**International Journal of Advances in Engineering and Management (IJAEM)**
**Volume 4, Issue 10 Oct. 2022, pp: 1113-1125 www.ijaem.net ISSN: 2395-5252**

# Comparative Analysis of Floating Storage and Offloading (FSO) Vessel Station Keeping, Using Taut and Catenary Mooring Arrangement

Maxwell, Enebeli, C. U. Orji, Dick, I. F and Engr. K.T. Johnson

*Marine Engineering Department, Rivers State University, Port Harcourt, Rivers State Nigeria.*
*Corresponding Author: Enebeli Maxwell*

Date of Submission: 15-10-2022 Date of Acceptance: 31-10-2022

**ABSTRACT**: This work carried out comparative analysis of station keeping capabilities between catenary and taut mooring arrangement for a FSO vessel in the Gulf of Guinea in terms of orientation ability, dynamic performance and effective design cost. ORCAFLEX computer software was employed with input of the FSO ship particulars to simulate and analyse catenary and taut -moored FSO vessel dynamic response at a depth of 45 meters. Broad based results showed that the surge, sway, roll, pitch, heave and the yaw motion responses of the FSO vessel are larger for catenary mooring system than the taut mooring system. The surge, sway, heave, roll and yaw motions responses for the FSO catenary mooring system were 137.5m, 13.15m, 5.53m, 5.92$^o$, 2.46$^o$ and 3.17$^o$ respectively while the surge, sway, heave, roll and yaw motions responses for the FSO taut mooring system were 126.61m, 5.7m, 2.36m, 2.71$^o$, 1.90$^o$ and 2.04$^o$ respectively. The phenomenon that the FSO vessel motion response value for catenary mooring system is larger than that of taut mooring system explains that the former is weaker than the latter in orientation ability. The dynamic tension for three sections of catenary mooring line1 is 306.4KN for the top chain dynamic tension, 280.8KN for the intermediate steel wire dynamic tension and 249.6KN for the bottom chain dynamic tension, which were larger than that of taut mooring line1 with 155.4KN for the top chain dynamic tension, 151.8KN for the intermediate polyester rope dynamic tension and 141.6KN for the bottom chain dynamic tension. This shows that taut mooring system guarantees positioning capability and bears smaller strength of the mooring system at the same time. From the results of the cost analysis, the cost of designing catenary mooring system was found to be~~N~~5, 350,000 while the cost of the taut mooring system was ~~N~~2, 775,000. Again, this showed that the taut mooring system is 48% more cost efficient than the catenary mooring system for the FSO vessel. Hence,it is suggested to adoptthe taut mooring system for the offshore environment considered for full operational benefit.

**KEYWORDS:** Response Amplitude Operator, seakeeping, OrcaFlex, Mooring Lines, Frequencies Domain and Time Domain.

## I. INTRODUCTION

Mooring systems are complex systems designed to maintain the desired position of a floating offshore vessel, whether docked or at sea as such vessels can be affected by naturally generated forces and reaction forces from the marine environment such as wind, current and tides (Browne, 2015). Under the influence of these external forces, the ship will respond in 6 degrees of freedom (6-DOF) of motion; three translational such as: heave, pitch, sway, and the other three, rotational such as; roll, yaw and sway. In addition, it will also be affected by passing ships. Offshore vessels and structures are typically moored with 8-16 mooring lines and consist of heavy chain, steel wire and/or polyester rope that are connected to an anchor (API RP 2SK, 2005). Mooring systems are considered critical to vessel and crew safety as they are required to providestability against vessel dynamics while also ensuring allowable excursion (Liu & He, 2006; Yu et al., 2013).

To design such a mooring system that can withstand these dynamic loads, the total load on the entire system must first be determined, and the dynamics responses of the vessel based on the six degrees of freedom can then be computed. The mooring typesfor offshore vessels mainly include single point turret mooring, multi-point spread mooring and dynamic positioning (Li et al., 2010). From the current application situation, turret moored mode is most widely used and more suitable for deep water and various environmental conditions. The inner turret tower mooring device generally located at stem consist of two major categories based on their configurations. The first category, most commonly preferred in shallow water, is the catenary mooring system (Duke et al., 2019; Sun et al., 2014; Patel & Brown, 2007). It derived its name from the shape of the freely hanging line from the vessel and so, changes shape due to vessel motions. The weight of the chain provides a restoring force against the motions of the structure and increases as water depth increases thus, reducing the working payload of the vessel. Consequently, conventional catenary systems become less and less economical with increasing water depth. For this reason, a different method has been developed, called taut-leg mooring system (You & Wang, 2009; Johnsen, 1999).

In the taut-leg mooring system, the lines are connected to the floating structures and progress in a fairly straight line to the bottom. This is only possible with light lines therefore modern polyester lines are needed to achieve this. These lines have large axial resistances and good fatigue properties. When the vessel drifts horizontally with wind or current, the lines stretch and set up opposing forces. The lines usually come in at 30 to 45 degrees angle on the seabed where they meet the anchor, which is loaded vertically (Johnsen, 1999).

In this work, the cost efficiency, the ultimate mooring line tension and vessel offset station-keeping characteristics of the catenary and taut mooring system of an FSO was analysed and compared. The analytical methods for estimating ultimate mooring line tension and vessel offset can be divided into frequency domain (FD) methods and time domain (TD) methods (Baoji& Yuhang, 2020). However, this study employed the TD methods with all non-linearities in the dynamic system (added mass forces, wave drift damping forces, viscous forces, restoring forces, mooring line damping forces and stiffness) and in the excitation taken into account. The environmental forces acting on the mooring lines of the mooring systems were also analysed. The TD simulations were analysed using relevant statistical methods in order to establish a reliable estimate of the characteristic load effect on the mooring lines of the catenary and taut mooring system of the FSO.

## Catenary Anchor Leg Mooring System

The catenary mooring system shown in figures 1 and 2below is the most commonly used system in shallow water of depth less than 1500m. Figure 2 typically shows Catenary system with associated environmental forces which the system must withstand to maintain vessel position.From these figures, the mooring lines are seen to arrive at the seabed horizontally where they are connected to the anchor point that resist only horizontal loads.Asnoted earlier, the prohibitive weight of chain as water depth increases, makes for synthetic ropes as good drop-ins for this system and so makes it becomes more and more uneconomical and unsuitable at greater water depths (Duke et al., 2019).

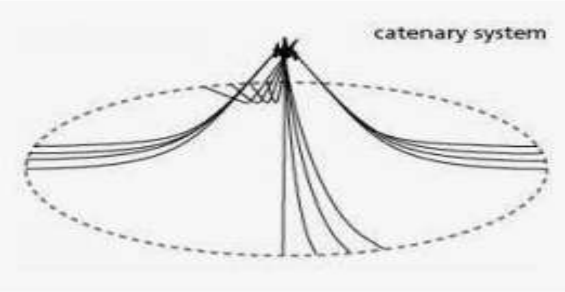

**Figure 1: Typical Catenary Mooring Layout (Patel & Brown, 2007).**

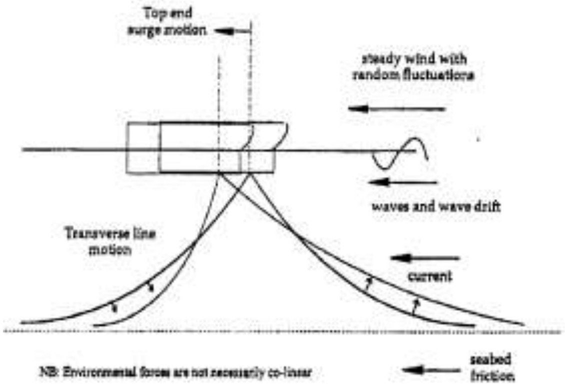

Figure 2: Environmental Forces on a Moored Vessel (Inegiyemiema et al., 2014)

**Taut Leg Mooring System**

In a taut leg mooring system as shown in figure 3 below, the pre-tensioned mooring lines arrive under an angel at the seabed. Typically, the angle between the line and the seabed is between 30 and 40 degrees (Del Vecchio, 1996). The anchor points in a taut leg mooring system have to be capable of withstanding horizontal and vertical forces. In a taut leg mooring, the restoring forces are generated by the elasticity of the mooring line made of synthetic polymeric ropes. Thus, line tensions are heightened at the fairlead as vertical load get enlarged on the vessel when the line is lifted from the sea bottom (Johnsen, 1999).

Figure 3: Typical Taut Leg Mooring Layout (You & Wang, 2009)

## II. MATERIALS AND METHODS

The materials used in this work are the relevant ship principal data needed for the comparative analysis of station-keeping for the considered mooring systemsnamely; taut and catenary mooring arrangement for an FSO vessel in sea waves, which include ship dimensions (like length, beam, depth and draft) and their proportions and displacement). The design and analysis conducted in this study used ORCAFLEX, a numericalhydrodynamic computer tool after the FSO vessel was modelled in a computer aided design (CAD) software. The JONSWAP wave spectrum was used to model the local wind sea wave for the simulation in ORCAFLEX. Starting with a static analysis as a necessary input to the dynamic analysis, the dynamic characteristics for both mooring systems were compared in the six (6) degrees of freedom of vessel motion.

**Analytical Development**

The spectral density function of ship response is equal to the product of the spectral density function of the waves and the response amplitude operator. For roll motion:

`

$$S_{\phi}(\omega_e) = S_{\zeta}(\omega_e).\left|H(\omega_e)\right|^2 \qquad (1)$$

Where:

$S_{\phi}(\omega_e) =$ density function of wave spectrum [ft$^2$ sec]

$S_{\zeta}(\omega_e) =$ spectral density function of ship response for rolling [deg$^2$.sec]

$\left|H(\omega_e)\right|^2 =$ response amplitude operator (RAO)

a. For rolling motion, the response amplitude operator (RAO) is given by:

$$RAO = \left(\frac{\phi_a}{\zeta}\right)^2 \left[\frac{\deg^2}{ft^2}\right] \qquad (2)$$

b. For pitching motion, the response amplitude operator (RAO) is given by:

$$RAO = \left(\frac{\theta_a}{\zeta}\right)^2 \left[\frac{\deg^2}{ft^2}\right] \tag{3}$$

c. For heaving motion, the response amplitude operator (RAO) is given by:

$$RAO = \left(\frac{z_a}{\zeta}\right)^2 \left[\frac{ft^2}{ft^2}\right] \tag{4}$$

d. For relative bow motion, the response amplitude operator (RAO) is given by:

$$RAO = \left(\frac{s_a}{\zeta}\right)^2 \left[\frac{ft^2}{ft^2}\right] \tag{5}$$

Etc.

Finally, the area under the motion amplitude spectrum is determined in order to obtain the necessary motion characteristics.

**JONSWAP Spectrum**

This is an extensive wave spectrum used to measure wind-generated seas with limited fetch wherein, wind speed and fetch length are inputs to the formulation. From the analysis of the measured wave spectra, a JONSWAP wave spectral formulation was derived. It is given as a function of frequency f in Hz expressed as:

$$S(f) = \alpha \frac{g^2}{(2\pi)^4} \frac{1}{f^5} \exp\left\{-1.25\left(\frac{f_m}{f}\right)^4\right\} x\ \gamma^{\exp\left\{\frac{-(f-f_m)^2}{2(\sigma f_m)^2}\right\}} \tag{6}$$

Where:

γ= peak shape parameter, 3.30 as an average

α= $0.076\left(\bar{x}\right)^{-0.22}$

σ= 0.07 for $f \le f_m$, and 0.09 for $f \succ f_m$

$f_m$= $3.5\left(\frac{g}{\bar{U}}\right)\left(\bar{x}\right)^{-0.33}$

$\bar{x}$ = dimensionless fetch = $\frac{gx}{\bar{U}^2}$

x= fetch length (Km)

$\bar{U}$ = mean wind speed (m/sec)

It should be noted that the peak-shape parameter γ obtained from the analysis of the original data varies approximately from 1 to 6, even for a constant wind speed. It is actually a random variable which is normally distributed with mean 3.30 and variance 0.62. Hence, it is possible to generate a family of spectra for various γ values with their weighting factors based on the probability distribution of γ.

Noting that equation (6) is given as a function of wind speed,it is very convenient in practice if the spectrum is presented in terms of significant wave height. Hence, a series of computations was carried out on equation (6) for various combinations of fetch and wind speed, and the following relationship was derived:

$$\bar{U} = kx^{-0.615} . H_S^{1.08} \tag{7}$$

Where:

k = 83.7 for γ = 3.30

Hs = significant wave height (meters)

Using equations (6) and (7), the JONSWAP spectrum can be obtained for a specified sea severity and fetch length. The relevant equations include Newton's second law of motion and Morrison's equation.

**Catenary Equation**

Mooring systems of vessels take the simple catenary shape. This is mathematically expressed in equation 11 as:

$$y = \frac{H}{w}\left[\cosh\left(w\frac{x}{H}\right) - 1\right] \tag{11}$$

Where:

w = weight per unit length

H = Horizontal component of tension.

Free Body Diagram (FBD) of the vessel under moored conditions:

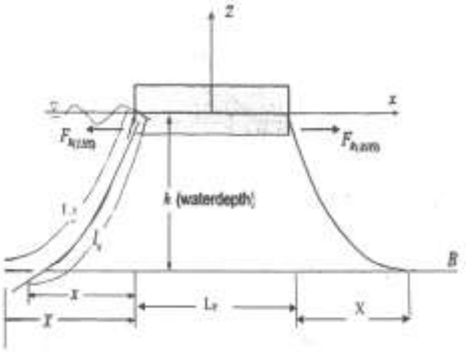

**Figure 4: Free Body Diagram of Vessel Catenary Mooring Lines**

### Distance between anchor A and B

From the geometry of the free body diagram above, the distance is (2x + Lp) m.

(12)

Using the expression,

$$X - x \quad = \quad L - L$$

$$X \quad = \quad L - L_S + x \tag{13}$$

Where:

$$L_S^2 \quad = \quad h^2 + 2ha \tag{13.1}$$

And

$$a \quad = \quad \frac{T_H}{W} \tag{14}$$

The suspended length of mooring line is given by:

$$L_s \quad = \quad a\mathrm{Sinh}\left(\frac{x}{a}\right) \tag{15}$$

### Line Tension at the Vessel

Tension at the top

$$T \quad = \quad W\frac{\left(L_S^2 + h^2\right)}{2h} \tag{16}$$

$$T \quad = \quad \sqrt{T_H^2 + T_Z^2} \tag{17}$$

And at the maximum displacement

$$T_{\max} \quad = \quad T_H + W_h \tag{18}$$

Where:

$T_H$ = Horizontal component of tension

$T_Z$ = Vertical component of tension

### Minimum Limit Length of Mooring Line

The minimum limit length of mooring line is given by:

$$L_{\min} \quad = \quad h\sqrt{2\frac{T\max}{Wh}} \quad - \quad 1 \tag{19}$$

Where:

h = Height of Water depth

### Computer Aided Modelling of the Mooring Systems

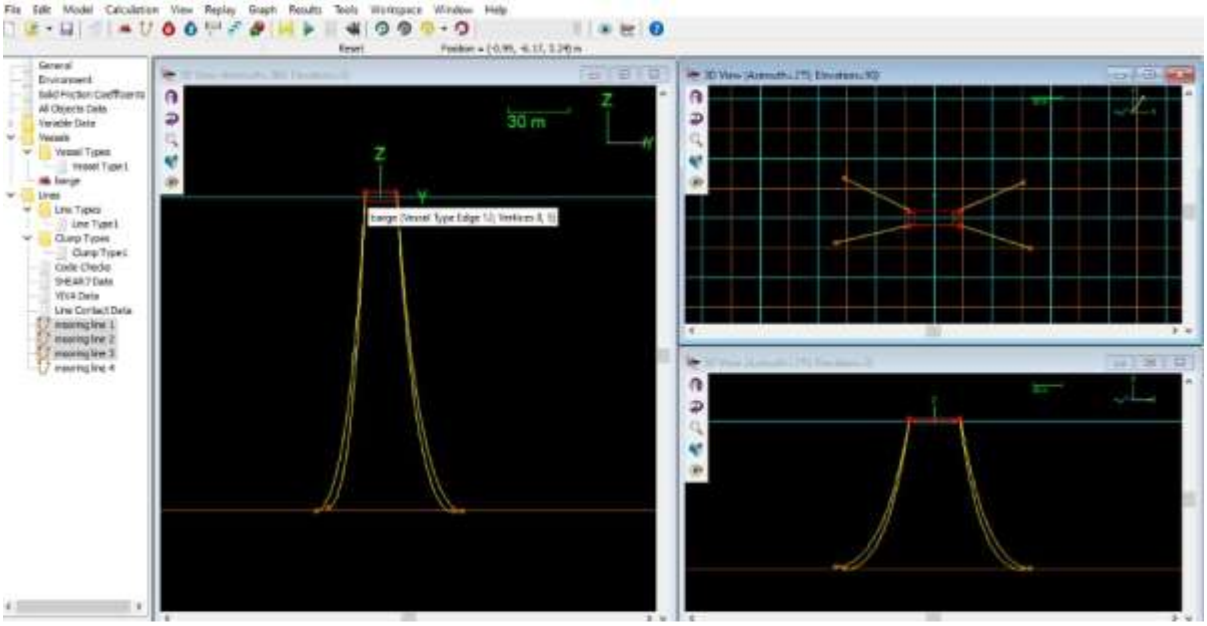

Figure 5: FSO Vessel Catenary Mooring System Design in ORCAFLEX

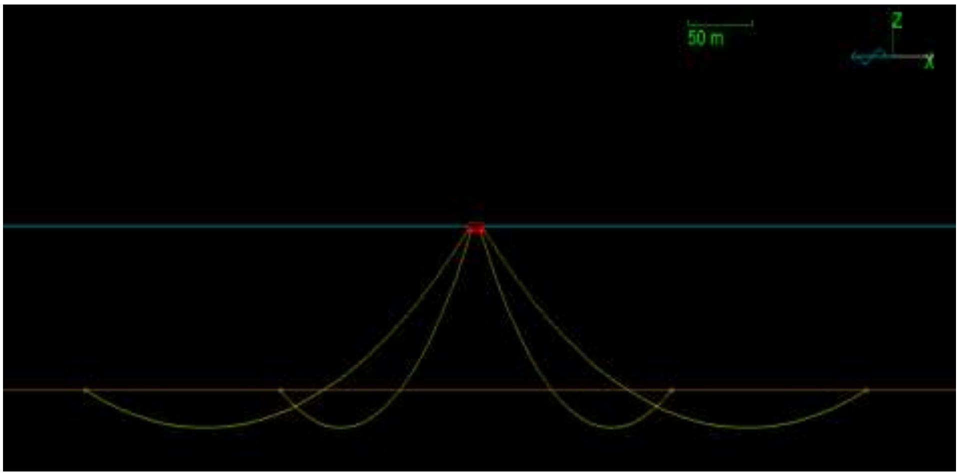

Figure 6: FSO Vessel Catenary Mooring System Design in ORCAFLEX

### Dynamic Analysis of the FSO Vessel's Mooring System

This analysis showed the dynamic movement of the vessel in the various degrees of freedom (heave, surge, sway, yaw, roll and pitch). It also analysed the mooring systems effectiveness operating in sea waves.

## III. RESULTS AND DISCUSSIONS

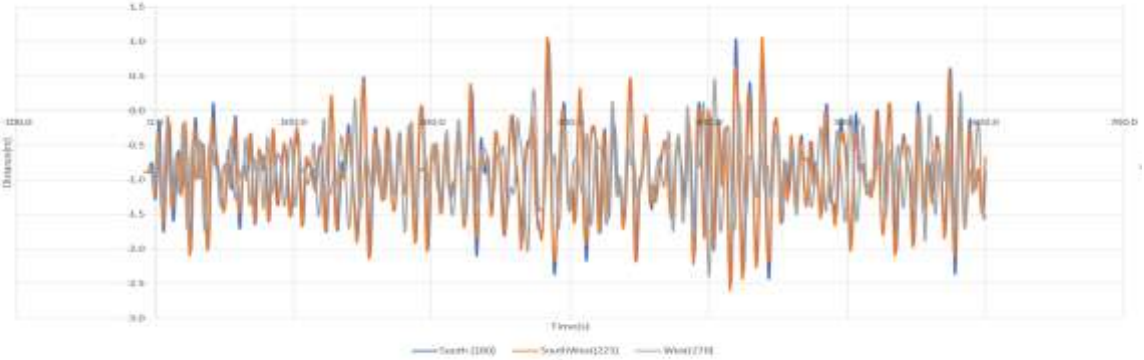

Figure 7: Catenary Configuration Heave offset of the FSO Vessel time history

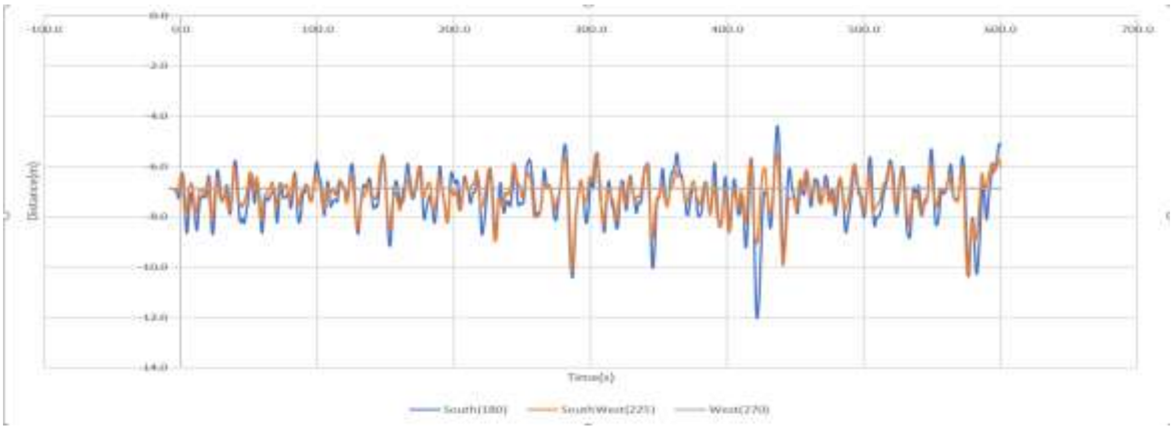

Figure 8: Catenary Configuration Surge offset of the FSO Vessel time history

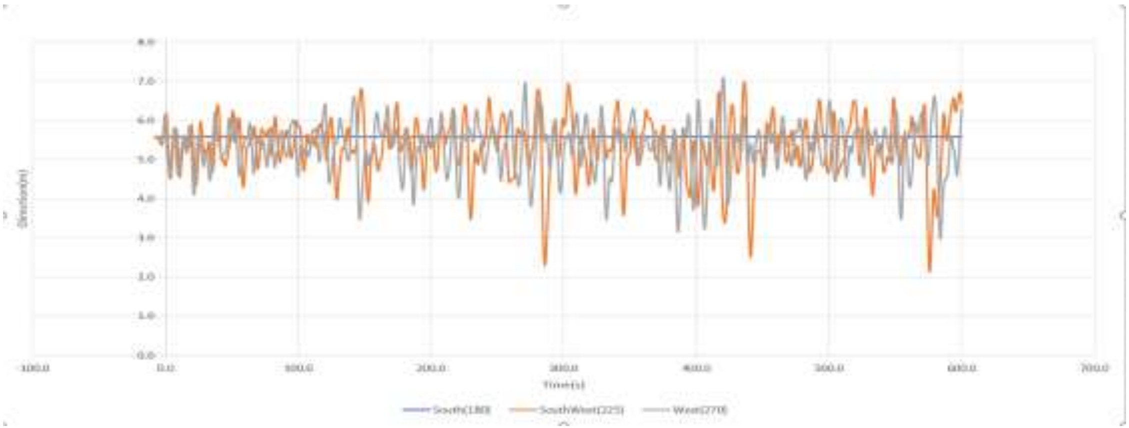

Figure 9: Catenary Configuration Sway offset of the FSO vessel time history

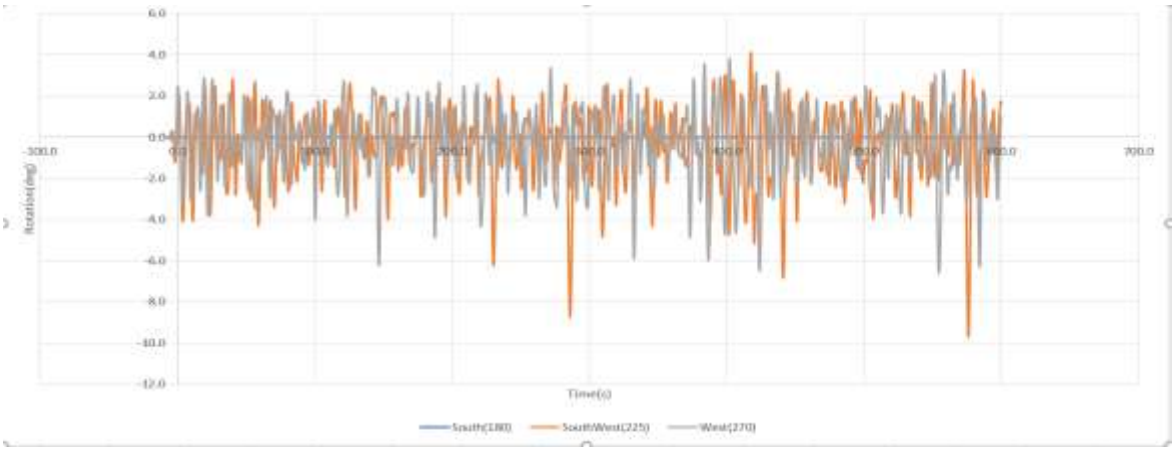

Figure 10: Catenary Configuration Roll offset of the FSO vessel time history

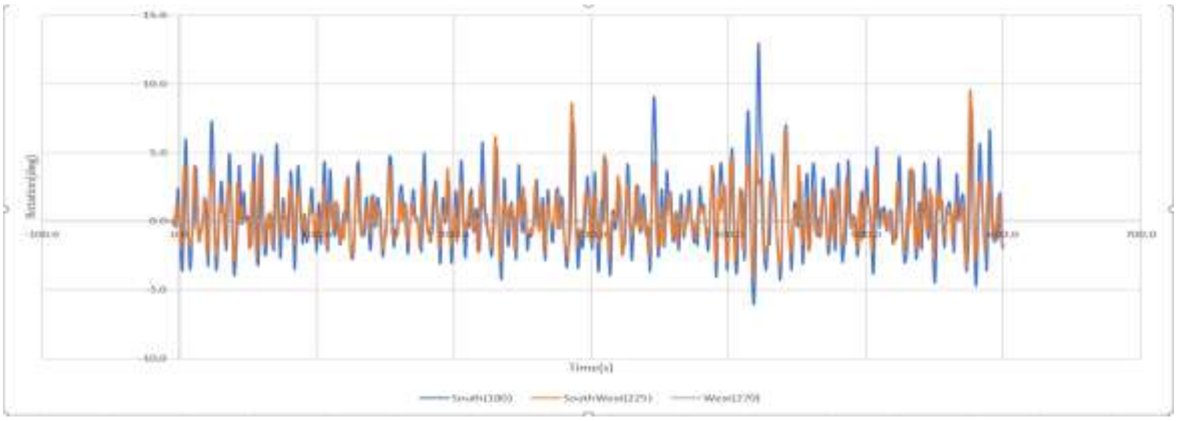

Figure 11: Catenary Configuration Pitch offset of the FSO vessel time history

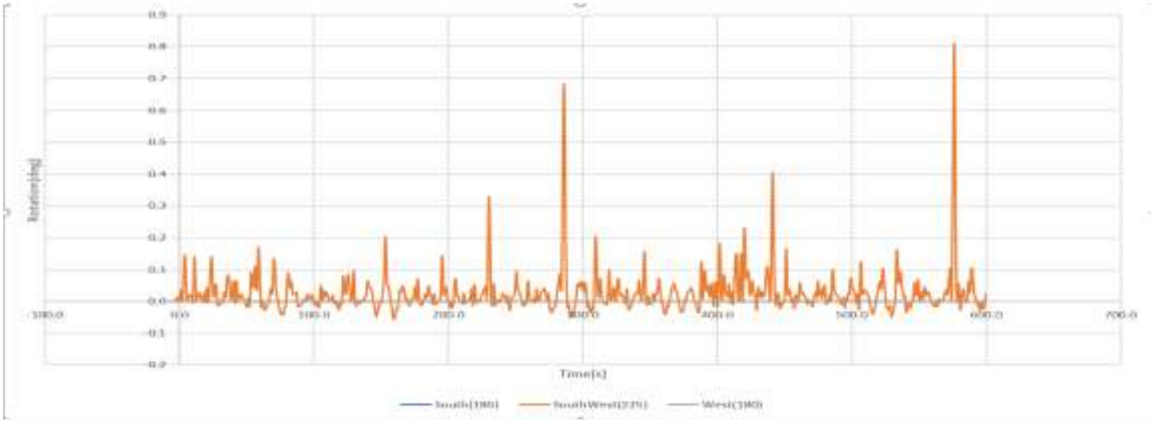

Figure 12: Catenary Configuration Yaw offset of the FSO vessel time history

Table 1: Motion Responses of the Different Mooring Systems at CG

| **Results** | **Max** | **Mean** | **RMS** |
|---|---|---|---|
| | Catenary Mooring System (chain-wire-chain) | | |
| Surge (m) | 137.5 | 111.8 | 6.36 |
| Sway (m) | 13.15 | 7.12 | 1.97 |
| Heave (m) | 5.53 | -2.83 | 1.86 |

| | | | |
|---|---|---|---|
| Roll (deg) | 5.92 | -3.34 | 1.52 |
| Pitch (deg) | 2.46 | -2.65 | 1.39 |
| Yaw (deg) | 3.17 | -2.07 | 1.05 |
| Taut Mooring System (Chain-polyester-chain) | | | |
| Surge (m) | 126.61 | 120.1 | 4.92 |
| Sway (m) | 5.7 | 1.06 | 3.27 |
| Heave (m) | 2.36 | -0.92 | 2.32 |
| Roll (deg) | 2.71 | -1.26 | 2.08 |
| Pitch (deg) | 1.9 | -1.98 | 1.73 |
| Yaw (deg) | 2.04 | -1.35 | 1.14 |

**Table 2: Comparative Analysis of FSO Vessel Catenary and Taut Mooring System Motion Responses at CG**

| Motion | Catenary Mooring System | Taut Mooring System |
|---|---|---|
| Surge (m) | 137.5 | 126.61 |
| Sway (m) | 13.15 | 5.7 |
| Heave (m) | 5.53 | 2.36 |
| Roll (deg) | 5.92 | 2.71 |
| Pitch (deg) | 2.46 | 1.9 |
| Yaw (deg) | 3.17 | 2.04 |

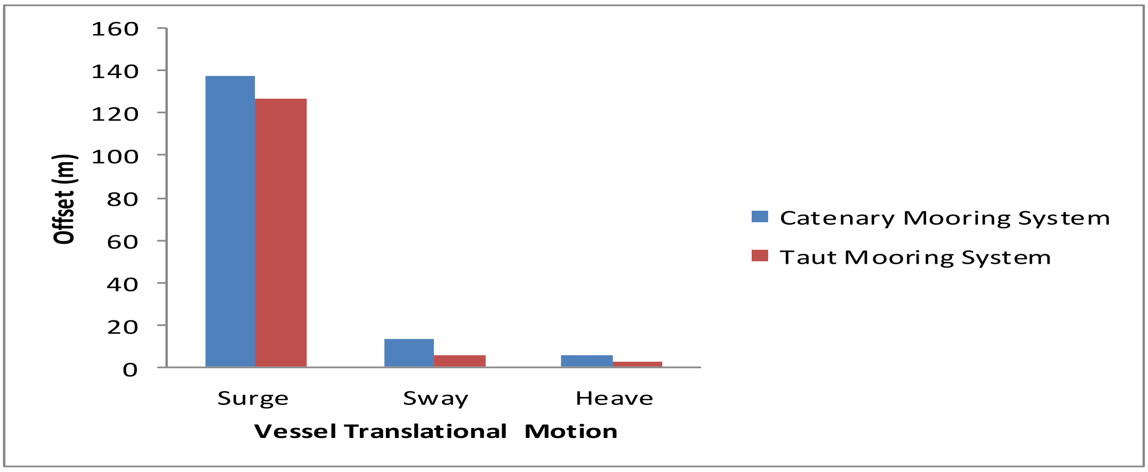

**Figure 13: Comparing Translational Motion of the FSO vessel Catenary and Taut Mooring System**

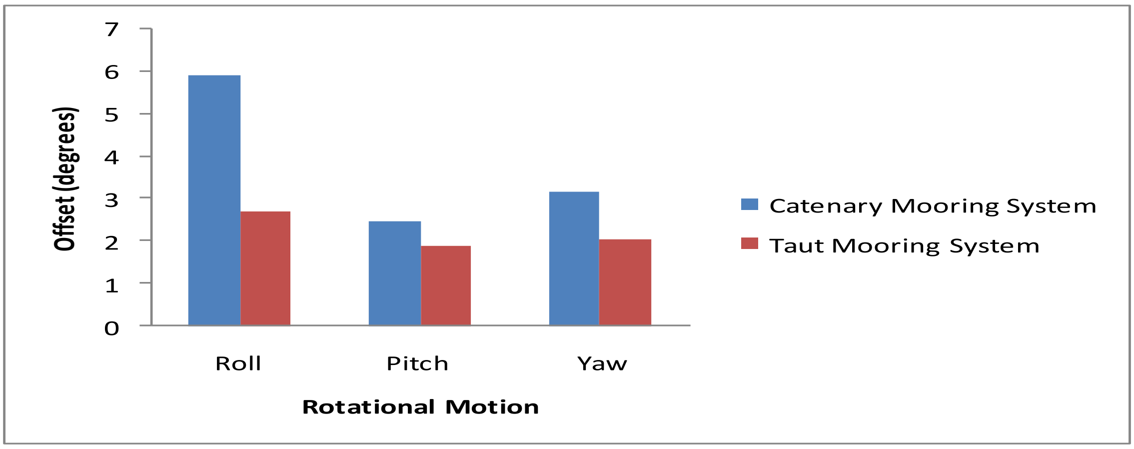

**Figure 14: Comparing Rotational Motion of the FSO vessel Catenary and Taut Mooring System**

**Table 3: Catenary (chain-wire-chain) Mooring System Dynamic Responses**

| Mooring Line | Max (KN) | Mean (KN) | Min (KN) | RMS (KN) |
|---|---|---|---|---|
| Line 1 | 306.4 | 164.1 | 110.7 | 31.4 |
| Line 2 | 296.1 | 162.4 | 109.9 | 29.3 |
| Line 3 | 284.7 | 160.4 | 109.1 | 29.2 |
| Line 4 | 148.5 | 112.4 | 112.3 | 10.3 |
| Line 5 | 148.8 | 109.6 | 61.0 | 84.3 |
| Line 6 | 146.8 | 106.9 | 75..1 | 71.35 |
| Line 7 | 139.6 | 52.2 | 407..6 | 30.41 |
| Line 8 | 141.4 | 64.4 | 425..5 | 30.81 |
| Line 9 | 144.5 | 98.0 | 38.8 | 31.34 |
| Line 10 | 206.2 | 144.1 | 971..0 | 49.61 |
| Line 11 | 217.2 | 147.2 | 996.1 | 63.55 |
| Line 12 | 230.6 | 150.1 | 100.8 | 85.50 |

**Table 4: Taut (Chain-polyester-chain) Mooring System Dynamic Responses**

| Mooring Line | Max (KN) | Mean (KN) | Min (KN) | RMS (KN) |
|---|---|---|---|---|
| Line 1 | 155.4 | 113.7 | 90.8 | 17.6 |
| Line 2 | 163.7 | 106.6 | 82.3 | 17.0 |
| Line 3 | 166.8 | 99.4 | 72.9 | 16.3 |
| Line 4 | 209.7 | 89.4 | 17.3 | 14.7 |
| Line 5 | 178.9 | 72.7 | 16.9 | 12.5 |
| Line 6 | 148.9 | 62.0 | 17.0 | 11.9 |
| Line 7 | 125.8 | 22.5 | 12.8 | 11.6 |
| Line 8 | 130.7 | 23.1 | 12.8 | 13.5 |
| Line 9 | 156.6 | 23.6 | 12.7 | 15.2 |
| Line 10 | 203.1 | 68.9 | 63.7 | 36.0 |
| Line 11 | 174.0 | 79.5 | 73.8 | 40.7 |
| Line 12 | 144.0 | 89.8 | 83.0 | 45.8 |

**Table 5: Dynamic Response of Mooring Line 1 in Different Mooring Types**

| Results | Max (Safety factor) | Mean | RMS |
|---|---|---|---|
| **Catenary mooring system (chain-wire-chain)** | | | |
| Top chain dynamic tension (KN) | 306.4 (2.12) | 160.4 | 77.7 |
| Intermediate wire dynamic tension (KN) | 280.8 (2.31) | 135.7 | 51.3 |
| Bottom chain dynamic tension (KN) | 249.6 (60) | 118.2 | 48.6 |
| **Taut mooring system (chain-polyester-chain)** | | | |
| Top chain dynamic tension (KN) | 155.4 (2.52) | 104.3 | 87.9 |
| Intermediate polyester dynamic tension | 151.8 (2.54) | 105.7 | 63.5 |

| | | | |
|---|---|---|---|
| (KN) | | | |
| Bottom chain dynamic tension (KN) | 141.6 (2.69) | 98.2 | 52.3 |

**Table 6: Comparative Analysis of FSO Vessel Catenary and Taut Mooring System Maximum Tension Dynamic Response**

| **Mooring type**<br>**Mooring Line** | **Catenary (chain-wire-chain)**<br>**Max (KN)** | **Taut (Chain-polyester-chain)**<br>**Max (KN)** |
|---|---|---|
| Line 1 | 306.4 | 155.4 |
| Line 2 | 296.1 | 163.7 |
| Line 3 | 284.7 | 166.8 |
| Line 4 | 148.5 | 209.7 |
| Line 5 | 148.8 | 178.9 |
| Line 6 | 146.8 | 148.9 |
| Line 7 | 139.6 | 125.8 |
| Line 8 | 141.4 | 130.7 |
| Line 9 | 144.5 | 156.6 |
| Line 10 | 206.2 | 203.1 |
| Line 11 | 217.2 | 174.0 |
| Line 12 | 230.6 | 144.0 |

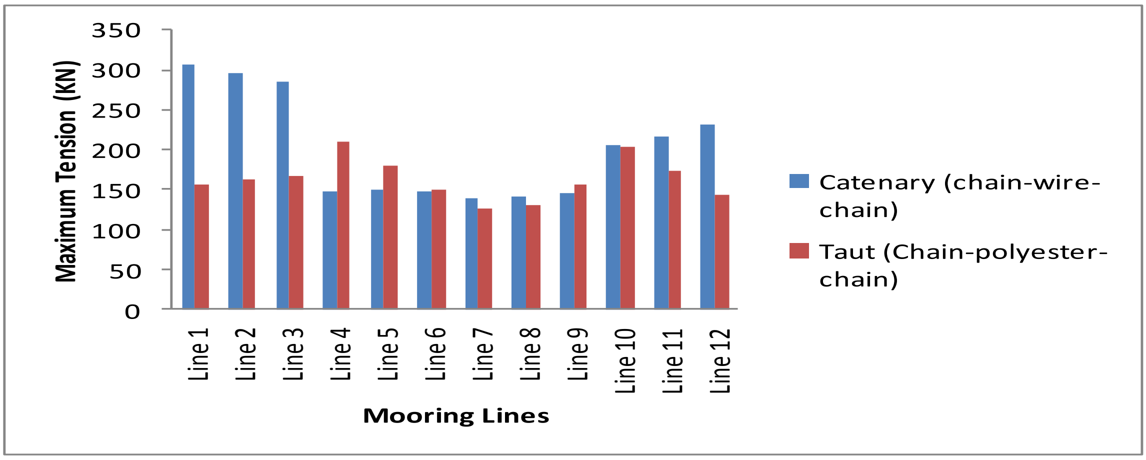

**Figure 15: Comparing Maximum Tension of the FSO vessel Catenary and Taut Mooring System**

**Table 7: Design Cost Analysis of Materials for Mooring Systems**

| **Composition** | **Cost of Catenary System (chain-wire-chain)** | **Cost of Taut System (chain-polyester-chain)** |
|---|---|---|
| Depth (m) | 45 | |
| Pretension (KN) | 588.39 | 588.39 |
| Total Length (m) | 800 | 550 |
| Chain connecting turret | Chain | Chain |
| Length (m) | 46 x ₦8000/metre = ₦368000 | 91 x ₦8000/metre = ₦728000 |
| Diameter (mm) | 112 | 112 |
| MBL (KN) | 6415 | 6415 |
| EA (KN) | 627740 | 627740 |
| Centre section | Wire | Polyester |
| Length (m) | 30 x ₦5000/metre = 1750000 | 250 x ₦1500/metre = ₦375000 |
| Diameter (mm) | 112 | 140 |
| MBL (KN) | 5215 | 5415 |
| EA (KN) | 690000 | 540000 |
| Chain connecting anchor | Chain | Chain |

| | | |
|---|---|---|
| Length (m) | 404 x ₦8000/metre = ₦3232000 | 209 x ₦8000/metre = ₦1672000 |
| Diameter (mm) | 112 | 112 |
| MBL (KN) | 6415 | 6415 |
| EA (KN) | 627740 | 627740 |
| **TOTAL COST (₦)** | **5,350,000.00** | **2,775,000.00** |

## IV. DISCUSSION

This study analysed and compared the catenary and taut mooring systems and introduced analytical method of FSO system dynamic response computation. The work also calculated catenary and taut FSO system dynamic response at a depth of 45 meters. The surge, sway, roll, pitch, have and the yaw motion responses of the FSO vessel are larger for catenary mooring system than taut mooring system from the results, as it is typical characteristics of FSO.Figures 13 and 14 show that the surge, sway, heave, roll, pitch and yaw motions responses for the FSO catenary mooring system were 137.5m at 5.92°, 13.15m at 2.46°, and 5.53m, at 3.17° respectively while the surge, sway, heave, roll, pitch and yaw motions responses for the FSO taut mooring system were 126.61m at 2.71°, 5.7m, at 1.90° and 2.36m at 2.04° respectively. The phenomenon that the FSO vessel motion response value of catenary mooring system is larger than that of taut mooring system explains that the former is weaker than the latter in orientation ability.

For the two kinds of mooring considered, all of the mooring line safety factors conform to API Specification, including the tension of mooring line1 which is the largest and coincides with the actual environmental condition. The dynamic tension of three sections of catenary mooring line1 is 306.4KN for the top chain dynamic tension, 280.8KN for the intermediate wire dynamic tension and 249.6KN for the bottom chain dynamic tension, which are larger than that of taut mooring line1 with 155.4KN for the top chain dynamic tension, 151.8KN for the intermediate wire dynamic tension and 141.6KN for the bottom chain dynamic tension as figure 15 reveals. It thus shows that taut mooring system guarantees positioning capability and bears smaller strength of the mooring system at the same time. The polyester rope taut leg mooring system offers a unique opportunity to reduce deep-water mooring system cost, while simultaneously improving station keeping performance. These gains are over catenary mooring system which uses all steel wire rope at the centre section. From the results of the cost analysis shown in Table 7, the cost of designing catenary mooring system is **₦5, 350,000** while the cost of the taut mooring system is **₦2, 775,000**. This shows that the taut mooring system is 48% more cost efficient than the catenary mooring system for the FSO vessel.

## V. CONCLUSION

This work focused on analysing and comparing the Station Keeping performance of Catenary and Taut mooring systems for an FSO vessel in the Gulf of Guinea utilizing ORCAFLEX, a hydrodynamic software and JONSWAP spectrum as the candidate spectrum representing the associated sea state distribution. The first objective of this work which is to describe the design characteristics of catenary and taut mooring systems for FSO vessels was achieved using a conceptual framework as presented.The second objective, to analyse and compare the ultimate mooring line tension of catenary and taut mooring systems for FSO vessel was achieved as presented in Table 6.The third objective, to determine and compare the offset in motion and dynamic response of the FSO ship as well as her mooring lines using catenary and taut mooring systems, was also achieved as presented in Table 5, and ultimately;the analysis and comparisonof the cost benefit of catenary and taut mooring systems' design characteristics for FSO vessel was achieved as presented in Table 7.

It suffices therefore to conclude from the results obtained that:

- Taut mooring system is most suitable for station keeping in the considered offshore environment as it guarantees stronger orientation capability for the FSO under investigation
- The possibility of line breakage is leaner for taut mooring system than for the catenary mooring system and so, makes for smoother productivity.
- Taut mooring system design is most efficient in terms of cost and should be deployed in preference to catenary system in the offshore environment considered.

## VI. ACKNOWLEDGEMENT

The Authors would want to appreciate the assistance of the staff of the software laboratory of the Marine Engineering Department of Rivers State University.

## REFERENCES

[1]. API RP 2SK. (2005). Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures, Third Edition. American Petroleum Institute.

[2]. Baoji, Z.&Yuhang, S. (2020). Study on Mooring Design and Calculation Method of Ocean Farm Based on Time-Domain Potential Flow Theory. Journal of Marine Science and Engineering, 2(3), 1-10.

[3]. Browne, V. (2015). Mooring Analysis for Safe Scandinavia. Global Maritime, 5 (1),1-13.

[4]. Del Vecchio, C. J. (1996). Taut Leg Mooring Systems Based on Polyester Fiber Ropes-Petrobas' Experience and Future Developments. International Conference on Mooring and Anchoring, Aberdeen, UK.

[5]. Duke, O. D., Ibiba, E. D. & Tamunodukobipi, D. (2019). Design Analysis of a Shallow Water Mooring System for Tanker Vessel. American Journal of Engineering Research, 8(7), 14-26.

[6]. Inegiyemiema, M., Nitonye S, Dick, I. F. & Erekosima, A. (2014) Design of a Mooring System for an Offshore Structure: A case study of 5000 Tonnes Offshore Work Barge (WB). International Journal of Engineering and Technology (IJET) – 4(12)

[7]. Johnsen, J. M. (1999). Design and Optimization of Taut-Leg Mooring Systems. Offshore Technology Conference, Houston, Texas.

[8]. Li, Z., Xu, X., & Wang, H. (2010). Development of Mooring System of Offshore Platform. J. Oil Field Machinery, 1(5), 75-78.

[9]. Liu, Z. & He, Y. (2006). FPSO Turret Mooring System Technical Features and Development Trend. China Offshore Platform, 5(1), 12-24.

[10]. Patel, M. H. & Brown, D. T. (2007). Analysis and Design of Catenary Mooring Systems. Economics of Floating Production Systems: Proceedings of an International Conference, London, UK.

[11]. Sun, Q., Peng, G. S. & Dong, Q. H. (2014). Design and Analysis of Catenary Single Point Mooring System. Papers on Green Shipbuilding and Shipping Forum (in China). China Association for Science and Technology, the People's Government of Yunnan Province, 6.

[12]. You, J. & Wang, Y. (2009). Designing Investigation of the Taut-Wire Mooring Systems for Deepwater Semi-submersible Platforms. J. China Offshore Platform, 24(1), 24-30.

[13]. Yu-Ho, R., Kookhyun, K., Chul-Hee J. & Do-Youb, K. (2013) Static and Dynamic Mooring Analysis - Stability of Floating Production Storage and Offloading (FPSO) Risers for Extreme Environmental Conditions. Int. J. Naval Archit. Ocean Eng. (2013) 5:179~187. http://dx.doi.org/10.3744/JNAOE.2013.5.2.179