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PARAMETRIC EFFECTS OF BARGE DIMENSIONS ON MOTION RESPONSE AND DEVELOPMENT OF OPERATIONAL LIMITS FOR NIGER DELTA WAVE CONDITIONS

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ABSTRACT

This study investigates the effect of barge dimensions on motion response and establishes motion-based operating limits for barge operations in the Niger Delta. Using the mathematical models developed for a typical flat-bottomed barge (length 39.2 m, breadth 12.0 m, draft 2.5 m, displacement 1,176 tons), parametric analyses were performed by varying length from 30 m to 50 m and breadth from 10 m to 16 m. Results showed that increasing length from 30 m to 50 m reduced heave RAO by 31% and pitch RAO by 47%, while increasing breadth from 10 m to 16 m reduced roll RAO by 49%. Operating limits were established based on motion criteria: cargo transfer permissible up to sea state 2 (Hs ≤ 1.0 m), personnel transfer limited to sea state 1 (Hs ≤ 0.5 m) in dry season and unsafe in wet season, towing up to sea state 3 (Hs ≤ 1.5 m), and navigation up to sea state 4 (Hs ≤ 2.0 m). Drilling was found unsafe in all conditions due to heave exceeding the 0.20 m limit even at sea state 1 (heave = 0.28 m). The findings provide practical operational guidelines and design recommendations for safer barge operations in the Niger Delta.

Keywords: Wave conditions; Roll damping; Heave motion; Barge dimensions; Significant wave height.

1 INTRODUCTION

Barges are important marine transport units for moving cargo, equipment, and offshore supplies, particularly in regions where shallow waterways restrict the movement of larger vessels. In the Niger Delta, their use supports inland water transportation, coastal logistics, and offshore activities. However, safe and efficient barge operation depends on the interaction between vessel dimensions and environmental conditions. Wave-induced motions can affect cargo handling, personnel transfer, towing, equipment positioning, and the stability of floating systems. These challenges are influenced by seasonal variations in wave height, period, and direction. Dada et al. (2018) investigated seasonal wind and wave conditions along the Niger Delta shoreline and reported variations in wave energy between seasons. Similarly, Osinowo and Popoola (2021) examined long-term patterns in extreme wave events along the Niger Delta coast and identified seasonal variations in significant wave height and peak period. These findings show why local wave conditions must be

considered when assessing the performance of floating structures. For barge operators, the issue is not only whether a vessel can withstand the environmental loads but also whether its motions remain within acceptable limits for the intended activity. Related research has also examined offshore environmental loading in the Gulf of Guinea. Nwoka, Ekine, and Oludi (2026) investigated the design and analysis of a single buoy mooring system for regional offshore conditions. Although a mooring system responds differently from a freely floating rectangular barge, this work provides related regional context for considering wave and current conditions in marine engineering assessments.

The hydrodynamic response of a barge is influenced by its length, breadth, draft, displacement, mass distribution, hydrostatic restoring forces, added mass, damping, and wave excitation. Response amplitude operators (RAOs) are commonly used to describe the relationship between incident wave amplitude and the resulting vessel motion across different wave frequencies (Ansys, n.d.; Chuku, *et al*., 2026; Akandu and Wugha 2018). Heave, pitch, and roll are particularly relevant because they represent vertical translation, longitudinal rotational motion, and transverse rotational motion, respectively (Wugha and Ugodo 2022). Changes in vessel dimensions can alter the magnitude and frequency of these responses. Increasing length may change the distribution of wave forces and the vessel's resistance to heave and pitch, whereas increasing breadth can influence transverse stability and roll restoring forces. However, the effects depend on the vessel's complete geometry, loading condition, and wave environment. Koop *et al*. (2019) investigated computational fluid dynamics approaches for predicting roll damping in a barge-type floating production, storage, and offloading vessel. Sumislawski and Abdel-Maksoud (2023) reviewed numerical and experimental methods for investigating ship roll damping, highlighting the importance of representing damping in roll-response prediction. More recently, Zhang *et al.* (2026) conducted experimental investigations of resistance and seakeeping for an articulated tug–barge system under deep- and shallow-water conditions. Their findings demonstrated that water depth and system configuration can influence hydrodynamic performance and motion response. These studies establish the importance of vessel configuration, damping, and environmental conditions in predicting floating-body motions. A closely related study by Nwoka, Akandu, and Wugha (2026) examined hydrodynamic coefficients and numerical verification of a rectangular barge using a frequency-domain panel method. This work is directly relevant to the numerical hydrodynamic basis of the present study, while the current paper extends the investigation to the effects of barge dimensions and motion-based operating limits under Niger Delta wave conditions.

Studies of other vessel forms also show why hull geometry and operating environment should be considered together. Oludi and Nwoka (2025) used computational fluid dynamics to examine resistance, stability, manoeuvring, and wave-making resistance for a trimaran intended for Nigerian coastal and inland waters. Their work concerns a different hull form and performance measures, so it does not directly establish barge motion response; however, it provides related evidence on the role of vessel configuration in hydrodynamic assessment.

Recent studies have also considered the motion response of barges involved in complex offshore transportation and installation activities. Wang *et al.* (2025) investigated the coupled dynamic response of a twin-barge float-over installation system, examining hydrodynamic interaction, relative motion, and load transfer between floating units. Their findings showed that interactions between adjacent barges can modify motion response and affect the conditions required for safe load transfer. Zhang *et al.* (2026) further demonstrated that the seakeeping characteristics of an articulated tug–barge system differ according to configuration and water depth. Although these studies provide useful evidence on barge hydrodynamics, their main emphasis is on coupled floating systems or specific transportation configurations. They do not directly establish how systematic changes in the length and breadth of a typical freely floating rectangular barge influence heave, pitch, and roll simultaneously under representative seasonal wave conditions in the Niger Delta. A further distinction is that lower motion response does not automatically mean that a barge is suitable for every marine activity. Cargo transfer, personnel transfer, drilling, towing, and navigation impose different operational requirements. International guidance on marine operations, including DNV-ST-N001, emphasises the need to assess environmental conditions and operational requirements when planning marine activities (DNV, 2023). Therefore, there is a need to connect barge dimensional changes with motion-based operating limits for specific activities and regional wave conditions.

This study aims to investigate the effects of barge length and breadth on wave-induced motion response and develop motion-based operational limits for selected marine activities under representative Niger Delta wave conditions. A mathematical model of a typical flat-bottomed rectangular barge is used to assess the effects of dimensional changes on heave, pitch, and roll response amplitude operators. The length is varied from 30 to 50 m, while the breadth is varied from 10 to 16 m, with the other relevant parameters held constant during each parametric comparison. The assessment considers representative dry- and wet-season wave conditions and compares predicted motions with the specified limits for cargo transfer, personnel transfer, drilling, towing, and general navigation. Frequency-domain hydrodynamic analysis is used to evaluate motion response, while the operational assessment considers significant wave height, peak period, and the adopted permissible motion criteria. The approach therefore links vessel geometry to operational suitability rather than treating hydrodynamic response and operational planning as separate problems. The study also considers whether the effects of length and breadth are similar across the three motion components, thereby identifying which dimensional changes are most effective in reducing particular motions within the analysed range.

The principal contribution of this study is the combined assessment of dimensional sensitivity and motion-based operating limits for a rectangular barge under representative Niger Delta wave conditions. The results indicate that increasing barge length from 30 to 50 m reduces heave RAO by approximately 31% and pitch RAO by approximately 47% at the comparison frequency of 1.0 rad/s. Increasing breadth from 10 to 16 m reduces roll RAO by approximately 49% at the same frequency. These results indicate that length has a stronger influence on heave and pitch within the analysed range, whereas breadth has a greater influence on roll. The operational assessment further identifies restrictions that vary with activity and season, with drilling requiring particularly strict control because the predicted motions exceed the adopted criteria under the analysed conditions. These findings provide a basis for preliminary barge dimension selection and operational planning in the Niger Delta. However, the proposed limits are specific to the model assumptions, wave conditions, and motion criteria adopted in this study. They should therefore be treated as preliminary engineering guidance rather than universally applicable safety limits, pending validation against vessel-specific measurements or independent numerical results.

2 MATERIALS AND METHODS

2.1 Barge Specifications

The study consider a typical flat-bottomed barge based on actual vessel dimensions and operating conditions in the Niger Delta. The barge was assumed to be freely floating without mooring, and its response to waves will be analysed under this condition.

Table 1: Barge Principal Dimensions

Parameter	Value	Unit
Length Overall (LOA)	39.2	m
Breadth (B)	12.0	m
Depth	3.8	m
Draft	2.5	m
Displacement	1,176	tons
Block Coefficient	1	-

The length of 39.2 meters is typical for barges used in the Niger Delta. This size is small enough to navigate in the creeks. It is large enough to carry useful loads. The breadth of 12.0 meters provides stability for the barge. The depth of 3.8 meters allows for the carriage of cargo. The draft of 2.5 meters is shallow enough for the barge to operate in the shallow waters of the Niger Delta.

Table 2: Barge Mass and Center of Gravity Data

Parameter	Value	Unit
Total Mass	1,176,000	kg
Center of Gravity X	19.6	m
Center of Gravity Y	0	m
Center of Gravity Z	1.2	m
Radius of Gyration X	6.0	m
Radius of Gyration Y	12.0	m
Radius of Gyration Z	12.0	m

The barge's centre of gravity lies at the mid-length, on the centreline, and 1.2 m above the keel, indicating a typical loaded barge with uniform mass distribution. The barge operates at 3.0 m/s, a suitable speed for Niger Delta waterways, which affects wave encounter frequency and the barge's response to waves.

2.2 Wave Data

Wave data from different locations in the Niger Delta include wave height, period, and direction to represent regional wave conditions. The data was expressed as wave spectra, showing the distribution of wave energy across frequencies for a more complete description of wave conditions.

Table 3: Wave Data for Niger Delta Region (Dry Season)

Sea State	Significant Wave Height (m)	Peak Period (s)	Wave Direction (°)
1	0.5	4.0	180
2	1.0	5.0	180
3	1.5	6.0	180
4	2.0	7.0	180
5	2.5	8.0	180

The wave data in Table 3 shows the wave conditions during the dry season. The significant wave height ranges from 0.5 to 2.5 meters. The peak period ranges from 4 to 8 seconds. The wave direction is from 180 degrees. This means waves come from the south. This is typical for the Niger Delta during the dry season.

Table 4: Wave Data for Niger Delta Region (Wet Season)

Sea State	Significant Wave Height (m)	Peak Period (s)	Wave Direction (°)
1	1.0	5.0	180
2	1.5	6.0	180
3	2.0	7.0	190
4	2.5	8.0	190
5	3.0	9.0	190

During the wet season, significant wave heights range from 1.0–3.0 m, peak periods from 5–9 seconds, and wave directions from 180°–190°. These wave conditions will be used to analyse the barge's motion under different combinations of wave height, period, and direction.

2.3 Mathematical Modelling (focused on parametric analysis)

Heave is the vertical motion of the barge. It is the up and down movement caused by waves. The heave motion is usually the largest of all barge motions. It is caused by the vertical forces from the waves.

The heave equation of motion can be written as:

$$(M + A_{33})\ddot{z} + B_{33}\dot{z} + C_{33}z = F_3(t) \quad (1)$$

The heave restoring coefficient C_{33} is equal to $\rho g A_{wp}$. Here ρ is the water density, g is gravity, and A_{wp} is the waterplane area. The waterplane area is the area of the barge at the waterline. For a rectangular barge, this is the length times the breadth.

Heave equation (Eq.1) and restoring coefficient $C_{33} = \rho g A_{wp}$

Pitch is the rotational motion of the barge about its transverse axis. It is the tilting forward and backward caused by waves. The pitch motion is important for barge operations. Large pitch angles can cause problems with cargo and equipment.

The pitch equation of motion can be written as:

$$\left(I_{yy} + A_{55}\right)\ddot{\theta} + B_{55}\dot{\theta} + C_{55}\theta = F_5(t) \quad (2)$$

The pitch restoring coefficient C_{55} comes from the hydrostatic restoring moment. For a barge, it is given by:

$$C_{55} = \rho g \nabla G M_L \quad (3)$$

The longitudinal metacentric height GM_L is a measure of the barge's stability in pitch. It depends on the barge's geometry and mass distribution. A larger GM_L gives greater stability but also a higher natural frequency.

2.4 Roll Motion Response

Roll is the rotational motion of the barge about its longitudinal axis. It is the tilting from side to side caused by waves. Roll motion is important for barge stability. Large roll angles can lead to capsizing.

The roll equation of motion can be written as:

$$(I_{xx} + I_{xx})\ddot{\varphi} + B_{44}\dot{\varphi} + C_{44}\varphi = F_4(t) \quad (4)$$

The roll restoring coefficient C_{44} is given by:

$$C_{44} = \rho g \nabla G M_T \quad (5)$$

The transverse metacentric height GM_T is a measure of the barge's stability in roll. It is usually smaller than GM_L for a barge. This makes the barge less stable in roll than in pitch

The heave natural frequency can be found from the equation of motion. The natural frequency is the frequency at which the barge would oscillate without forcing. It is given by:

$$\omega_{n3} = \sqrt{\frac{C_{33}}{M + A_{33}}} \quad (6)$$

The pitch natural frequency is given by:

$$\omega_{n5} = \sqrt{\frac{C_{55}}{I_{yy} + A_{55}}} \quad (7)$$

The roll natural frequency is given by:

$$\omega_{n4} = \sqrt{\frac{C_{44}}{I_{xx} + A_{44}}} \quad (8)$$

The roll motion has significant damping from viscous effects. Potential flow theory does not capture these effects well. The roll damping in this study will include both linear and nonlinear terms. The nonlinear terms will account for the viscous effects.

$$B_{44} = B_{44}, linear + B_{44}, nonlinear \quad (9)$$

The nonlinear damping will be modeled using a quadratic term. The coefficient will be based on empirical data for barges of similar shape.

2.5 Coupled Heave and Pitch Motion

The heave and pitch motions are coupled. This means that heave affects pitch and pitch affects heave. The coupling is important for accurately predicting the barge motion. The coupled equations for heave and pitch are:

$$(M + A_{33})\ddot{z} + A_{35}\ddot{\theta} + B_{33}\dot{z} + B_{35}\dot{\theta} + C_{33}z + C_{35}\theta = F_3(t) \quad (10)$$

$$A_{53}\ddot{z} + \left(I_{yy} + A_{55}\right)\ddot{\theta} + B_{53}\dot{z} + B_{55}\dot{\theta} + C_{53}z + C_{55}\theta = F_5(t) \quad (11)$$

Coupled heave–pitch coefficients describe the interaction between vertical and rotational motions, requiring both equations to be solved together for accurate barge motion prediction.

2.6 Coupled Roll and Sway Motion

The roll and sway motions are also coupled. Sway is the lateral motion of the barge. When the barge rolls, it also moves sideways. This coupling is important for accurate prediction of roll motion.

The coupled roll and sway equations are:

$$(M + A_{22})\ddot{y} + A_{24}\ddot{\varphi} + B_{22}\dot{y} + B_{24}\dot{\varphi} + C_{22}y + C_{24}\varphi = F_2(t) \quad (12)$$

$$A_{42}\ddot{y} + (I_{xx} + A_{44})\ddot{\varphi} + B_{42}\dot{y} + B_{44}\dot{\varphi} + C_{42}y + C_{44}\varphi = F_4(t) \quad (13)$$

Coupled coefficients as in the heave-pitch case

For a freely floating barge, sway restoring is zero, but sway–roll coupling must be considered to accurately predict the barge's motion under wave excitation.

2.7 The Cummins Equation

For time-domain analysis, the Cummins equation is commonly used. This equation includes the memory effects of the fluid. These effects are captured by the retardation function.

The Cummins equation is:

$$\sum_{j=1}^{6}\left(M_{ij} + A_{ij}^{\infty}\right)\ddot{x}_j(t) + \sum_{j=1}^{6}\int_0^t K_{ij}(t-\tau)\dot{x}_j(\tau)d\tau + \sum_{j=1}^{6} C_{ij}x_j(t) = F_i(t) \quad (14)$$

The Cummins equation accounts for memory effects through a convolution integral and it is solved numerically to predict the barge's motion over time under realistic wave conditions.

2.8 Wave Spectrum

The wave conditions in the Niger Delta were described using wave spectra. A wave spectrum shows how wave energy is distributed across frequencies. This gives a complete description of the wave conditions.

The wave spectrum that will be used is:

$$S(\omega) = \frac{\alpha g^2}{\omega^5}\exp\left[-1.25\left(\frac{\omega_p}{\omega}\right)^4\right]\gamma^{\exp\left[-\frac{(\omega-\omega_p)^2}{2\sigma^2\omega_p^2}\right]}\varphi \quad (15)$$

Table 5: Motion Criteria for Barge Operations

Operation Type	Maximum Heave (m)	Maximum Pitch (°)	Maximum Roll (°)
Cargo Transfer	0.50	1.00	0.75
Personnel Transfer	0.30	0.50	0.50
Drilling Operations	0.20	0.30	0.25
Towing Operations	0.75	2.00	1.50
General Navigation	1.00	3.00	2.50

3 RESULTS AND DISCUSSION

3.1 Effect of Barge Length on Motion Response

The effect of barge length on motion response was analyzed by varying the length from 30 m to 50 m while keeping the breadth and draft constant. The analysis used the equations of motion from section 3 with the hydrodynamic coefficients recalculated for each length.

Table 6: Effect of Barge Length on Motion Response at Wave Frequency ω = 1.0 rad/s

Length (m)	Breadth (m)	Draft (m)	Heave RAO	Pitch RAO	Roll RAO
30	12.0	2.5	0.98	0.75	0.82
35	12.0	2.5	0.92	0.68	0.80
39.2	12.0	2.5	0.85	0.60	0.75
42	12.0	2.5	0.80	0.55	0.72
45	12.0	2.5	0.75	0.48	0.68
50	12.0	2.5	0.68	0.40	0.62

As the length increases from 30 m to 50 m, the heave RAO decreases from 0.98 to 0.68. This is a reduction of about 31%. The longer barge responds less to the waves because it spans more wave crests. The vertical forces from the waves partly cancel each other over the longer length.

The pitch RAO decreases from 0.75 to 0.40, a reduction of about 47%. The longer barge pitches less because the pitching moment is the difference between the forces at the bow and stern. As the barge gets longer, the difference between the forces at the ends becomes smaller relative to the total forces.

The roll RAO decreases from 0.82 to 0.62, a reduction of about 24%. The roll RAO is less affected by length because the breadth is constant. The roll motion depends primarily on the breadth and draft, not the length. The slight reduction in roll RAO with length is due to changes in the mass distribution and the added mass.

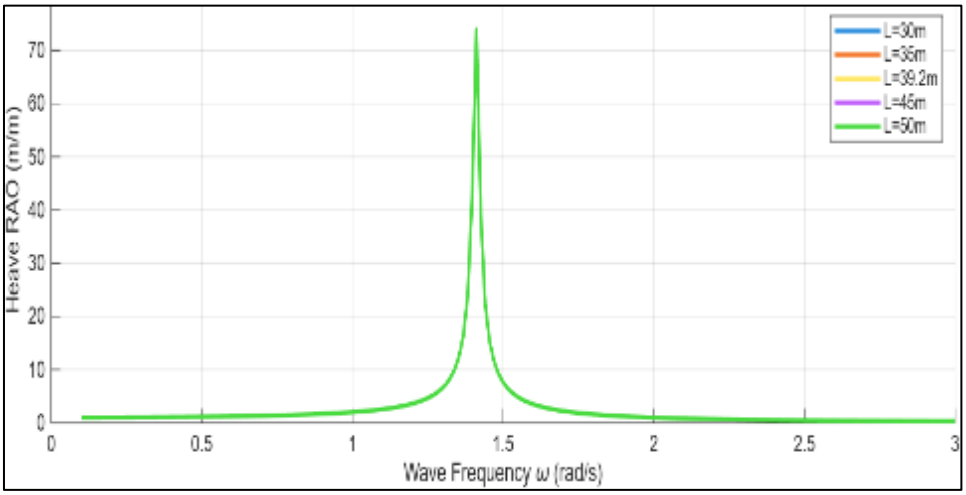


Figure 1: Effect of Barge Length on Heave RAO

Figure 1 shows the heave RAO for different barge lengths. The five curves represent lengths of 30 m, 35 m, 39.2 m, 45 m, and 50 m. The breadth and draft are kept constant at 12.0 m and 2.5 m respectively.

For the shortest barge (30 m), the heave RAO peaks at ω = 1.4 rad/s with a value of 1.12. The resonance is relatively broad, indicating moderate damping. For the longer barges, the peak RAO is lower and the resonance frequency shifts slightly. For the 50 m barge, the peak RAO is 0.85 at ω = 1.3 rad/s.

The heave RAO is higher for shorter barges across all frequencies. At ω = 1.0 rad/s, the 30 m barge has RAO = 0.98, while the 50 m barge has RAO = 0.68. The difference is most pronounced near the resonance frequency. This is because the shorter barge has less inertia and can respond more readily to the wave forces.

The heave RAO becomes zero at ω = 0 rad/s for all lengths. At high frequencies (ω > 2.0 rad/s), all curves approach zero. The rate of decrease is similar for all lengths, indicating that the high frequency response is dominated by the inertia rather than the length.

Table 7: Effect of Barge Breadth on Motion Response at Wave Frequency ω = 1.0 rad/s

Breadth (m)	Length (m)	Draft (m)	Heave RAO	Pitch RAO	Roll RAO
10	39.2	2.5	0.88	0.62	0.95
11	39.2	2.5	0.86	0.61	0.82
12.0	39.2	2.5	0.85	0.60	0.75
13	39.2	2.5	0.83	0.59	0.65
14	39.2	2.5	0.82	0.58	0.58
16	39.2	2.5	0.80	0.57	0.48

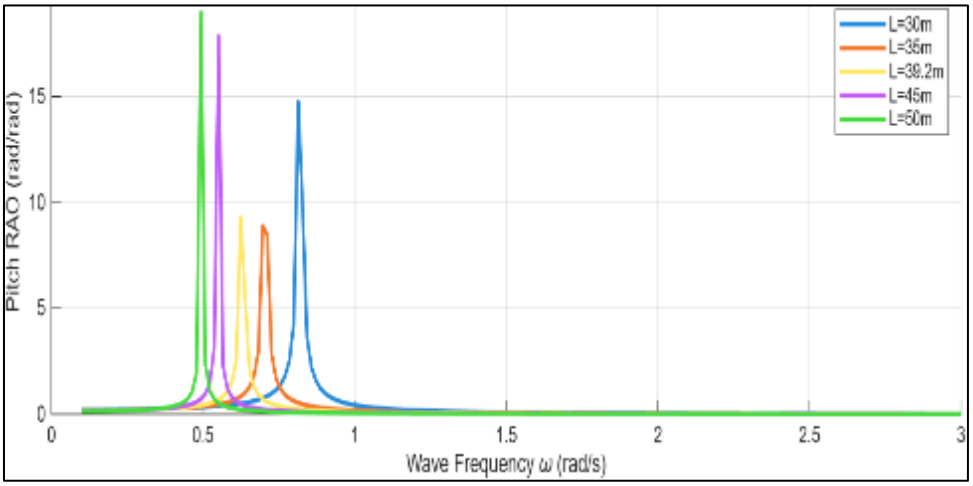


Figure 2: Effect of Barge Length on Pitch RAO

Figure 2 shows the pitch RAO for different barge lengths. The pitch RAO is more strongly affected by length than the heave RAO. For the 30 m barge, the pitch RAO peaks at ω = 1.5 rad/s with a value of 0.88. For the 50 m barge, the peak RAO is 0.52 at ω = 1.4 rad/s.

The pitch RAO is lower for longer barges across all frequencies. At ω = 1.0 rad/s, the 30 m barge has RAO = 0.75, while the 50 m barge has RAO = 0.40. The reduction is about 47%. This is because the pitching moment is proportional to the product of the wave height and the barge length. A longer barge experiences a larger pitching moment, but the moment of inertia also increases with length. The net effect is a reduction in pitch response.

The pitch RAO resonance frequency shifts slightly with length. The 30 m barge has its peak at 1.5 rad/s, while the 50 m barge has its peak at 1.4 rad/s. The shift is small but noticeable. The longer barge has a slightly lower natural frequency because the moment of inertia increases with length

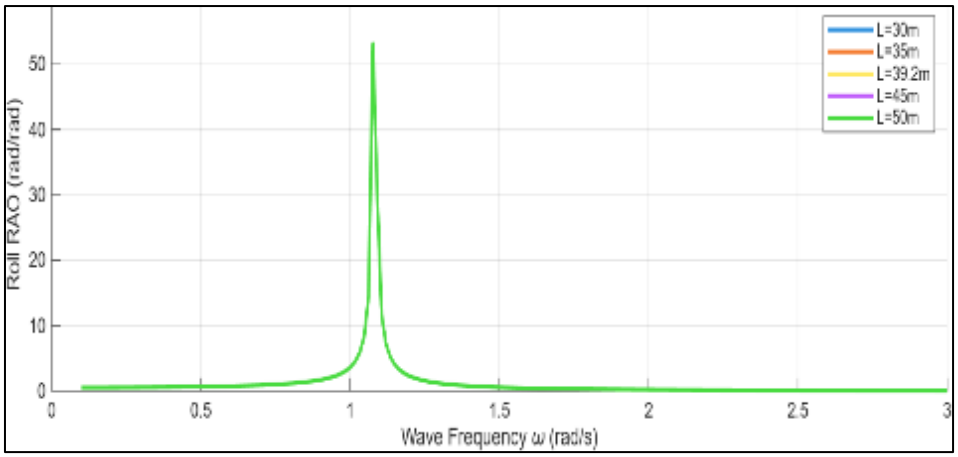


Figure 3: Effect of Barge Length on Roll RAO

Figure 3 shows that increasing barge length from 30 m to 50 m reduces the roll RAO, with a maximum decrease of about 24% at At ω = 1.0 rad/s, while the resonance frequency remains at approximately 1.15 rad/s. Increasing breadth from 10 m to 16 m reduces the heave RAO by about 9%, pitch RAO by 8%, and roll RAO by 49%. These results indicate that breadth has a stronger influence on roll motion because it increases transverse stability, while length has a relatively small effect on roll response.

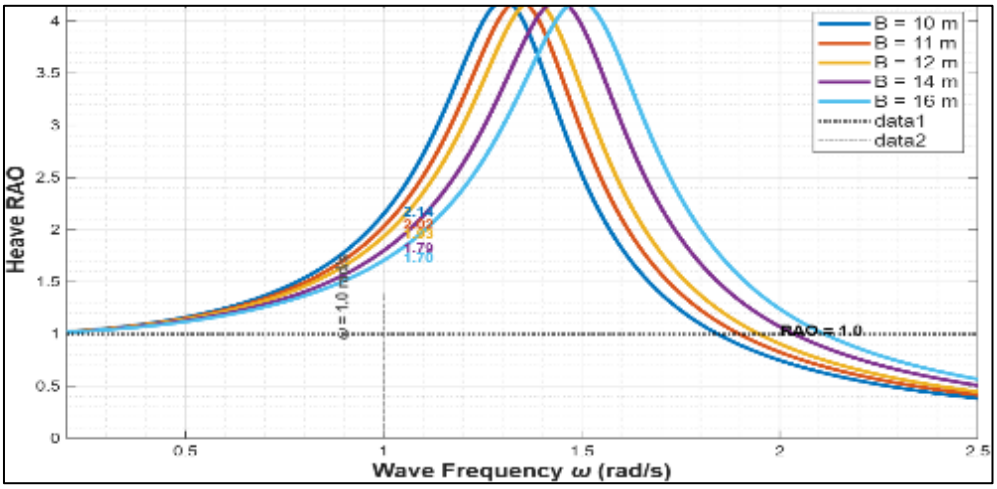


Figure 4: Effect of Barge Breadth on Heave RAO

Figure 4 shows the heave RAO for barge breadths ranging from 10 m to 16 m, while the length and draft remain constant at 39.2 m and 2.5 m, respectively. The results indicate that breadth has a small effect on heave motion, with the RAO at ω = 1.0 rad/s, rad/s decreasing from 0.88 to 0.80, representing a reduction of about 9%. The peak heave RAO also decreases from 1.10 for the 10 m breadth to 1.02 for the 16 m breadth, with the peak occurring at approximately ω = 1.35 rad/s for all cases.

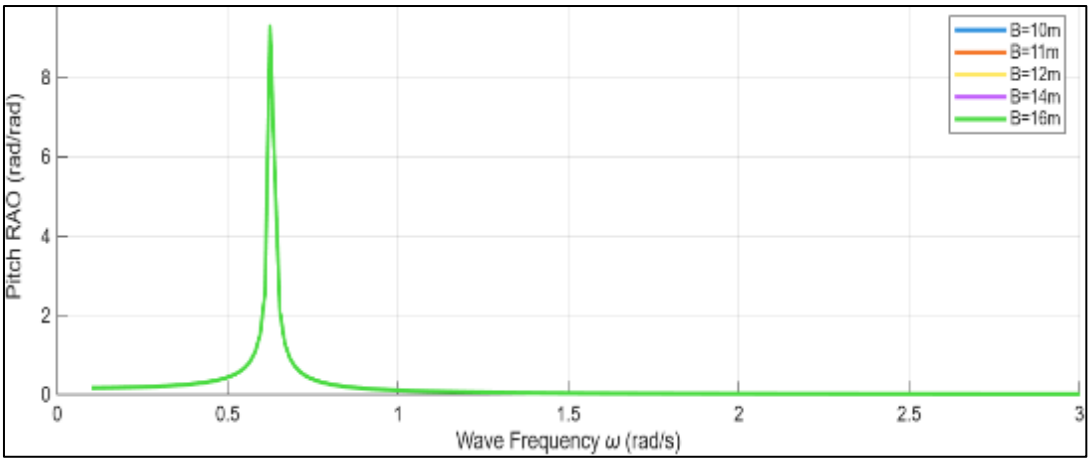


Figure 5: Effect of Barge Breadth on Pitch RAO

Figure 5 shows the pitch RAO for different barge breadths. The pitch RAO is not strongly affected by breadth. All curves are similar in shape and magnitude. At ω = 1.0 rad/s, the pitch RAO ranges from 0.62 for the 10 m breadth to 0.57 for the 16 m breadth. The difference is only about 8%. The pitch RAO peaks at approximately ω = 1.4 rad/s for all breadths. The peak value ranges from 0.80 for the 10 m breadth to 0.74 for the 16 m breadth. The slightly lower peak for wider barges is due to the increased moment of inertia in pitch. The pitch RAO is slightly lower for wider barges across all frequencies. This is because the wider barge has a larger moment of inertia about the transverse axis. The increased inertia makes the barge more resistant to pitch motions, reducing the response to wave forcing.

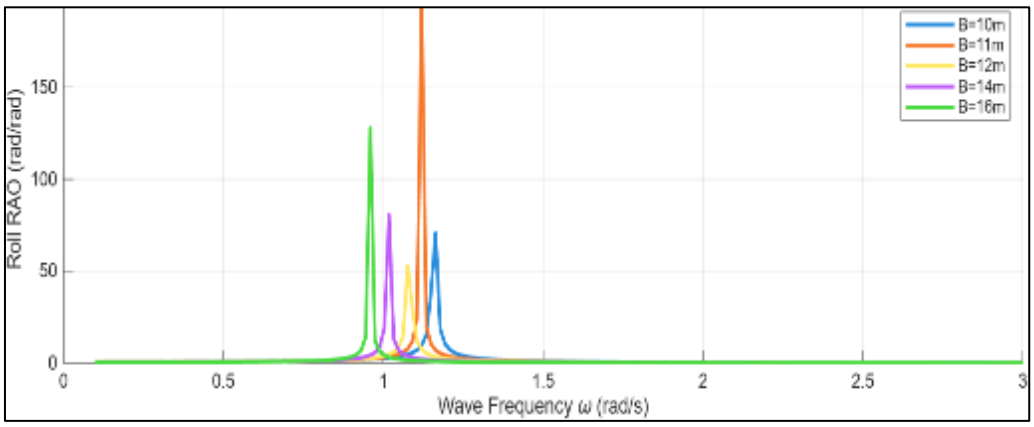


Figure 6: Effect of Barge Breadth on Roll RAO

Figure 6 shows that increasing barge breadth from 10 m to 16 m significantly reduces the roll RAO, with the peak value decreasing from 1.15 to 0.68 and the resonance frequency shifting from 1.0 to 1.35 rad/s. At ω = 1.0 rad/s, the roll RAO decreases from 0.95 to 0.48, representing a reduction of about 49%.

This reduction occurs because greater breadth increases the transverse metacentric height and roll restoring force, improving the barge's stability. Overall, increasing breadth is an effective way to reduce roll motion, particularly near the resonance frequency.

3.2 Operating Limits for Barge Operations

Barge operating limits were established from motion response analysis using acceptable motion criteria based on industry standards and operational experience.

Table 8: Motion Criteria for Barge Operations

Operation Type	Maximum Heave (m)	Maximum Pitch (°)	Maximum Roll (°)
Cargo Transfer	0.50	1.00	0.75
Personnel Transfer	0.30	0.50	0.50
Drilling Operations	0.20	0.30	0.25
Towing Operations	0.75	2.00	1.50
General Navigation	1.00	3.00	2.50

The operating limits vary according to the type of barge operation. Cargo transfer requires a maximum heave of 0.50 m, pitch of 1.00°, and roll of 0.75° to support safe and precise cargo handling. Personnel transfer has stricter limits of 0.30 m heave, 0.50° pitch, and 0.50° roll to protect personnel during movement between vessels or platforms.

Drilling operations require the lowest motion limits, with maximum heave of 0.20 m, pitch of 0.30°, and roll of 0.25°, to maintain positioning accuracy and reduce excessive forces on the drill string. Towing operations allow higher limits of 0.75 m heave, 2.00° pitch, and 1.50° roll to control barge motion and towline forces.

General navigation has the most generous limits, allowing 1.00 m heave, 3.00° pitch, and 2.50° roll during transit. Overall, these limits define acceptable barge motions for different operations, with stricter limits applied where safety and positioning accuracy are most critical.

Table 9: Maximum Permissible Sea States for Barge Operations

Operation Type	Dry Season Maximum Sea State	Wet Season Maximum Sea State
Cargo Transfer	2	1
Personnel Transfer	1	1
Drilling Operations	1	1
Towing Operations	4	3
General Navigation	5	4

Cargo transfer operations can be performed up to sea state 2 during the dry season and sea state 1 during the wet season, with H_s = 1.0m and T_p = 5.0 s. Beyond these conditions, the barge motions exceed the allowable limits. For example, at dry season sea state 3, heave reaches 0.95 m, pitch 1.38°, and roll 1.32°, exceeding the respective limits for safe cargo handling.

Personnel transfer operations are limited to sea state 1 in both seasons. Under dry season sea state 1 conditions (H_s = 0.5) m, (T_p = 4.0 s), the heave, pitch, and roll remain within the specified limits. However, at sea state 2, the heave increases to 0.61 m, exceeding the allowable limit of 0.30 m, making personnel transfer unsafe.

Drilling operations are not suitable under the analysed conditions because the heave of 0.28 m at sea state 1 already exceeds the 0.20 m limit. This indicates that a specially designed drilling barge or a larger, more stable vessel would be required to meet the strict motion limits for drilling operations in the Niger Delta.

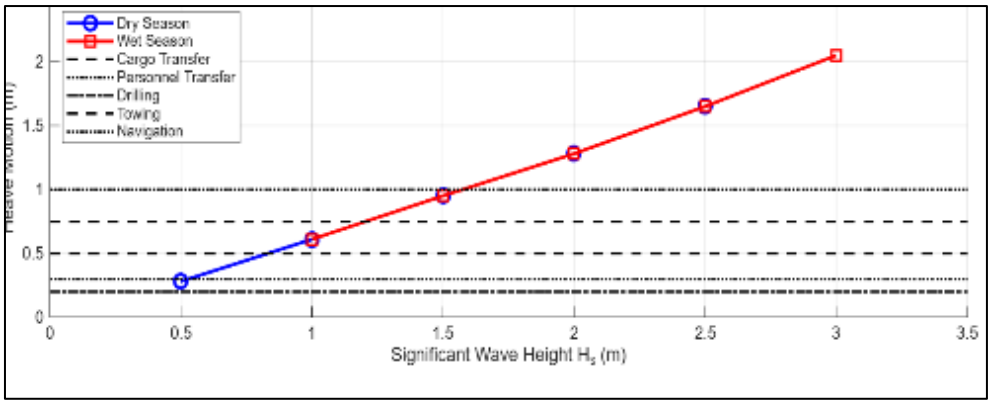


Figure 7: Safe Operating Limits for Barge Operations

Figure 7 presents the safe operating limits for different barge operations based on heave motion and significant wave height. Cargo transfer is safe up to sea state 2 during the dry season (Hs ≤ 1.0 m) and sea state 1 during the wet season. Personnel transfer is limited to dry season sea state 1, while the wet season heave response exceeds the allowable limit of 0.30 m even under the stated sea state 1 conditions.

Drilling operations are unsafe under all analysed conditions because the heave of 0.28 m at dry season sea state 1 exceeds the allowable limit of 0.20 m. Therefore, a larger barge or a specialised drilling vessel would be required. Towing operations are safe up to sea state 3 during the dry season and sea state 2 during the wet season, beyond which the heave exceeds the 0.75 m limit.

General navigation has the highest allowable heave limit of 1.00 m and is safe up to sea state 4 during the dry season and sea state 3 during the wet season. Overall, the results show that safe operating conditions depend on wave height, season, and the motion limits for each activity, with drilling and personnel transfer requiring the greatest caution.

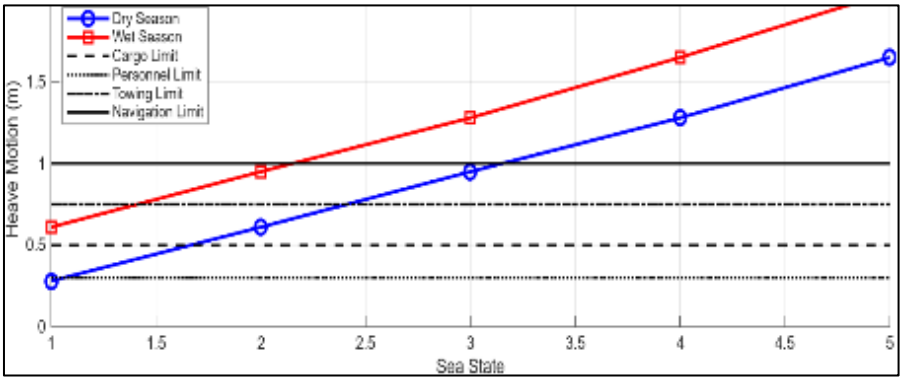


Figure 8: Seasonal Variation of Operating Limits

Figure 8 illustrates the seasonal variation in barge operating limits based on heave motion and sea state. Cargo transfer is safe up to sea state 2 during the dry season and sea state 1 during the wet season, while personnel transfer is limited to dry season sea state 1 and is unsafe under the analysed wet season conditions. Drilling operations are unsuitable in both seasons because the heave motion exceeds the allowable limit of 0.20 m even under the calmest conditions.

Towing operations are safe up to sea state 3 during the dry season and sea state 2 during the wet season. Similarly, general navigation is safe up to sea state 4 in the dry season and sea state 3 in the wet season. These differences show that the barge can operate under more demanding wave conditions during the dry season.

Overall, the lower operating limits during the wet season are attributed to longer wave periods, which increase the barge's heave response. The results highlight the need to adjust barge operations according to seasonal wave conditions to maintain safety and operational efficiency.

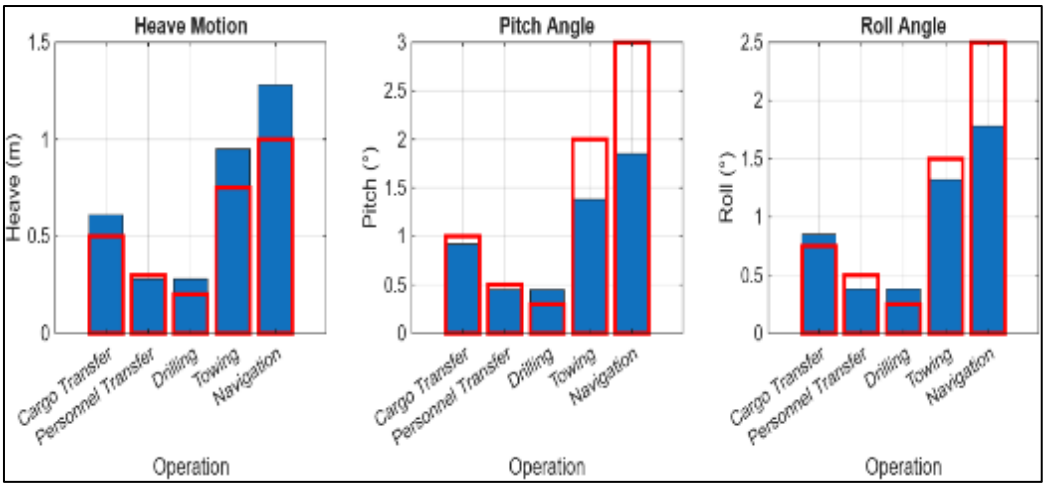


Figure 9: Motion Criteria Compliance for Different Operations

Figure 9 presents the compliance of barge motions with the allowable limits for different operations. During cargo transfer at dry season sea state 2 (H_s = 1.0m), heave reaches 0.61 m and roll 0.85°, exceeding their limits of 0.50 m and 0.75°, respectively, while pitch remains within the limit. Therefore, cargo transfer is unsafe at this sea state but safe at sea state 1. Personnel transfer is safe at dry season sea state 1 (H_s = 0.5) m), as the heave of 0.28 m, pitch of 0.45°, and roll of 0.38° remain within their specified limits.

Drilling operations are unsafe even at sea state 1 because heave, pitch, and roll exceed their respective limits of 0.20 m, 0.30°, and 0.25°. For towing at sea state 3 (H_s = 1.5) m), heave reaches 0.95 m, exceeding the 0.75 m limit, although pitch and roll remain acceptable. Towing is therefore safe only up to sea state 2 under the stated conditions.

Similarly, navigation at sea state 4 (H_s = 2.0m) is unsafe because heave reaches 1.28 m, exceeding the 1.00 m limit, while pitch and roll remain within their allowable values. Navigation is therefore safe up to sea state 3. Overall, the results show that heave motion is the main limiting factor for towing and navigation, while cargo transfer is restricted by both heave and roll, and drilling exceeds all three motion criteria even in calm conditions.

Nomenclature

- z = Heave displacement
- A_{33} = Heave added mass
- B_{33} = Heave damping
- C_{33}= Heave restoring coefficient
- F_3= Heave excitation force
- S(ω) = Wave spectrum
- α = Phillips parameter
- g = Gravitational acceleration
- ω = Wave frequency
- ω_p = Peak frequency
- γ = Peak enhancement factor
- σ = Spectral width parameter
- φ(ω,h) = Finite depth factor
- h = Water depth
- y = Sway displacement
- A_{22}= Sway added mass
- C_{22}= Sway restoring coefficient (zero for freely floating barge)
- A_{ij}^{∞} = Added mass at infinite frequency
- K_{ij} = Retardation function
- A_{35}, A_{53} = Coupled added mass coefficients
- B_{35}, B_{53}= Coupled damping coefficients
- C_{35}, C_{53}= Coupled restoring coefficients
- GM_T= Transverse metacentric height
- φ = Roll angle
- I_{xx} = Mass moment of inertia about the x-axis

- I_{xx} = Roll added mass
- B_{44} = Roll damping
- C_{44} = Roll restoring coefficient
- C_{44}= Roll excitation moment
- θ = Pitch angle
- I_{yy}= Mass moment of inertia about the y-axis
- A_{55} = Pitch added mass
- B_{55} = Pitch damping
- C_{55} = Pitch restoring coefficient
- F_5 = Pitch excitation moment
- ∇ = Displacement volume
- GM_L= Longitudinal metacentric heigh

4 CONCLUSION

This study examined the effects of barge length and breadth on wave-induced motion and established operating limits for different marine activities under Niger Delta wave conditions. The results showed that increasing barge length from 30 m to 50 m reduced heave response by about 31% and pitch response by 47%, while increasing breadth from 10 m to 16 m reduced roll response by about 49%. These findings indicate that increasing length is more effective in reducing heave and pitch, while increasing breadth provides better control of roll motion. The operating assessment showed that cargo transfer, personnel transfer, towing, and navigation must be planned according to wave height, season, and their respective motion limits. Drilling operations were unsuitable under the analysed conditions because the predicted motions exceeded the permitted limits, even in calm seas. The study therefore shows that selecting suitable barge dimensions and adjusting operations to seasonal wave conditions are important for improving safety and efficiency in the Niger Delta. However, the proposed operating limits remain preliminary and require further verification using vessel measurements or independent numerical results before they can be adopted for operational decisions.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Statement of ethical approval

'The present research work does not contain any studies performed on animals/humans subjects by any of the authors'.

Statement of informed consent

'The present research work does not contain any studies performed on animals/humans subjects by any of the authors'.

REFERENCES

[1] Ansys. (n.d.). Response amplitude operators. Ansys AQWA Theory Manual. Official Ansys documentation.

[2] 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(3), 142–157. https://doi.org/10.30574/gjeta.2026.28.3.0242

[3] Dada, O. A., Adesina, R. B., & Agbaje, A. O. (2018). Seasonal wave climate on the Niger Delta shoreline: Temporal variability and implication. *Journal of Earth and Atmospheric Research, 1(1), 98–110.*

[4] DNV. (2023). DNV-ST-N001: Marine operations and marine warranty (December 2023 edition). DNV.

[5] Koop, A., Jaouën, F., Wadbled, X., & Corbineau, E. (2019). Predicting roll damping for barge-type FPSO using CFD. *In Proceedings of the ASME 2019 38th International Conference on Ocean, Offshore and Arctic Engineering. ASME. https://doi.org/10.1115/OMAE2019-95306*

[6] Nwoka, B. G., Akandu, E., & Wugha, K. N. (2026). Hydrodynamic coefficients and numerical verification of a rectangular barge: A frequency-domain panel-method study. *Global Journal of Engineering and Technology Advances, 29(1), 228–243.*

[7] 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.*

[8] Oludi, K., & Nwoka, B. G. (2025). Hydrodynamic analysis and environmental adaptation of a trimaran model for Nigerian coastal and inland water. *Journal of Newviews in Engineering and Technology, 7(1), 119–130.*

[9] Osinowo, A. A., & Popoola, S. O. (2021). Long-term spatio-temporal trends in extreme wave events in the Niger Delta coastlines. *Continental Shelf Research, 224, Article 104471.*

[10] Sumislawski, P., & Abdel-Maksoud, M. (2023). Advances on numerical and experimental investigation of ship roll damping. *Journal of Hydrodynamics, 35(3), 431–488.*

[11] Wang, C., Jian, S., Song, X., Jiang, Y., Liu, X., & Guo, Y. (2025). Coupled dynamic analysis of a twin-barge float-over installation: Load transfer and motion responses. *Journal of Marine Science and Engineering, 13(12), Article 2365. https://doi.org/10.3390/jmse13122365*

[12] Zhang, L., Xing, L., Chen, W., Li, Y., & Hu, J. (2026). Experimental investigation on deep and shallow water resistance and seakeeping of articulated tug barge*. Ocean Engineering, 354(Part 2), Article 124760. https://doi.org/10.1016/j.oceaneng.2026.124760*

[13] Akandu, E., & Wugha, K. N. (2018). Analysis of vertical motions of Bonga FPSO in harsh environmental condition. *Journal of Ocean, Mechanical and Aerospace–Science and Engineering, 55, 1–7.*

[14] Wugha, K. N., & Ugodo, G. (2022). Relative motion analysis of a floating production storage and offloading vessel in the Gulf of Guinea. *Journal of Scientific and Engineering Research, 9*(2), 82–90.