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Longitudinal Structural Strength Characterization of a Deep-U Catamaran Vessel

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ABSTRACT

This paper sets out to characterize the structural behaviour of a Cork composite hullform of a deep-U Catamaran vessel (DUC) based on the conventional longitudinal shear force and bending moment theory and Henky's von-Mises Stress criteria. It considered the longitudinal Still-water and Maximum Global wave induced loads on the vessel. Further, it ascertained the deformation and stresses imposed on the structure as a result of both the Still-water and wave-induced loads. The Still-water loads utilized existing conventional principles, whereas the wave-induced loads were derived from the vessel's hydrodynamic motion characterization based on the Modified Pierson Moskowitz Spectrum for narrow banded wave and benign sea state, solved through the numerical analysis on the ANSYS. From the analysis on the global longitudinal shear force (kN), the hogging and sagging shear forces exhibit similar trends, with initial increases, fluctuations, sharp reversals, and gradual recoveries. Both forces reach their maximum values at different vessel length. Results of the real time simulation of the structural response of the DUC vessel showed the still-water shear force had a maximum -100 kN and 100kN crest and trough values respectively. The maximum global longitudinal bending moment exhibited a hogging bending moment starts at 0 and increases steadily, reaching a peak of 1250 kNm at vessel length of 4m. After reaching the peak, the moment decreases, going down to -20 kNm at 7.9m, indicating a slight downward bend at the ends. The sagging bending moment starts at 0, increases to a peak of 910 kNm at vessel length of 4.5m, and then decreases quadratically to -8 kNm at 7.9m. This indicates a significant downward bend in the middle section of the structure. Both curves demonstrate the variation in bending moments along the length of the structure. Wave crest acting at fore and aft perpendicular of the DUC vessel hull had loads of 103kN at the midsection of hull and near the midship a load of 51.5kN at two corners on the deck surface of the vessel were applied. This resulted in the maximum total deformation of 1.8229e-004m and maximum shear stress of 1.44MPa. The equivalent Henky's von-Mises stress criteria of 2.8677M6Pa was statically lower than the ultimate strength of 3.0MPa of the Cork composite. By this results, the structural integrity of the DUC vessel is not threatened.

Key words: Numerical, Structural, Catamaran, Strength, von-Mises

I. INTRODUCTION

Catamarans, characterized by their twin-hull structure, have garnered significant attention in marine engineering for their stability, efficiency, and versatility across various applications, including passenger transport, military use, and recreational boating. Understanding the structural response behaviour of catamaran vessels under different loading conditions is critical for optimizing design and ensuring safety.

The design of a vessel structure generally involves an expert selection of the materials that are required in order to withstand numerous forces due to static loads, dynamic wave loads, hydrostatic pressures, lightship of the vessel and its components. Therefore, the forces and the resulting combinations of stresses and moments (bending and torsional) which act on the hull structure must be adequately estimated so that the structural integrity of the vessels is sufficient for its intended through-life time mission.Recent studies have focused on optimizing the structural layout of catamarans to enhance torsional stiffness without significantly increasing weight. Gao et al. (2022) employed optimization techniques based on FEA to redesign the cross-deck structure, achieving a balance between structural strength and weight reduction. Their findings suggest that optimizing internal stiffeners and employing lightweight materials such as carbon fiber composites can significantly improve the torsional stiffness of catamarans. In addition, the structure must be fit for purpose both in terms of strength, stiffness, fatigue life and cost. The ability of a vessel to maintain its smooth operations through-life depends largely on the accurate determination of its hydrodynamic behaviour especially it resistance characteristics (Chuku et al, 2017).

The core objective of this pape is to investigate the structural response behaviour of the composite cork material of the Deep-U keel hull structure to the various Still-water and wave induced loads that have been predicted and this will be performed in two distinct facets, which are;

i. Analyzing the Still-water and Maximum global shear force and bending moment in longitudinal direction of the vessel;
ii. Assessing the strength hull structure through Henky's von-Mises stress criteria.

Therefore this paper seeks to carryout structural response characterization of the prototype Deep-U Catamaran vessel based on conventional Bending Stress Equations.

This research considered the global longitudinal shear force and bending moment in hogging and sagging conditions.

II. MATERIALS AND METHODS

2.1 Materials

2.1.1 Material Properties of the Hull Structure of the Deep-U Catamaran Vessel

The mission requirement for this design is specifically to combat debris in the coastal areas and as such, it is important that a lightweight vessel is utilized. Since, Catamaran vessels are essentially prone to complex geometrical configurations, it is only reasonable that a lightweight environmentally friendly material, though strong enough to withstand stress is deployed.

The composite of cork reinforced polymers will be used as the main structural materials in the design of the Deep-U keel catamaran vessel. The selected properties of the material are given in Table (1).

Table (1): Mechanical Properties of Cork Composite Material

Material Properties	Value
Material composition	Cork Composite
Relative density (t/m^3)	0.235
Young's Modulus of Elasticity (GPa)	230GPa
Poisson Ratio	0.3
Shear Modulus	8GPa
Yield Stress	0.5MPa
Ultimate Strength	1.5-3.0MPa

The composite can be fabricated or moulded as the case maybe and does not have compatibility challenges with other materials used in its alloy. The cork fibre composite material is widely applicable in the high speed craft construction duly because of the benefits it confers in terms of environmental sustainability, corrosion resistance, toughness, relative high strength and lightweight.

2.1.2 The Boundary Conditions

The structural coordinates and boundary conditions are more explicitly stated in the ANSYS simulated results attached as seen in Tables (2) and (3).

Table (2): Definition of the Structural Coordinate System

Coordinate	Direction
X,	Longitudinal direction
Y,	Vertical direction
Z,	Transverse direction

Table (3): Boundary Conditions that were applied to the Deep-U Catamaran Vessel Finite Element Model

Type of Constraints	Position of the Constraints
FIXED-X, FIXED-Y,FIXED-Z	X=0.0m;Y =1.01m & Z= -3.01m
FREE-X, FIXED-Y, FREE-Z	X=0.0m;Y =1.01m & Z= 3.01m
FREE-X, FIXED-Y, FREE-Z	X=7.9m;Y =1.01m & Z= -3.01m
FREE-X, FIXED-Y, FREE-Z	X=7.9m;Y =1.01m & Z= 3.01m

2.1.3 Summary of the Principal Particulars of the Deep-U Catamaran Vessel

After undergoing methodical dissections, the principal dimensions of the Catamaran vessels was abstracted and an accompanying model dimensions was computed as seen in Table (4).

Table (4): Summary of the Principal Particulars of the Deep-U Catamaran Vessel

Ship Principal Particulars	Full Scale
Length Overall (L_{OA})	7.9m
Length Between Perpendiculars (L_{BP})	7.5m
Overall Breadth (B)	3.6m
Demihull breadth (b)	1.2m
Demihull Block Coefficient (Demihull C_B)	0.85
Maximum speed	10knots
Waterline Length (LWL)	6.9m
Separation between centers of the demi-hulls (S_C)	2.4m
Transverse distance between the demi-hulls (S_T)	1.2m
Spacing demi-hull ratio (Sc/L)	0.133
Displacement Volume (∇)	16.10m^3
Mass Displacement (Δ_T)	16.51ton
Depth (D)	1.20m
Draught (T)	1.00m
Block coefficient of the Catamaran, C_B	0.85
Height of the vessels below freeboard (H_T)	1.00m
Height of the body from freeboard (H_B)	0.2m

2.14 The Structural Configuration of the Deep-U Catamaran Vessel on ANSYS

A global Finite Element (FE) model of the vessel was developed using the ANSYS program (ANSYS, 2024). The model consists of the two demi-hulls and it is rigidly connected by a cross-deck structure, otherwise also known as the Spine deck structure. The main particulars of the vessel have been defined earlier in Table (4). Since the vessel is symmetrical along the centre-line, only a half of its full scale global FE model was created. This half was then mirrored using the command tools available in the program to produce the full scale vessel. The significance of modelling a half of the vessel is that it allows for the application end-moments to the model as a cut-model – an essential requirement in the structural analysis using fixed-ends moment. On the other hand, the full scale model allows for an adequate definition of the boundary conditions and the application of the design loads at their actual position on the vessel.

The FE model was developed using sub structural units which collectively formed the half side of the vessel along the line of symmetry and mirrored to represent the full vessel. The structural configuration of the model, which consists of 3 traverse frames per meter, 34, 036 structural nodes, and 174, 351 elements were created in such a way that the stiffeners and frames were modelled as strake and homogenous elements.

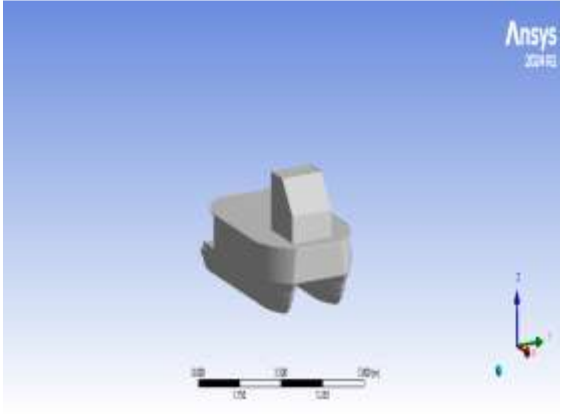

Figure 1: Front View of the Deep-U Catamaran Vessel

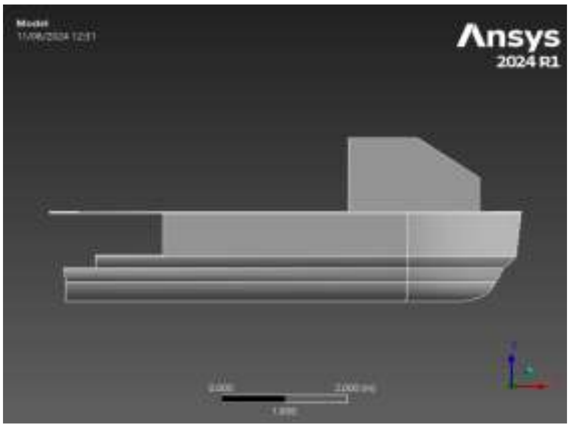

Figure 2: Profile, Body and a Global FE Model of the Deep-U keel Catamaran Vessel Developed using ANSYS

2.2 Methods

2.2.3 Stillwater and Wave-induced Shear Force and Bending Moments of the Deep-U Catamaran Vessel

Assuming the weight and buoyancy distributions are$w_x \; and \; b_x$, then the load distribution is given by equation (1):

$$q_x = b_x - w_x \tag{1}$$

The distributions of the shear force and bending moment along ship length are given by equations (2) and (3):

$$F_x = \int_0^x (b_x - w_x) d_x \tag{2}$$

$$W_x = \int_0^x F_x d_x \tag{3}$$

Where:

$w_x \; and \; b_x$are the weight (static) and buoyancy loads respectively,

F_x is the shear force distribution along the length of the Deep-U Catamaran,
W_x is the bending moment along the ship length.
Because the distribution of load along ship length is never a continuous function, the above integrations are carried out using numerical methods and in this work, ANSYS (2024) was used to analyze the hull girder loads and moments of the Deep-U Catamaran vessel.

2.2.1 Bending Stress Determination

The ground for the initial strength design of the hull structure of a catamaran vessel is similar to that which is used for monohull in the sense that both of them largely employ the principles and assumptions of the small deflection elastic bending theory of beams and plates (Heggelund et al., 2002; Hughes and Paik, 2010). The bending theory allows for the quick determination of the stresses and strength of the hull structure using the appropriate limiting criteria and by assuming that the hull girder structure itself behaves as a simple elastic beam. The elastic bending formula is the actual basis upon which the calculations of stresses and moments that are acting on this nature of structure is predicated and it is expressed as equation (4):

$$\sigma = \frac{My}{I} \qquad (4)$$

Where:
σ is the bending stress (MPa);
M is the moment about the neutral axis;
y is the coordinate of the plate measured from the cross section neutral axis;
I is the moment of inertia of the cross section

2.2.2 Assessment of Failure Modes and Structural Acceptability Criterion for the Computational Structural Response of the Deep-U Catamaran Vessel

The principles for the evaluation of structural adequacy for structural elements and members in the ANSYS Finite Element Program are based on failure modes of their constituent structural elements. The evaluation of these failure modes for a hull structure has been carried out based on failure of structure in yielding and buckling. These failure modes are directly dependent on the structural geometry of the ship, their appropriate boundary conditions, and most importantly, the structural loads being applied. For a given ship structural system and other relevant loading conditions, the calculated stresses must not be greater than the limits prescribed and/or computed for these failure modes (ANSYS, 2024).

The ANSYS FEA Program (ANSYS, 2024), considers a beam or plate element subjected to biaxial stress, a specific combination of stress components, rather than a single maximum normal stress component constitutes the limiting condition. In this regard, the total equivalent stress is to be based on the Hencky von-Mises criterion as seen in equation (5):

$$\sigma_e = \left[\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2\right]^{1/2} \qquad (5)$$

Where:
σ_e is the total equivalent stress
σ_x is the normal stress in the x-coordinate direction of the element
σ_y is the normal stress in the y-coordinate direction of the element
τ_{xy} is the in-plane shearing stress
For the cork composite, the total equivalent stress (σ_e) is to be less than or equal to the design stress (σ) as seen in equation (6): Thus ($\sigma_e \leq \sigma_d$).

$$\sigma_d = 0.37\sigma_u \qquad (6)$$

Where:
σ_u is the ultimate tensile or compressive strength of the laminate, whichever is less.
Component stresses (σ_x, σ_y, τ_{xy}) are to be less than or equal to allowable local structure design stress. (Hughes and Ma, 1996); (Hughes and Ma, 1997); (ABS, 2013) & (ANSYS, 2024).

2.2.3 Total Wave-induced Loads on Cross-Section

For a ship moving through waves, the wave loads on the vessel are generated by the incident waves, diffracted waves, and radiated waves. Additionally, the loads include the inertia force of the ship's mass and the forces resulting from changes in hydrostatic and hydrodynamic pressures due to the ship's motions. The six components of wave loads on a given cross-section, Xc, can be determined by directly integrating the inertial forces of the ship's mass forward of Xc, along with the hydrodynamic and hydrostatic pressure increments over the wetted hull surface in front of Xc, as described in equation (7).Liu et al. (1981), Brown (2012), and Heggelund et al. (2002).

$$F_j^W = Re\left[f_J^{WLD} e^{-i\omega_e t}\right] \qquad j = 2, 3 \ldots 6 \qquad (7)$$

Where:

$$f_J^{WLD} = I_j - \iint_{S_x} (p_{ht} + p_{st})\, N_j\, dS \qquad (8)$$

Where:
p_{ht} is the hydrodynamic pressure
p_{st} is the hydrostatic pressure
Sx is the mean wetted surface of the transverse section

$$N_j = n_j \text{ for j =1,2, 3, 4} \qquad (9)$$

$$N_5 = -xn_3 \qquad (10)$$

$$N_6 = xn_2 \qquad (11)$$

$$I_2 = -\omega_e^2(A_1\bar{x}_2 + A_2\bar{x}_6 - A_4\bar{x}_4) \qquad (12)$$

$I_3 = -\omega_e^2(A_1\bar{x}_3 - A_2\bar{x}_5)$ (13)
$I_4 = -\omega_e^2(I_{fx}\bar{x}_2 + A_4\bar{x}_2 - A_5\bar{x}_6)$(14)
$I_5 = (x - s_s)I_3$ (15)
$I_6 = (x - s_s)I_2$ (16)
With
$I_{fx} = \int_{Lx}^{\cdot} di_x$ (17)
$A_1 = \int_{Lx}^{\cdot} dm'$ (18)
$A_2 = \int_{Lx}^{\cdot} (x - x_g)dm'$ (19)
$A_4 = \int_{Lx}^{\cdot} (z - z_g)dm'$ (20)
$A_5 = \int_{Lx}^{\cdot} (x - x_g)(z - z_g)dm'$(21)

Where m' is the sectional mass distribution along the ship length; x_s is the longitudinal coordinate of the section; i_x is the sectional mass moment of inertia about x-axis; L_s is the length between X_c; and the forward perpendicular of the ship.

III. RESULTS AND DISCUSSION

3.1 Stillwater Longitudinal Shear Force

Figure 3 shows the behaviour of the Stillwater longitudinal shear force where the Initial Phase (0 - 1.5m) of the shear force starts at zero and remains zero until 1.5m along the ship length and immediately it begins to increase. Rising Phase (1.5 – 4m): The shear force increases from 8 kN at the vessel length of 1.5m to a peak of 100 kN at 4m. However, at the dropping Phase (4m – 5m), there is a sudden drop in the shear force from 100 kN to -100 kN between positions 4m and 4.5m along the length of the vessel and this is 6ollowed by Recovery Phase (5m - 7.9m), where the shear force recovers from -100 kN to -6 kN, indicating a decrease in the negative shear force as the length increases. Final Phase (7.9m – 8m), the shear force returns to zero. A cursory observation shows a significant peak at 4m with a force of 100 kN, followed by a sharp drop to -100 kN at position 4.5m along the vessel length. The negative values indicate a reversal in the direction of the shear force. The behavior suggests a symmetrical distribution of forces, possibly indicating points of maximum stress and potential areas of concern for structural integrity of the Deep-U Catamaran vessel

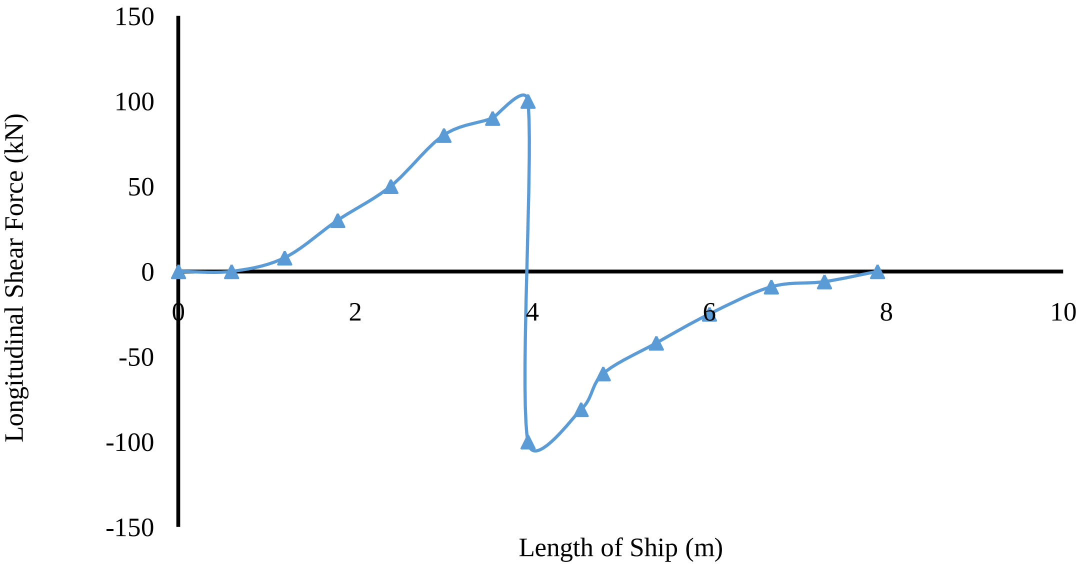

Figure 3: Stillwater Longitudinal Shear Force (kN)

3.2 Still-water Longitudinal Bending Moment (kNm)

Figure 4 can be portioned in four phases. At initial phase that is from 0m – 1m, the bending moment starts at zero and remains zero until about 1m along the vessel length. Second phase is the increasing phase that is between 1m – 4m. At this phase, the bending moment increases from 0 kNm at 1m to a peak of 180 kNm at position 4m. Constant Peak between 4 - 4.5m, the bending moment remains constant at 180 kNm between positions 4 and 4.5m. Decreasing Phase which is between 5 – 7m shows that the bending moment decreases from 180 kNm at vessel length of 4.5m to 14 kNm at position of 7m. Final Phase which starts 7m to 8m, suggest that the longitudinal bending moment returns to zero from 7m to 8m of the vessel length. The general observation is that the graph shows a gradual increase in bending moments reaching a peak of 180 kNm at vessel length of 4m and 4.5m, indicating the maximum bending stress in this region. The bending moment then gradually decreases, reflecting a symmetrical load distribution. The behavior suggests a critical region around 4m along the vessel length where the bending moment is highest, and it is essential to consider this in structural design to ensure integrity and safety.

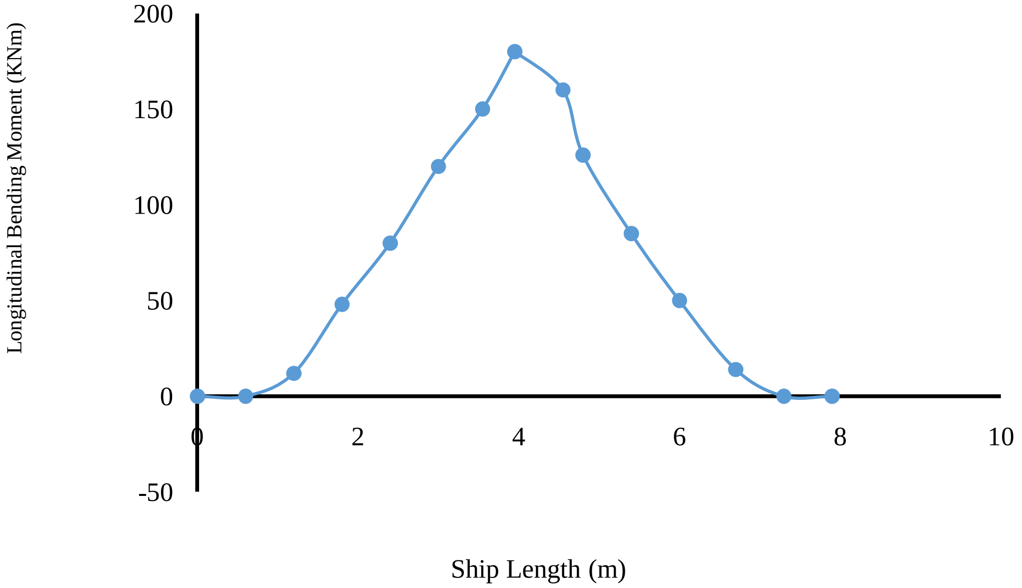

Figure 4: Stillwater Longitudinal Bending Moment (kNm)

3.3 Maximum Global Longitudinal Shear Force (kN)

Figure 5 can be portioned in four phases. At initial phase that is from 0 to 1.5m, the hogging shear force increases from 60 kN to 209 kN. However, from the fluctuation phase which is from 1.5m to 4m, the shear force fluctuates, dropping to 86 kN at exactly 2m along the vessel length followed by increase to 135 kN at 3.5m and making a peak of 310 kN at position of 4m. Then on the reversal phase which is between 4m - 4.5m, a significant reversal occurs, with the shear force dropping sharply to -310 kN at position of 4.5m.Recovery Phase (4.5m – 8m) expresses a shear force which gradually improves from -310 kN to 0kN. For the Sagging Shear Force, initial phase 0 - 1.5m, the sagging shear force increases from 60 kN to 200kN. Fluctuation phase which is from 1.5m – 4m, see the shear force fluctuates, dropping to 79 kN at 2m and further to 0 kN at 3m along the vessel length. It then rises to 160 kN at 4m. In the reversal phase which is from 4 - 4.5m, the shear force reverses, dropping to -160kN at about 4.5m. This is immediately followed by the recovery phase which is between 4.5m to 8m along the vessel length, where the shear force recovers from -160 kN to 0 kN. The hogging and sagging shear forces exhibit similar trends, with initial increases, fluctuations, sharp reversals, and gradual recoveries. Both forces reach their maximum values at different vessel length. For the hogging the maximum 310kN is reached at 4m and for the sagging, the maximum of 200kN is reached at 1.5m. The sharp reversals in both forces indicate critical points that may require special attention in structural design to ensure safety and integrity of the DUC vessel.

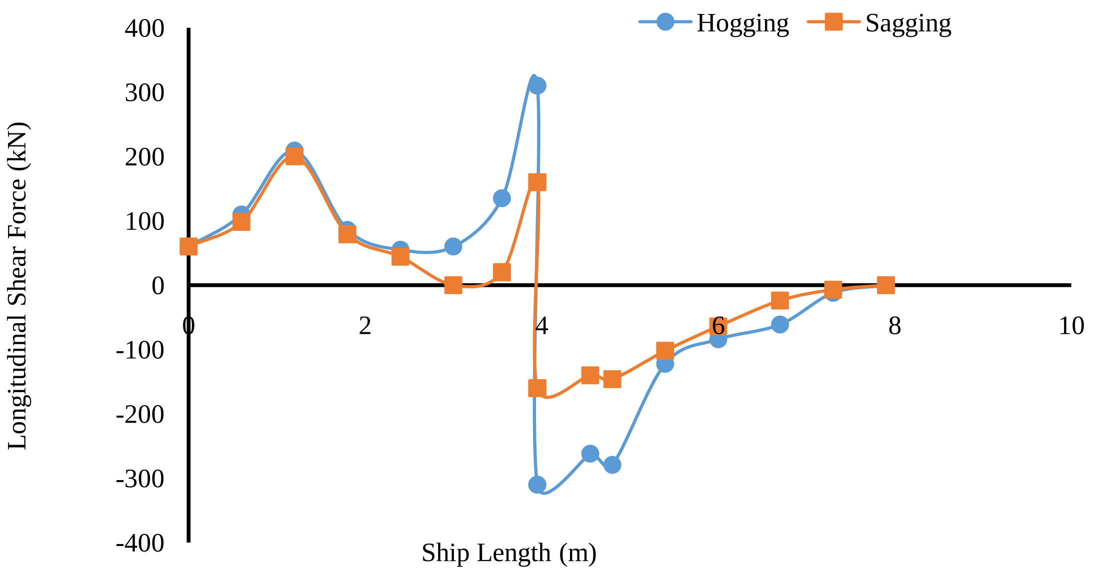

Figure 5: Global Longitudinal Shear Force (kN)

3.4 Maximum Global Longitudinal Bending Moment (kNm)

Figure 6 is a graph of two different plots, the hogging and sagging moments respectively. **Hogging** occurs when the middle section of a structure bends upwards, and the ends bend downwards. The hogging bending moment starts at 0 and increases steadily, reaching a peak of 1250 kNm at vessel length of 4m. After reaching the peak, the moment decreases, going down to -20 kNm at 7.9m, indicating a slight downward bend at the ends. The sagging bending moment starts at 0, increases to a peak of 910 kNm at vessel length of 4.5m, and then decreases quadratically to -8 kNm at 7.9m. This indicates a significant downward bend in the middle section of the structure. Both curves demonstrate the variation in bending moments along the length of the structure. The peaks of the hogging and sagging moments indicate the points of maximum stress and the negative values towards the end of the graph for both moments suggest a reversal in the bending direction.

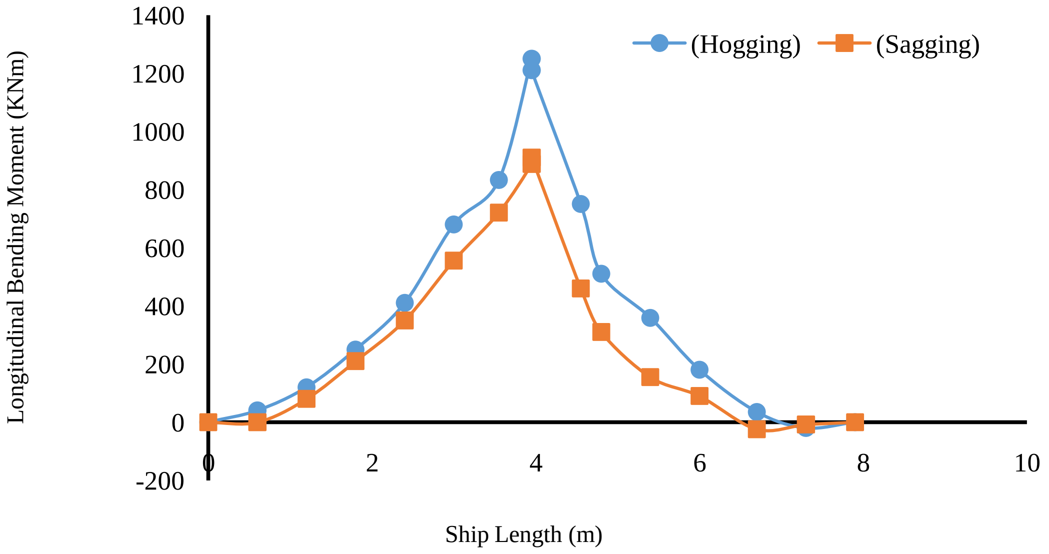

Figure 6: Maximum Global Longitudinal Bending Moment (kNm)

3.5 Numerical Stress and Deformation Examination of the Deep-U Catamaran Vessel

An arbitrary ship hull of 7.9m length (L), 3.6 m (B) and 1.2m depth (D) is taken under some non-uniform distributed loads. The L/D ratio here is 6.58 which implies that the ship can be considered as a slender beam. The material of the ship is structural cork composite. The shape of the meshes is non-uniform, the size is taken randomly, the nodal points are 34,036 and the elements were 174,351. Displacement load is applied on line 1→3 and line 4→5 of the hull model which magnitude is taken as 0. 2. The upward direction of loading is taken as positive and downward direction of loading is taken as negative for y axis.

3.5.1 Case 1: Wave Crest Acting at Midship of a Hull

The loading on the vessel for the case 1, where the reaction force here acts at the single point of wave crest located in the midsection of the hull bottom with a value of 310kN.

Wave crest located at the middle position of the ship hull has taken the whole weight of vessel, which results in the hogging effect. ANSYS has simulated the results very correctly in this regard. The values of the maximum and minimum deformation, stress and strain are shown in Table 5. The stress developed at this hogging condition is so severe that there is possibility of catastrophic break down of the vessel at the midship section. Total deformations are also shown in Figure 7 indicating the region of higher deformation and it is also an indication of the relation between developed stresses to linearly applied loads.

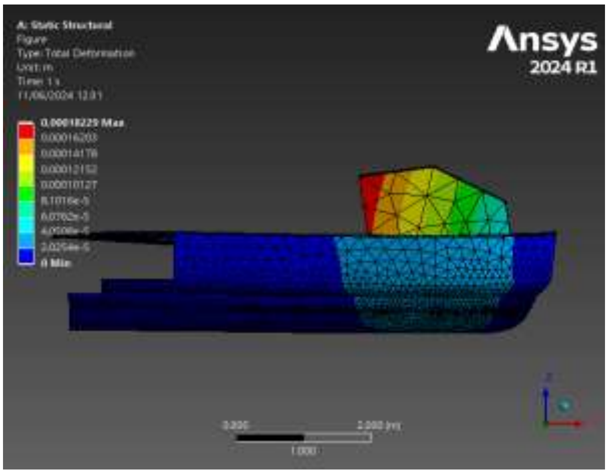

Figure 7: Total Deformation of Vessel Hull for Case 1

3.5.2Case 2: Wave Crest Acting at Fore and Aft Perpendicular of the Deep-U Catamaran Vessel Hull

In case 2, the wave crest acting at fore and aft perpendicular of the Deep-U Catamaran vessel was first modelled, meshed and then load applied. The load applied are 103kN at the midsection of hull, 2 x 51.5kN at fore and aft side near the midship and 2 x 51.5kN at two corners on the deck surface of the vessel. As the vessel is becoming at equilibrium with the reaction forces are at two ends of the hull bottom due to the crest positions of the wave.

The value of the maximum and minimum deformation, stress and strain are shown in Table 5. The von-Misses stress criterion and the maximum shear stresses are also shown in Figures 8 and 9 respectively indicating the region of higher deformation and stress. The hull appear sagged owing to higher value of loading at the midship area on the deck of the Deep-U Catamaran vessel. Therefore, the developed stress from central loading affects the parallel body of the vessel at the highest and makes the midship region more prone to failure. Adequate strengthening is necessary to protect the hull from such failure.

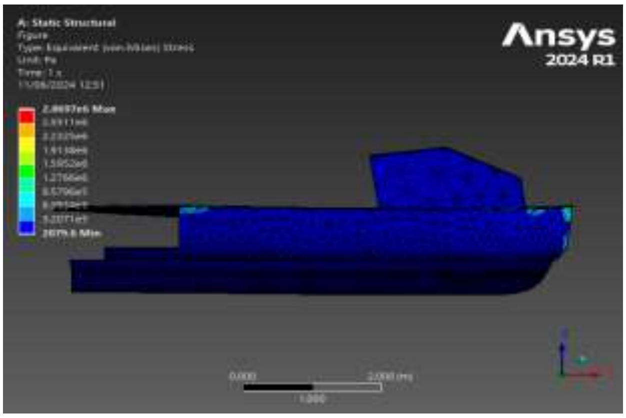

Figure 8: Equivalent von-Mises Stress (MPa)

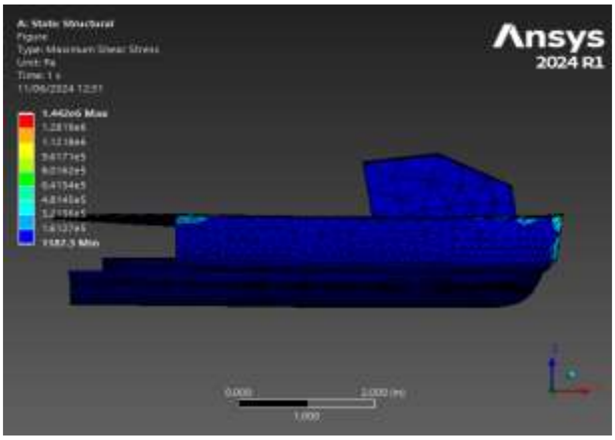

Figure 9: Maximum Shear Stress (MPa)

Table 5: Summary of the Values of the Maximum and Minimum Deformation, Stress and Strain

Type	Total Deformation (m)	Equivalent Elastic Strain(m/m)	Maximum Shear Elastic Strain(m/m)	Equivalent (von-Misses) Stress (Pa)	Maximum Shear Stress (Pa)
Minimum	0.0	1.6614e-007	1.6068e-007	2079.6	1187.3
Maximum	1.8229e-004	1.1005e-004	6.9747e-005	2.8697e+006	1.442e+006
Average	1.3347e-005	3.8331e-006	3.8514e-006	84525	44631

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

i. The hydrostatic analysis of the deep-U Catamaran vessel determined that at the design draft of 1.00m, the block, prismatic, midship area and waterplane area coefficients were discovered to be approximately, 0.85, 0.71, 0.383 and 0.421 respectively. The values of the hydrostatic characteristics at the design draft of 1.00m demonstrates the total mass displacement of the DUC to be 16.51 tonnes.

ii. The design loads of the DUC vessel have been calculated using the FEM approach and validated with ABS rules for the classification of special service craft. From the investigated behaviour of the structural response of the DUC, it can be conclude that the Stillwater longitudinal shear force where the initial Phase (0 - 1.5m) of the shear force starts at zero and remains zero until 1.5m along the ship length and immediately it begins to increase. Rising Phase (1.5 – 4m): The shear force increases from 8 kN at the vessel length of 1.5m to a peak of 100 kN at 4m. However, at the dropping Phase (4m – 5m), there is a sudden drop in the shear force from 100 kN to -100 kN between positions 4m and 4.5m along the length of the vessel and this is followed by Recovery Phase (5m - 7.9m), where the shear force recovers from -100 kN to -6 kN, indicating a decrease in the negative shear force as the length increases. Final Phase (7.9m – 8m), the shear force returns to zero.

iii. A cursory observation shows a significant peak at 4m with a force of 100 kN, followed by a sharp drop to -100 kN at position 4.5m along the vessel length. The negative values indicate a reversal in the direction of the shear force. The behavior suggests a symmetrical distribution of forces, possibly indicating points of maximum stress and potential areas of concern for structural integrity of the Deep-U Catamaran vessel. The global response is an estimation of the extreme load impacting the vessel. It is therefore, a combination of the Stillwater loads (static) and the wave-induced (hydrodynamic) loads being exerted on the hull of the Deep-u catamaran vessel. This research considered the global longitudinal shear force and bending moment in hogging and sagging conditions. From the analysis on the global longitudinal shear force (kN), the hogging and sagging shear forces exhibit similar trends, with initial increases, fluctuations, sharp reversals, and gradual recoveries. Both forces reach their maximum values at different vessel length.

iv. For the hogging the maximum 310kN is reached at 4m and for the sagging, the maximum of 200kN is reached at 1.5m. The sharp reversals in both forces indicate critical points that may require special attention in structural design to ensure safety and integrity of the DUC vessel. From the analysis conducted on the Maximum global longitudinal bending moment for the hogging and sagging moments respectively, it was observed that the h**ogging** occurs when the middle section of a structure bends upwards, and the ends bend downwards.

v. Wave crest acting at fore and aft perpendicular of the DUC vessel hull and loads of 103kN at the midsection of hull, 2 x 51.5kN at fore and aft side near the midship and 2 x 51.5kN at two corners on the deck surface of the vessel were applied, it resulted in the maximum total deformation of 1.8229e-004m, maximum shear stress of 1.44e+006Pa and equivalent von-Misses criteria of 2.8677e+006Pa. By this results, the structural integrity of the DUC vessel is not threatened.

4.2 Recommendations

i. Due to unavailability of structural testing kits, it is recommended that experimental structural response analysis of the Deep-U Catamaran vessel model using cork composite material is conducted.

ii. It is also recommended that the transverse Still-water and Global Structural response behaviour is researched on to ascertain the strength and structural integrity of the Deep-U Catamaran when faced with buoyancy and wave loads on the transverse aspects.

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