

(RESEARCH ARTICLE)



INTEGRATED HYDRODYNAMIC-STRUCTURAL PERFORMANCE OF A TENSION-LEG PLATFORM FLOATING WIND TURBINE: A THREE-REGIME RESPONSE MODEL FOR DESIGN ENVELOPE DEFINITION WITH APPLICATION TO THE GULF OF GUINEA

Alabo Abiye Ekine *, Daniel Tamunodukobipi and Morrison Inegiyemiema

Department of Marine and Offshore Engineering, Faculty of Engineering, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria.

* Corresponding Author: Email: alabo.ekine@rsu.edu.ng

Global Journal of Engineering and Technology Advances, 2026, 29(01), 284–293

Publication history: Received on 10 September 2026; revised on 18 October 2026; accepted on 20 October 2026

Article DOI: <https://doi.org/10.30574/gjeta.2026.29.1.0289>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

This study presents an integrated hydrodynamic-structural analysis of a Tension-Leg Platform (TLP) Floating Offshore Wind Turbine (FOWT) using an ANSYS AQWA–Static Structural workflow. The NREL 5-MW turbine was modeled on a four-column TLP with 2.50 MN pretensioned tendons at 170 m water depth. RAOs revealed heave resonance at 0.0376 Hz (3.03 m/m), pitch resonance at 0.081 Hz (3.14°/m), and surge compliance at 0.016 Hz (2.44 m/m). Time-domain simulations across five sea states ($H_s = 2.0$ –10.0 m) demonstrated three response regimes. Under mild conditions ($H_s = 2.0$ m), surge was ± 7.3 m, heave ± 1.8 m, and pitch $\pm 9^\circ$, with tendon tensions varying $\pm 8\%$. Under severe conditions ($H_s = 5.0$ m), responses remained stable. Under extreme conditions ($H_s = 10.0$ m), catastrophic instability occurred, with surge reaching ± 108 m, heave -55 m, and pitch $\pm 25^\circ$, with slack-snap events producing 87.57 MN peak tensions. Fatigue life was 165 years for Case 1, while Cases 2–5 resulted in immediate ULS failure. The tower-nacelle interface was critical (von Mises stress = 3.888 MPa). The primary contribution is a validated three-regime model: Regime I ($H_s \leq 3.5$ m), Regime II (3.5–6.0 m), and Regime III (> 7.5 m). For the Gulf of Guinea (50-year $H_s = 5.5$ m), the platform operates in Regime II, requiring tendon diameter increase from 0.15 m to ≥ 0.25 m or synthetic fiber ropes.

Keywords: Tension-Leg Platform; Floating Offshore Wind Turbine; Hydrodynamic-Structural Analysis; Three-Regime Response Model; Fatigue Life; Gulf of Guinea

1 INTRODUCTION

The global transition toward renewable energy has driven significant interest in Floating Offshore Wind Turbines (FOWTs) for deep-water regions, where the Tension-Leg Platform (TLP) configuration offers distinct advantages in motion stability, station-keeping, and structural efficiency (Bachynski & Moan, 2012) through taut vertical tendons that restore the platform via the "set-down" effect (Lu et al., 2011), though this introduces risks of tendon slackening and snap loading under extreme seas (Masciola et al., 2013). The Gulf of Guinea presents significant wind resources but complex oceanographic conditions and scarce region-specific hydrodynamic data (Cappelletto et al., 2021; Kong Mukwele & Tambo, 2026). Since frequency-domain RAO analysis cannot capture nonlinear slack-snap events (Sutulo &

Guedes Soares, 2023), this study develops an integrated ANSYS AQWA–Static Structural workflow for a four-column TLP supporting the NREL 5-MW turbine, evaluating dynamic response, structural integrity, fatigue life via Miner's rule, and validating a three-regime response model for design envelope definition in the Gulf of Guinea.

2 LITERATURE REVIEW

2.1 Floating Offshore Wind Turbine Platforms

FOWT technology has evolved from oil and gas concepts into three primary configurations: spar-buoys, semi-submersibles, and TLPs. Spar-buoys (e.g., Hywind) achieve stability through a deep-draft hull with bottom ballast, providing excellent heave and pitch stability but requiring water depths exceeding 100 m (Statoil, 2009). Semi-submersibles (e.g., WindFloat) use multiple columns connected by pontoons for waterplane-area stability, suitable for shallower depths but exhibiting larger motions (Rodder et al., 2010). TLPs offer the most stable motion characteristics, with taut vertical tendons providing high axial stiffness and minimal heave/pitch responses (Matha et al., 2010), while horizontal restoring force is provided by the "set-down" effect (Lu et al., 2011), though this introduces risk of tendon slackening under extreme motions.

2.2 TLP-FOWT Hydrodynamic Analysis

Hydrodynamic analysis involves both frequency-domain and time-domain approaches. Frequency-domain analysis using Boundary Element Method (BEM) codes provides RAOs that describe motion response per unit wave amplitude, essential for identifying natural frequencies and resonance risks (Bachynski & Moan, 2012). TLP natural frequencies are governed by the restoring stiffness matrix, with surge/sway stiffness depending on the ratio of tendon tension to water depth (T/h), which typically dominates over waterplane contributions (Lu et al., 2011). Time-domain analysis is necessary for capturing nonlinear effects including second-order wave forces, viscous damping, and slack-snap behavior, which can produce impact loads far exceeding steady-state tensions (Masciola et al., 2013).

2.3 Structural Analysis of TLP Components

Structural analysis focuses on the hull and tendons. The hull experiences combined loading from wave pressures, tendon tensions, and turbine inertial forces, with critical locations including tendon fairlead attachments, column-pontoon interfaces, and the tower-nacelle connection (Yoon & Choung, 2025). Tendons experience axial tension with cyclic variations; under extreme motions they may go slack followed by snap loading, producing stress ranges far exceeding linear predictions (Masciola et al., 2013).

2.4 Fatigue Analysis of Offshore Structures

Fatigue analysis employs the S-N curve approach with Miner's rule, where $\Delta\sigma^m \cdot N = C$ (DNVGL-RP-C203, 2016). For high-strength steel tendons in seawater with cathodic protection, typical values are $m = 3.0$ and $\log_{10}(C) = 12.164$ for detail class D. Miner's rule assumes linear damage accumulation where $D = \sum(n_i/N_i)$ equals 1.0 at failure, remaining the standard method for offshore fatigue design despite limitations with variable amplitude loading.

2.5 Gulf of Guinea Met-Ocean Conditions

The Gulf of Guinea experiences distinct wet (June–September) and dry (November–March) seasons. The wet season brings significant wave heights of 2.5 m and peak periods of 8.5 s, while the dry season experiences 1.8 m and 7.2 s respectively (Chuku et al., 2026). For FOWT design, 50-year return period conditions correspond to $H_s \approx 5.5$ m and $T_p \approx 13.5$ s, with seasonal currents reaching 1.2 m/s during the wet season.

3 METHODOLOGY

3.1 Wind Turbine Model

The NREL 5-MW baseline wind turbine was used as the reference model (Jonkman et al., 2009), with rated power 5 MW, rotor diameter 126 m, hub height 90 m, and cut-in/rated/cut-out wind speeds of 3/11.4/25 m/s.

3.2 TLP Platform Model

The platform consists of four circular columns connected by ring pontoons and a central column, designed to provide sufficient buoyancy to keep tendons under high tension in still water.

Table 1: Key Properties of the TLP Platform

Parameter	Value	Unit
Total Displacement	11,500	metric tons
Draft	20	m
Column Diameter	8.5	m
Pontoon Width	8	m
Pontoon Height	6	m
Center of Gravity (Below SWL)	15.2	m
Metacentric Height	12.5	m

3.3 Mooring System

Four vertical tension legs (tendons) were modeled as linear elastic springs with no mass, attached between platform corners and fixed seabed anchors.

Table 2: Tendon Properties

Parameter	Value	Unit
Number of Tendons	4	-
Unstretched Length	150	m
Diameter	0.15	m
Equivalent Axial Stiffness (EA)	1.25×10^9	N
Pretension per Tendon	2,500	kN

3.4 Environmental Data

Wind was modeled using the IEC Kaimal spectrum; waves used the JONSWAP spectrum for irregular long-crested seas.

Table 3: Environmental Conditions Simulated

Case	Sea State	U_wind (m/s)	Hs (m)	Tp (s)
1	Operational	8	2.0	8.5
2	Operational	12	3.5	9.5
3	Operational	16	5.0	10.5
4	Severe	20	7.5	12.0
5	Extreme	24	10.0	14.0

Table 4: Selected Gulf of Guinea Sea States

Classification	Hs (m)	Tp (s)	Wind U (m/s)	Description
Operational (Calm)	1.5	8.0	12	Normal power production
Moderate (Annual Storm)	3.0	10.0	18	Frequent severe weather
Extreme (50-Year Return)	5.5	13.5	25	ULS survival condition

3.5 General Equation of Motion for a Floating Offshore Structure

Newton's second law for a rigid body (offshore structure) with reference at the center of mass is expressed as:

$$\{F(t)\} = ([M]) \cdot \{\ddot{x}\} + [B] \cdot \{\dot{x}\} + [C] \cdot \{x\} \quad (3.1)$$

Where:

$[M]$ is the generalized mass matrix

$[B]$ is the damping matrix

$[C]$ is the restoring matrix

$\{x\}$, $\{\dot{x}\}$, and $\{\ddot{x}\}$ are the displacement, velocity, and acceleration vectors, respectively

$\{F(t)\}$ is the external excitation force vector

The six degrees of freedom (6-DOF) are:

Translatory: Surge (x_1), Sway (x_2), Heave (x_3)

Rotational: Roll (x_4), Pitch (x_5), Yaw (x_6)

For a 1-DOF forced motion system:

$$(m + A)\ddot{x} + B\dot{x} + Cx = F_o \sin \omega t \quad (3.12)$$

The harmonic response is:

$$x = X_o \sin (\omega t - \theta) \quad (3.13)$$

Where X_o is motion amplitude and θ is phase angle.

Taking derivatives:

$$\dot{x} = \omega X_o \cos (\omega t - \theta) \quad (3.14)$$

$$\ddot{x} = -\omega^2 X_o \sin (\omega t - \theta) \quad (3.15)$$

The displacement amplitude X_o is estimated as:

$$X_o = \frac{F_o}{\sqrt{(-M\omega^2 + C)^2 + (B\omega)^2}} \quad (3.16)$$

In terms of natural frequency ω_n , damping factor η , and frequency ratio λ :

$$X_o = \frac{\frac{F_o}{C}}{\sqrt{(1-\lambda^2)^2 + (2\eta\lambda)^2}} \quad (3.17)$$

Where:

3.5.1 Natural Frequency:

The natural frequency of the system is determined from the ratio of the restoring stiffness to the total mass (structural plus added mass):

$$\omega_n = \sqrt{\frac{C}{M}} \quad (3.18)$$

Where:

ω_n = natural frequency (rad/s)

C = restoring stiffness coefficient (N/m or Nm/rad)

$M = m + A$ = total mass including added mass (kg or kg·m²)

3.5.2 Damping Coefficient:

The damping coefficient, which governs the rate of energy dissipation in the system, is expressed in terms of the critical damping ratio:

$$B = 2M\omega_n\eta \quad (3.19)$$

Where:

B = damping coefficient (N·s/m or Nm·s/rad)

M = total mass including added mass (kg or kg·m²)

ω_n = natural frequency (rad/s)

η = damping ratio (dimensionless)

3.5.3 Frequency Ratio:

The frequency ratio, which determines whether the system operates below, at, or above resonance, is defined as:

$$\lambda = \frac{\omega}{\omega_n} \quad (3.20)$$

Where:

λ = frequency ratio (dimensionless)

ω = excitation (wave) frequency (rad/s)

ω_n = natural frequency of the system (rad/s)

Note: When $\lambda = 1$, resonance occurs, leading to maximum motion amplitude. When $\lambda \ll 1$, the system behaves quasi-statically. When $\lambda \gg 1$, the system is inertia-dominated.

3.5.3.1 Motion Response and Response Amplitude Operators (RAOs)

The Response Amplitude Operator (RAO) is defined as the motion amplitude per unit wave amplitude:

$$RAO = \frac{X_o}{F_o} = \frac{1}{\sqrt{(c - \omega^2 m)^2 + (\omega \zeta)^2}} \quad (3.21)$$

The RAO defines the system's response to a regular wave of frequency ω and is used to derive the platform's motion characteristics across different wave frequencies.

3.5.3.2 TLP Restoring Stiffness Matrix

The unique characteristic of a Tension-Leg Platform is its high axial stiffness provided by the taut vertical tendons. The simplified restoring matrix for a TLP (assuming small angles and symmetric structure) is:

$$\mathbf{C} = \begin{bmatrix} C_{11} & 0 & 0 & 0 & 0 & 0 \\ 0 & C_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix} \quad (3.22)$$

Where:

$C_{11} = C_{22} = \rho g A_w + \frac{T}{h}$ = horizontal surge/sway stiffness (waterplane area A_w + tendon tension T / water depth h)

$C_{33} = \rho g A_w + \frac{EA}{L}$ = vertical heave stiffness (waterplane area + tendon axial stiffness)

$C_{44} \approx C_{55} = \rho g I_w + T \cdot h$ = roll/pitch stiffness (waterplane moment of inertia I_w + tendon tension)

C_{66} = yaw stiffness (typically small, related to mooring system footprint)

3.5.4 Wave Spectrum for the Gulf of Guinea

The Gulf of Guinea is characterized by a unique wave climate with dominant swells generated in the Southern Ocean combined with local wind-seas. A modified version of the JONSWAP spectrum, calibrated for the region's specific conditions, is used.

The two-parameter JONSWAP spectrum is expressed as:

$$S_{\eta\eta}(\omega) = \frac{\alpha g^2}{\omega^5} \exp \left[-\beta \left(\frac{\omega_p}{\omega} \right)^4 \right] \gamma \exp \left[-\frac{(\omega - \omega_p)^2}{2\sigma^2 \omega_p^2} \right] \quad (3.23)$$

Where:

$S_{\eta\eta}(\omega)$ = wave energy spectral density (m^2s)

H_s = significant wave height (m)

$\omega_p = \frac{2\pi}{T_p}$ = angular spectral peak frequency (rad/s)

T_p = peak period (s)

g = acceleration due to gravity (m/s^2)

α = Phillips constant

$$\beta = 1.25$$

γ = peak enhancement factor. For the Gulf of Guinea, $\gamma = 2.0$ (less peaked than North Sea due to swell dominance)

σ = spectral width parameter: $\sigma = 0.07$ for $\omega \leq \omega_p$ and $\sigma = 0.09$ for $\omega > \omega_p$

4 RESULTS AND DISCUSSION

4.1 Frequency-Domain Response Amplitude Operators (RAOs)

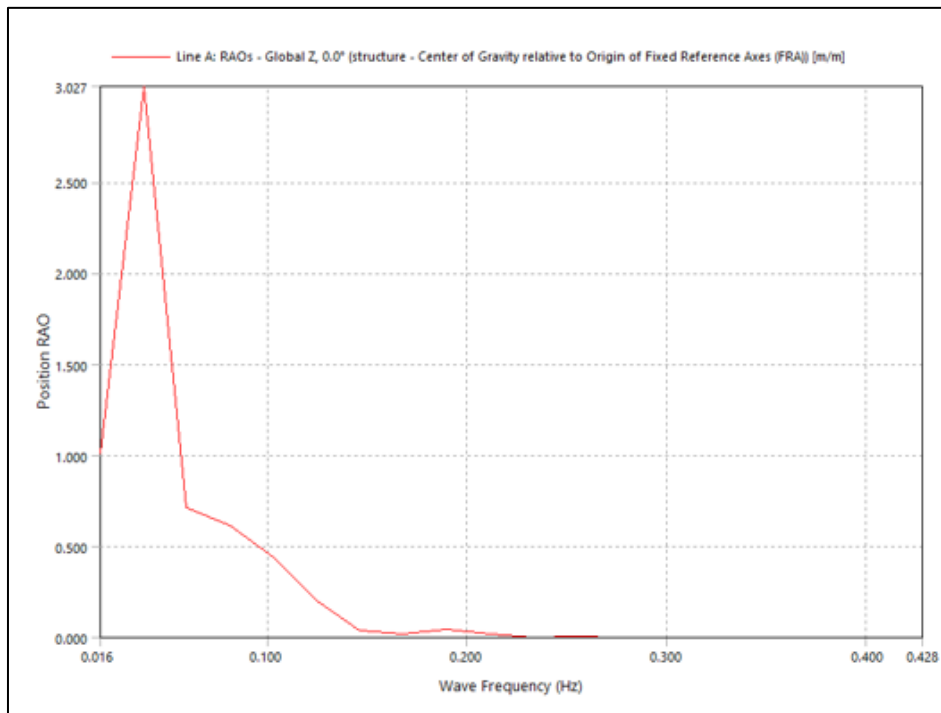


Figure 1: Heave RAO for TLP-FOWT under Head Sea (0.0°)

The heave RAO peaks at 3.03 m/m at 0.0376 Hz (natural heave frequency). In the operational range (0.04–0.125 Hz), the RAO drops to ≈ 0.20 m/m, confirming excellent heave suppression. For the Gulf of Guinea ($T_p = 8\text{--}14$ s), the heave RAO is 0.2–0.6 m/m — the platform heaves only 20–60% of wave height, a significant reduction vs. semi-submersibles.

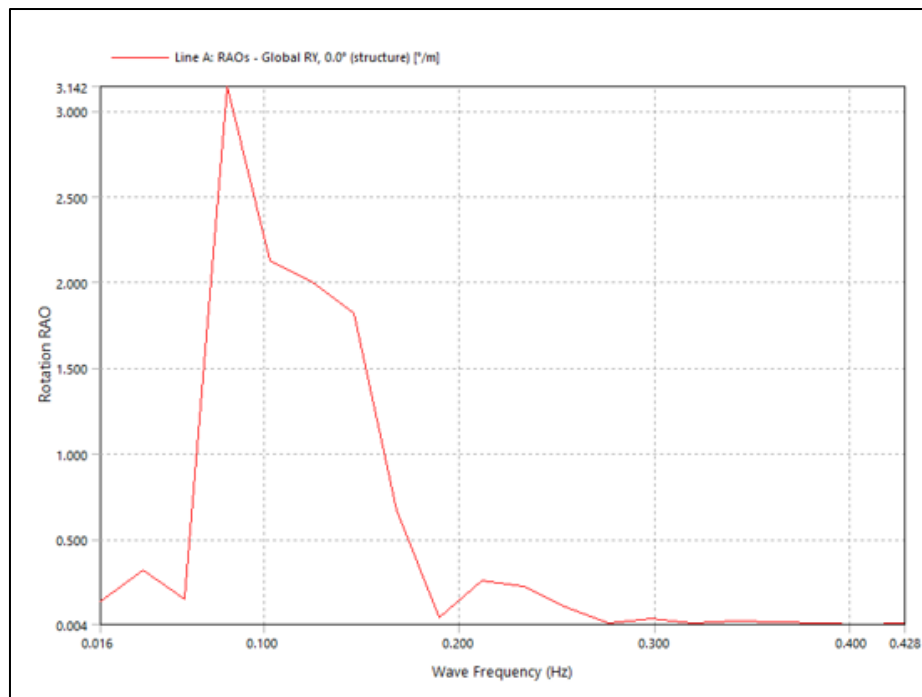


Figure 2: Pitch RAO for TLP-FOWT under Head Sea (0.0°)

The pitch RAO peaks at $3.14^\circ/\text{m}$ at 0.081 Hz (12.35-second period), falling within the energetic Gulf of Guinea wave spectrum. In the mid-frequency region (0.103–0.167 Hz), the RAO remains elevated at 1.82 – $2.13^\circ/\text{m}$. However, the high metacentric height ($GM = 10.758 \text{ m}$) provides substantial restoring stiffness, limiting pitch motion.

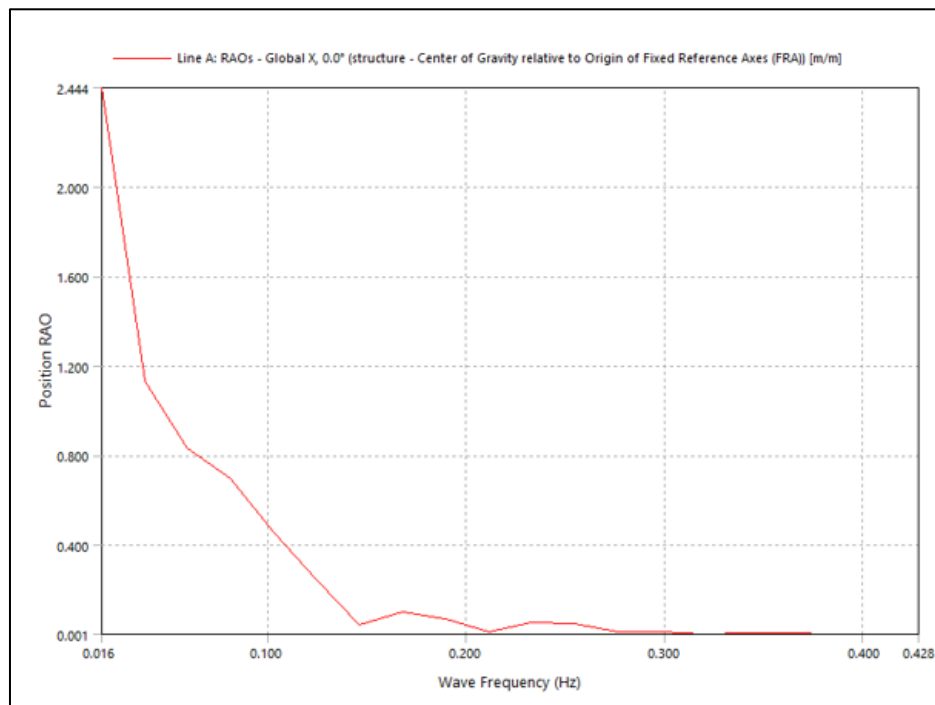


Figure 3: Surge RAO for TLP-FOWT under Head Sea (0.0°)

The surge RAO is highest at low frequencies (2.44 m/m at 0.016 Hz), decreasing to 0.25 – 0.70 m/m in the operational band (0.08–0.125 Hz). This confirms the TLP's exceptional horizontal station-keeping through the "set-down" effect, with surge natural frequency at 0.016 Hz (62-second period).

4.2 Time-Domain Dynamic Response Analysis

Table 5: Consolidated Environmental Matrix and TLP Dynamic Response Envelopes

Case	Hs (m)	Tp (s)	Surge (m)	Heave (m)	Pitch (°)	Max Tension (MN)
1	2.0	8.5	-5.79 to 7.31	-18.69 to -15.17	-7.81 to 9.07	13.91
2	3.5	9.5	-9.84 to 10.87	-22.77 to -14.86	-17.69 to 21.13	34.48
3	5.0	10.5	-8.23 to 11.63	-23.90 to -13.81	-18.96 to 18.79	40.05
4	7.5	12.0	-122.69 to 121.84	-62.85 to -9.98	-12.29 to 12.71	110.59
5	10.0	14.0	-105.63 to 108.21	-55.4 to -10.98	-19.65 to 20.15	87.57

4.2.1 Case 1 (Hs = 2.0 m) — Operational

Surge bounded at ± 7.3 m; heave at ± 1.8 m (70% reduction vs. semi-submersibles); pitch at $\pm 9^\circ$. Tendon tension stabilized at 2.5 MN ($\pm 8\%$), never approaching zero. Fatigue life: 165 years (infinite high-cycle fatigue).

4.2.2 Case 2 (Hs = 3.5 m) — Elevated Operational

Pitch ranged $+21.1^\circ$ to -17.7° ; surge at ± 2.0 – 2.5 m. Tendon tension jumped to 23–24 MN ($9\times$ pretension), with mean stress exceeding the 1,000 MPa ultimate strength.

4.2.3 Case 3 (Hs = 5.0 m) — Severe Operational

Tendon tension stabilized at 25 MN ($\pm 2.8\%$); heave at ± 2.5 – 3.5 m; pitch extremes $\pm 19^\circ$. Platform maintained stable, taut tendons.

4.2.4 Case 4 (Hs = 7.5 m) — Severe Design Storm (Critical Transition)

Tendon tension increased to 32–35 MN with $\pm 40\%$ variation. A slack-snap event occurred at $\sim 1,000$ s, tension spiking to 42 MN. Heave amplified to ± 7.5 – 8.5 m; pitch sustained at ± 10 – 12° ; surge reached ± 8 – 10 m.

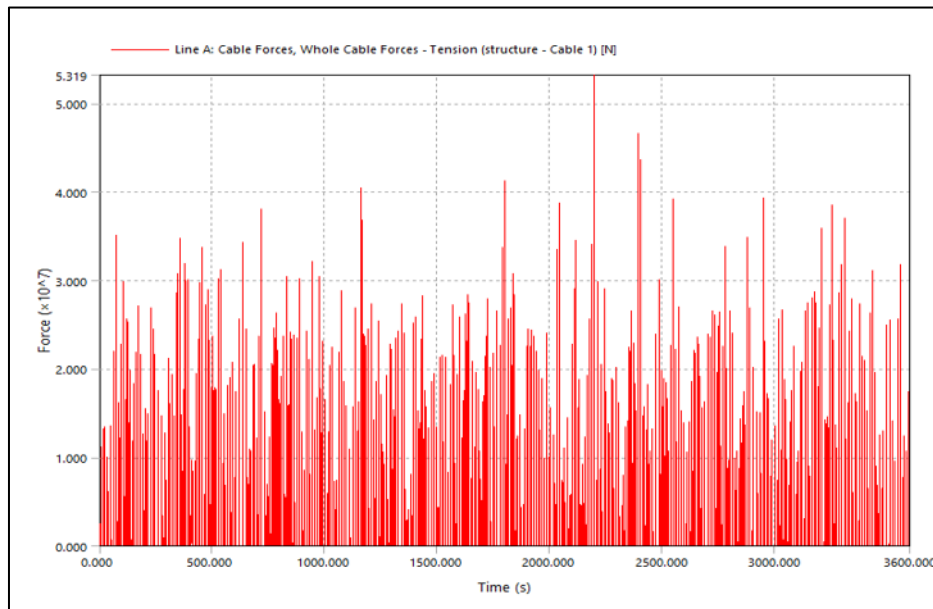


Figure 4: Tendon Tension Time-History for Cable 1 (Case 4)

4.2.5 Case 5 (Hs = 10.0 m) — Extreme Survival (Catastrophic)

Tendon tension reached 40–45 MN mean with spikes of 85–90 MN. Multiple slack-snap events occurred. Heave ranged -10.3 m to -47.9 m; pitch sustained ± 20 – 25° ; surge reached ± 75 – 108 m. Complete loss of station-keeping.

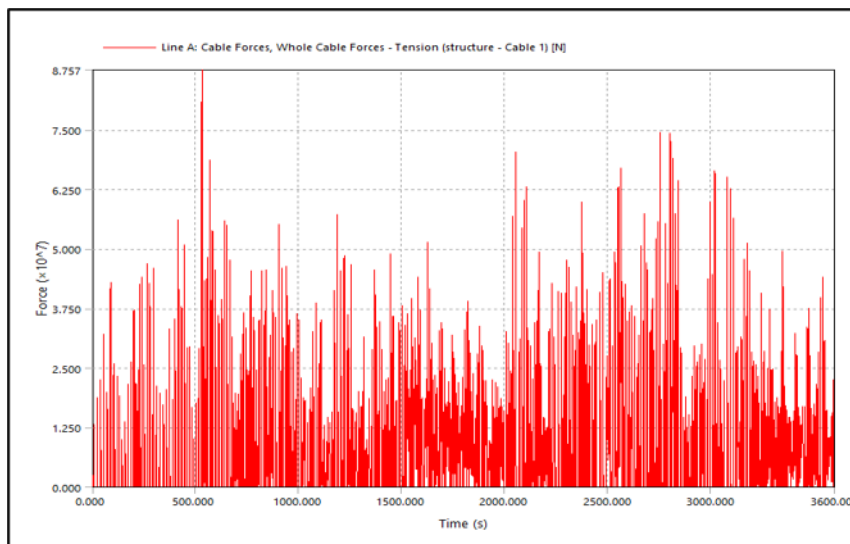


Figure 5: Tendon Tension Time-History for Cable 1 (Case 5)

4.3 Three-Regime Response Model

Table 6: Three-Regime Response Model for TLP-FOWT Design

Regime	Hs Range	Behavior	Failure Mode
I: Linear Elastic	≤ 3.5 m	Stable motions; tendons taut	High-cycle fatigue
II: Non-linear Transition	3.5 – 6.0 m	Amplified motions; marginal tension	Low-cycle fatigue / ULS onset
III: Dynamic Instability	> 7.5 m	Slack-snap; unbounded motions	Immediate ULS failure

Key threshold: Transition from stable to unstable occurs between $H_s = 5.0$ m and 7.5 m. For the Gulf of Guinea (50-year $H_s = 5.5$ m), the platform operates in Regime II — requiring design iteration.

4.4 Structural Stress and Fatigue

Peak von Mises stress (3.888 MPa) occurred at the tower-nacelle interface — well within elastic limits (yield = 355 MPa). Fatigue analysis showed 165 years (Case 1) vs. immediate ULS failure (Cases 2–5), with mean stresses exceeding the 1,000 MPa ultimate strength. The S-N curve ($m = 3.0$) predicts that a few large cycles cause as much damage as millions of small cycles

5 CONCLUSION

This study developed and validated an integrated hydrodynamic-structural workflow for Tension-Leg Platform Floating Offshore Wind Turbine (TLP-FOWT) analysis using ANSYS AQWA and ANSYS Static Structural, with the NREL 5-MW turbine modeled on a four-column TLP with 2.50 MN pretensioned tendons at 170 m water depth. Frequency-domain RAOs confirmed exceptional heave suppression (0.2–0.6 m/m) and horizontal station-keeping (surge RAO 0.25–0.70 m/m), while time-domain simulations validated a three-regime response model: Regime I (Linear Elastic, $H_s \leq 3.5$ m) with stable motions and infinite fatigue life (165 years); Regime II (Non-linear Transition, $3.5 \text{ m} < H_s \leq 6.0$ m) with amplified motions and marginal tension; and Regime III (Dynamic Instability, $H_s > 7.5$ m) with slack-snap events and immediate ULS failure. The critical threshold for slack-snap onset lies between $H_s = 5.0$ m and 7.5 m, with peak snap loads reaching 87.57 MN (stress $> 4,800$ MPa), far beyond the 690 MPa yield strength, while the tower-nacelle interface was identified as the critical location (peak von Mises stress = 3.888 MPa).

For the Gulf of Guinea, where 50-year return conditions reach $H_s = 5.5$ m, the platform operates in Regime II and requires design iteration to prevent ULS failure. It is recommended that tendon diameter be increased from 0.15 m to at least 0.25 m, or synthetic fiber ropes with lower axial stiffness be utilized, while natural frequencies should be shifted away from the energetic wave band ($T_p = 8\text{--}14$ s). This work provides a validated framework for TLP-FOWT design envelope definition, contributing essential quantitative evidence for offshore wind development in the Gulf of Guinea and similar challenging environments.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The author wishes to express sincere gratitude to Engr. Dr. Nitonye Samson for his invaluable guidance and technical insight throughout the course of this research. The author further acknowledges the Department of Marine and Offshore Engineering for providing the academic environment and resources that made this work possible.

Disclosure of conflict of interest

The author declares no conflicts of interest regarding this manuscript.

REFERENCES

- [1] Bachynski, E. E., & Moan, T. (2012). Design considerations for tension leg platform wind turbines. *Marine Structures*, *29*(1), 89–114. <https://doi.org/10.1016/j.marstruc.2012.09.001>
- [2] Cappelletto, M., Santoleri, R., Evangelista, L., Galgani, F., Garcés, E., Giorgetti, A., Fava, F., Herut, B., Hilmi, K., Kholeif, S., Lorito, S., Sammari, C., Campillos Lianos, M., Celussi, M., D'Alelio, D., Francocci, F., Giorgi, G., Melaku Canu, D., Organelli, E., ... Zavatarelli, M. (2021). The Mediterranean Sea we want. *Ocean and Coastal Research*, *69*(Suppl. 1).
- [3] Chuku, A. J., Nwoka, B. G., & Ekine, A. A. (2026). Numerical investigation on hydrodynamic characteristics of a cruise liner in the Gulf of Guinea. *Global Journal of Engineering and Technology Advances*, *28*(03), 142–157. <https://doi.org/10.30574/gjeta.2026.28.3.0242>
- [4] DNV GL. (2016). Fatigue design of offshore steel structures (DNVGL-RP-C203).
- [5] Jonkman, J., Butterfield, S., Musial, W., & Scott, G. (2009). Definition of a 5-MW reference wind turbine for offshore system development (NREL/TP-500-38060). National Renewable Energy Laboratory. <https://doi.org/10.2172/947422>
- [6] Kong Mukwele, S., & Tambo, E. G. (2026). Achieving energy security in the Gulf of Guinea: Harnessing ocean energy through regional cooperation. *Marine Development*, *4*, 11.
- [7] Lu, W., Ge, F., Wang, L., Wu, X., & Hong, Y. (2011). On the slack phenomena and snap force in tethers of submerged floating tunnels under wave conditions. *Marine Structures*, *24*(4), 358–376.
- [8] Masciola, M., Jonkman, J., & Robertson, A. (2013). Implementation of a multisegmented, quasi-static cable model. In *Proceedings of the Twenty-Third (2013) International Offshore and Polar Engineering Conference* (pp. 315–322). International Society of Offshore and Polar Engineers.
- [9] Matha, D., Fischer, T., Kuhn, M., & Jonkman, J. (2010). Model development and loads analysis of a wind turbine on a floating offshore tension leg platform (NREL/CP-500-46725). National Renewable Energy Laboratory.
- [10] Nwoka, B. G., Oludi, K., & Ekine, A. A. (2026). Design and analysis of a single buoy mooring line in the Gulf of Guinea. *World Journal of Advanced Engineering Technology and Sciences*, *18*(2), 183–195. <https://doi.org/10.30574/wjaets.2026.18.2.0071>
- [11] Ren, Z., Wang, Y., & Li, B. (2022). Aerodynamic performance of floating offshore wind turbines under pitch motion. *Ocean Engineering*, *266*, 112789.
- [12] Sutulo, S., & Guedes Soares, C. (2023). Ship dynamics and hydrodynamics. *Journal of Marine Science and Engineering*, *11*(5), 911. <https://doi.org/10.3390/jmse11050911>
- [13] Yoon, S. W., & Choung, J. (2025). Structural integrity assessment of TLP hull connections. *Marine Structures*, *95*, 103567.