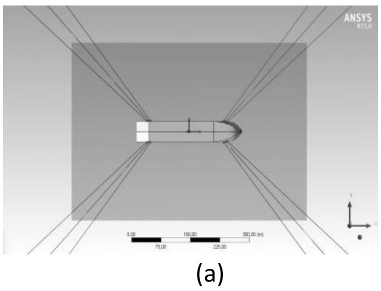
(e) (f)

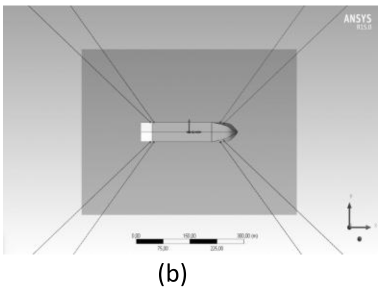
Fig. 3. Graphics RAO free floating; surge axis-x (a); sway axis-y (b); heave axis-z (c); roll axis-Rx (d); pitch axis-Ry (e); yaw axis-Rz (f).

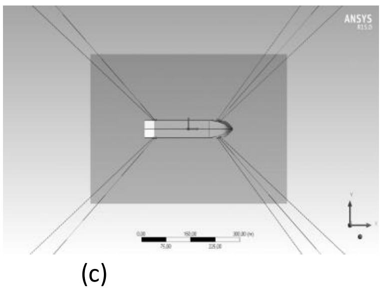
RAO is the ratio between the amplitude of the motion response and the amplitude of the wave with the direction of loading [11] as shown in Fig. 2. Based on the results obtained in this analysis, it shows that when the direction of loading (heading) in translational motion, namely movement surge largest due to loading from the 180 direction° (head) with a value of 1.6705256 with a frequency of 0.1 rad/sec; movement sway Also heave occurs at 90° loading (beam) with values sequentially sway 11728 at a frequency of 0.1 rad/sec and heave 2.1940863 with a frequency of 0.505 rad/sec; for rotational movement itself is in the direction of 90° (beam) value2.96E-01 occurs at a frequency of 0.505 rad/sec in motion roll; and for pitch and yaw The largest loading occurs in the 135 direction° (bow quartering) with values in sequential order of pitch1.1835219 at a frequency of 0.505 rad/sec and yaw 0.2977116 at a frequency of 0.424 rad/sec.

3.5 Mooring System

The mooring system usually has 8 to 16 mooring strips which consist of chains, steel wire ropes and polyester that connect from fairlead which is on the side of the ship to the seabed at anchor [6]. Mooring system the commonly used ones are spread mooring with profile catenary mooring. Where, when on the seabed, the mooring position is horizontal, so that on catenary mooring in this case, the anchor only carries horizontal loads. On catenary mooring, the restoring force is produced by the weight of the mooring rope itself [9]. The floating structure model used three (4) variations of the mooring rope configuration in the model, namely three ropes, two ropes, and a mixture of the previous two variations with the materials used chain (Studless R4) with the degree of inclination of string A on the right front side (A1: 315°, A2: 321°, A3: 310°) ; B front left side (B1: 45°, B2: 39°, B3: 50°) ; C rear left side (C1: 135°, C2: 130°, C3: 141°) ; D back right side (D1: 225°, D2: 219°, D3: 230°) where number 1 is the middle of the rope, rope 2 is the left side of the middle rope and number 3 is the right side of the middle rope. This rope angle applies to all three rope variations.





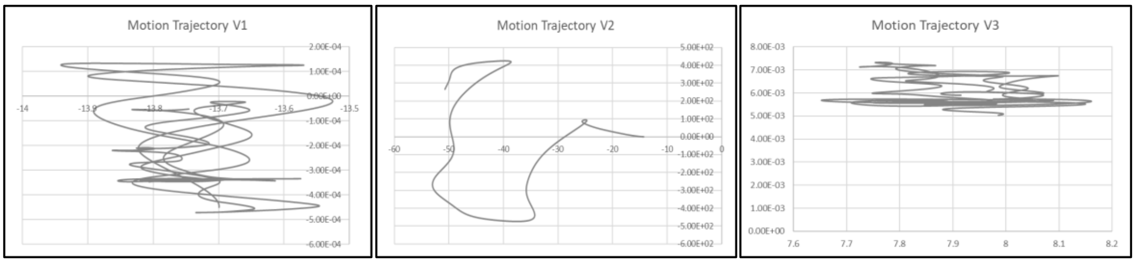


(a) (b) (c)

Fig. 4. Variation in the number of ropes; mooring model 4x2 (a); mooring model 4x2 (b); mooring models 2x2 and 2x3 (c).

3.6 Motion Trajectory

Motion Trajectory in a floating building such as an FPSO, it is a movement path or trajectory that the floating building follows when it experiences movement influenced by the marine environment. Where this path describes the physical movement of buildings in response to waves, currents and wind in the marine environment. In this context there are two movements that can be monitored, namely surge (x axis) which moves back and forth parallel to the direction of waves or wind coming from the front or rear of the structure and sway (y axis) that moves from side to side.



(a) (b) (c)

Fig. 5. Chart motion trajectory (surge and sway) on the 4x2 mooring model (a); 4x2 mooring model (b); 2x2 and 2x3 mooring models (c).

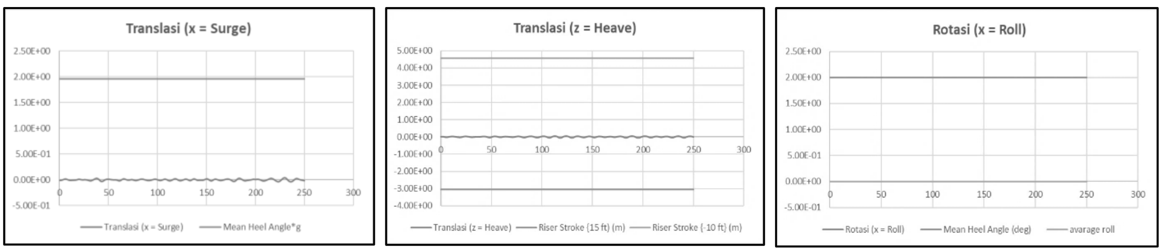
Table 7. Maximum and minimum values motion trajectory

Motion	Variation in Number of Ropes					
	4x3 variation		4x2 variation		2x2 and 2x3 variations	
	Surge (x)	Sway (y)	Surge (x)	Sway (y)	Surge (x)	Sway (y)
Maximum	-13.525743	0.0001337	-14.288152	-14.288152	8.1611195	0.0073286
Minimum	-13.941063	-0.000472	-53.008564	-53.008564	7.33E-03	-1.48E+00

This graph shows that there are differences in ship movements from the model variations used with the same movements repeated in the first and third variations. However, the second variation is very different from the previous two variations, this is because time domain The 250 seconds used allow for a far shift from the starting point where the ship is moored where a Large FPSO vessels can generate high dynamic stresses on mooring lines, especially when affected by environmental loads. This can cause the mooring rope to experience high tension in a short period of time. Apart from the large forces acting on the ship, excessive movement can also be caused by the cyclical component of these forces. A force or load that has a repeating or repeating pattern over a certain period of time. This means that the force or load does not only vary randomly or is constant, but has recurring properties that can be found in certain cycles [3].

3.7 Motion Characteristic

Motion characteristic (motion characteristics) of a floating building structure is the movement response of the structure to various external forces in the conditions of the marine environment around its location. Where this section covers pitch, roll, heave, sway, surge.



(a) (b) (c)

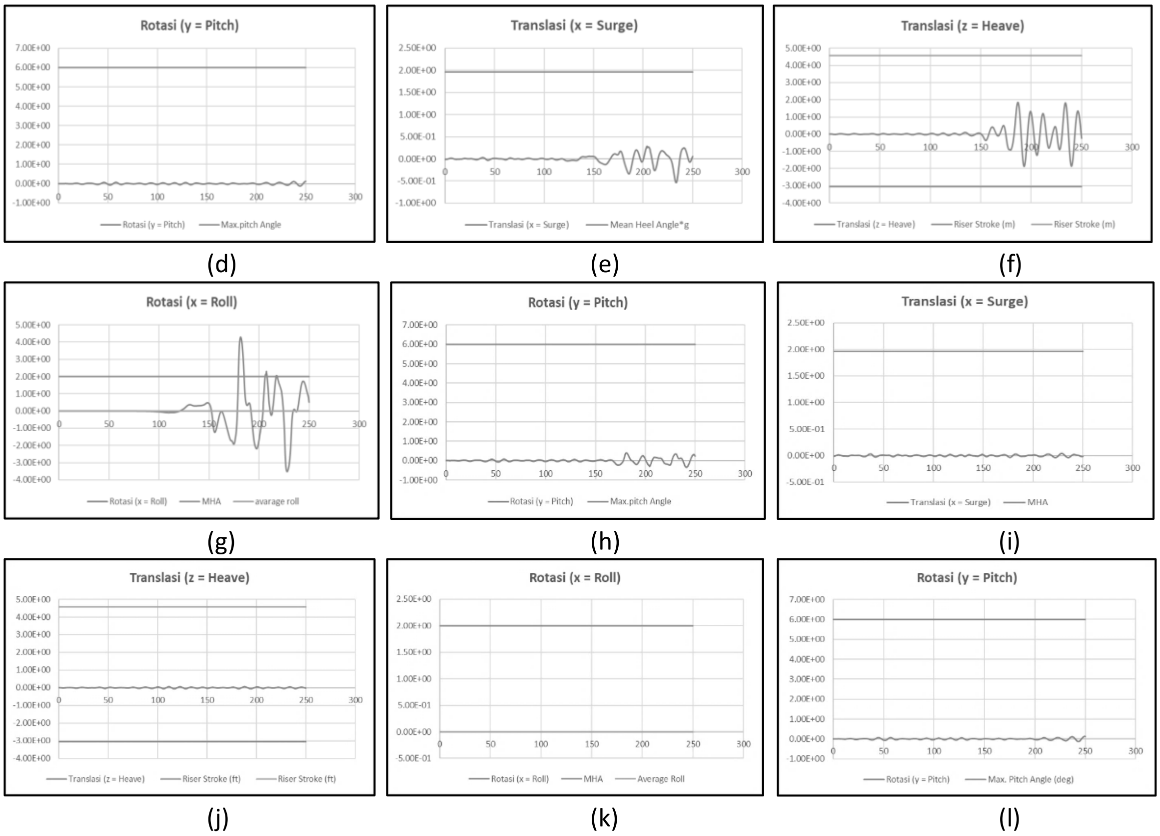


Fig. 6. Chart motion characteristic on the 4x2 mooring model (a-d); 4x2 mooring model (e-h); 4x2 mooring model (i-l).

On this matter output from the results obtained, a graph was created to display a comparison of each model with the number of mooring ropes used and meeting the characteristic criteria for ship movement. Where if the movement of the ship exceeds the criteria limits that have been determined at the mooring time then this does not meet the desired model results.

Table 8. Movement characteristic values

Criteria	Well Production
Mean Roll [degree]	2
Max. Pitch [degree]	6
Surge Acceleration [g {gravity}]:	0,20
Heave Motion [feet]	15
	-10

3.8 Mooring Line Stress

Rope tension is the result of a comparison between the amplitude of the tension on the mooring rope and the wave amplitude. In mooring systems catenary mooring, the rope tension tends to be high compared to the system taut mooring because there is greater movement, and increasing the length of the mooring rope increases the load force acting on the rope. Increasing the length of the rope also causes movement surge, heave, and pitch larger, and also the natural frequency of these three movements decreases. This is caused by a decrease in the stiffness of the mooring rope as the length of the rope increases, which also increases the mass of the rope. In addition, longer mooring ropes cause greater tension in the rope, because greater movement and increased mass of the rope contribute to increased tension in the rope [9]. The use of the number of ropes can be due to the high tension exerted by external loads, such as large waves or strong winds, the stronger the mooring rope is needed to withstand this tension. As tension increases, additional mooring lines are often required to ensure that the mooring system can handle the pressure.

$$\sigma = \frac{F}{A} \qquad (3)\ [12]$$

Information:

σ = tension (N/m^2)

A = cross-sectional area (m^2)

F = disance (N)

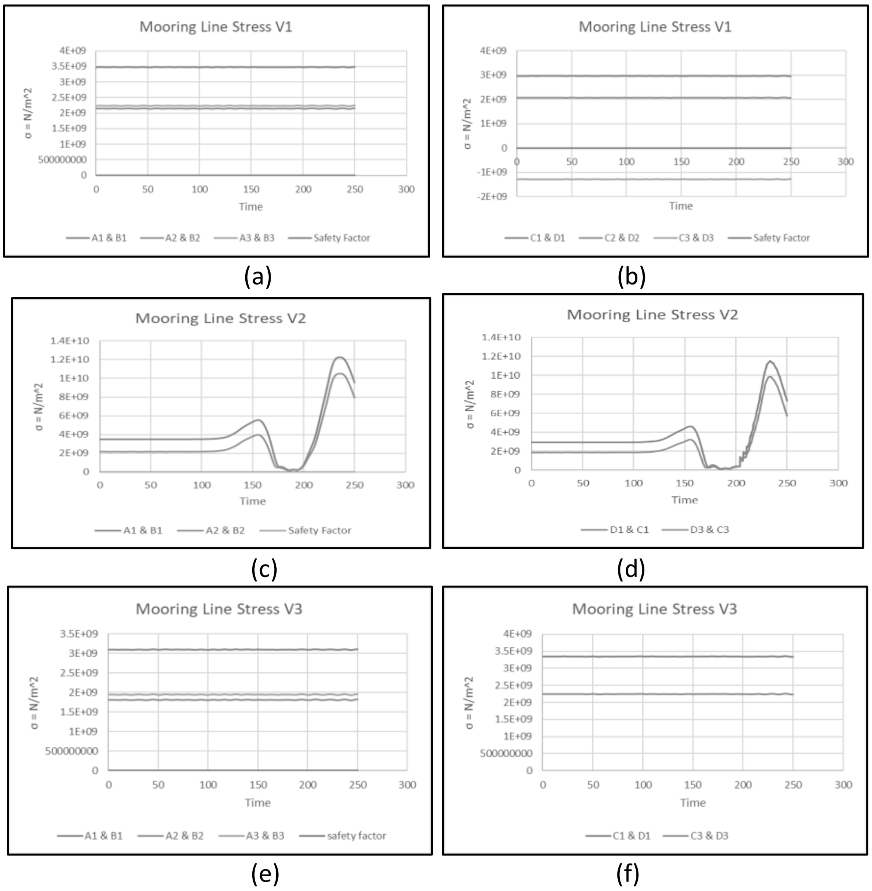


Fig. 7. Chart mooring line stress on the 4x2 mooring model front (a) rear (b); mooring model 4x2 front (c) rear (d); mooring model 4x2 front (e) rear (f).

This graph shows the formation of the increase in rope tension in 250 seconds with the safety factor as the relationship between the carrying capacity of the structure and the applied load. The safety factor is used to measure the robustness of a design [12] and/or the tension limit of the mooring ropes on each ship. Of all the mooring ropes, only the front and rear on each side are displayed, because the values are generated from computational results where the values taken are representative of each position of the mooring ropes on the other side of the ship.

Table 9. Mark Safety factor

Condition	Safety Factor
ULS	1,67
IF	1,25

Source: API 2005 [13]

$$\text{Safety Factor} = \frac{\text{Minimum Breaking Load}}{\text{Maximum Tension}} \qquad (3)$$

Source: API RP 2SK 2nd edition [13]

5. Conclusions

From the results of the analysis conducted on the effect of the number of mooring lines on the mooring system of the FPSO vessel, it was found that the use of a larger number of mooring lines resulted in a result where the motion characteristics experienced by the floating building structure were closely related to the motion of the floating structure, compared to the use of a smaller number of mooring lines. The use of a larger number of mooring lines also tends to produce more stable motions and experience less extreme movements due to environmental loading conditions. Therefore, the use of the number of mooring lines should take into account all environmental aspects in the design.

From the results of the analysis that has been carried out, the effect of the number of ropes on the ship's mooring system is, with three variations in the use of the number of ropes, namely the 4x2 mooring model (a); mooring model 4x2 (b); mixed mooring model 2x2 and 2x3 (c). In the first and third variations, it can be seen that using a large number of ropes produces a result where the movement characteristics experienced by the floating building structure are well anchored starting from the movement of the floating structure rather than in the second variation where the resulting movement is shifted far from the starting point. Basically, the use of the number of ropes will affect the amplitude of the FPSO movement in each six degrees of freedom movement, the number of ropes will be more stable and experience less extreme movement (horizontal and vertical displacement) due to environmental loading conditions, the use of the number of mooring ropes must also take into account all environmental aspects in the design.

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