Stress and Resistance Analysis for the Design of a Work Barge

Nitonye Samson

Abstract—A barge is usually a flat bottom vessel mainly used as cargo tanker, equipment supply carriers, crane platform and support accommodation bases in offshore operations. The work barge considered in this paper has special features like a deck crane, helicopter landing platform and a pollution department. This work barge serves a multipurpose offshore function for oil and gas industries, marine establishment and other companies that require manpower to work offshore without possible return of workers daily to shore. To ensure that this barge has the capacity to withstand all forms of stresses and forces that act on it, a good structural rigidity has to be ascertained. This work further estimated the weight of all components, machines, machineries, tanks, system etc to obtain the center of gravity which can be accomplished through a three dimensional analysis. With the help of the classification of ships’ rules and regulations of Lloyd’s Register various formulae were used to obtain various thickness of plates (side, bulk, deck etc), frame, girder, flanges, pillars etc. This helped to estimate the weight of the various component of the vessel. This includes all deck plates, frames, flanges, girder, pillars etc. The selection and positioning of these were in consonance with classification rules. Hence all forms of stresses were analyzed and the resistance of the vessel calculated. In all the analysis it was deduced that the work barge has the capacity to withstand all forms of stress and keep the vessel in a safe condition.

Index Terms—Stress analysis, Resistance analysis, Work barge, Plate thickness, Stiffness, Mass, Vessel.

1 INTRODUCTION

A work barge is usually a flat bottom vessel mainly used as cargo tanker, equipment supply carriers, crane platform and support accommodation bases in offshore drilling. Most work barges do not operate under their own power but require a tugboat to pull or push them to their destination. Only in few cases do we see self-propelled work barges. Therefore barges are specially designed for specific purposes, depending on the type of barges, which is characterized by the function of the said barge, its design procedures are slightly different or rather the chosen characteristic may differ in one way or the other [1].

The work barge under consideration will have special features like a deck crane, helicopter landing platform and a pollution department. She will serve a multipurpose offshore function for oil and gas industries, marine establishment and other companies that require manpower to work offshore without possible return of workers daily to shore. To ensure that this barge has the capacity to withstand all forms of stresses and forces that will act on it, a good structural rigidity must be attained.

Therefore obtaining a good structural rigidity and estimation of the weight of all components, machines, machineries, tanks, system etc to ascertain the center of gravity which can be accomplished through the three dimensional analysis fronted by John in his work. With the help of the classification of ships’ rule and regulation part 2 [2], part 3 [3], No 3 [4] and part 4 [5] of Lloyd’s Register various formulae were used to obtain various thickness of plates (side, bulk, deck etc), frame, girder, flanges, pillars etc. hence to estimates the weight of the various component of the ship, that is, all deck plates (inner bottom plates, outer bottom plate, deck plate, 1st floor deck plate, 2nd floor deck plate and the plate for the helicopter platform), frames flanges, girder, pillars etc. The selection and positioning of these were in consonance with the iterative of Robert [6].

The strength calculation of the shear force and the bending moment determination and estimate were reviewed from Edward [7]. The estimations for tank selection were done from Nitonye [8] and Ekpenyong [9] from which insight came for the first stage of the estimations of tank capacity for the water, fuel, ballast etc. The final stage of the work will involve the analysis of the stability of the entire barge when deck crane is in offshore working condition, to ensure that the limit of load to be carried by the crane is not exceeded or points loads does not exceed a safe value for the vessel. There have been several development or giant strides made in the field of marine engineering in general and the design of barge in particular.

The design of a work barge of this magnitude with a crane and helicopter-landing platform following rules and regulation will yield several results from classification societies, laws, principles, experiments, calculations and assumptions.
etc. hence the structure must be strong enough to carry all induced stress (internal and external). Similarly, the structural arrangement of the designed work barge will be taken into consideration in this paper.

2 MATERIALS AND METHODS

2.1 Strength Calculations and Analysis

The calculations of the strength of the work barge are to enable us to know its ability to withstand the stress (es) or load(s) imposed on it while in operation. By this we will know and provide adequate strength without the structure(s) of the work barge yielding under normal condition of loading and even emergency situation [10].

Deck Plating Calculations

\[ t = (6.5 + 0.02L)C \sqrt{\frac{KS_t}{S_b}} \]  

\[ t = \text{thickness of plating in mm} \]
\[ L = \text{length 80m} \]
\[ C = \frac{D + 2/3 - T}{\text{Height Of Deck Above Load Line At F.P.}} \]  

By

\[ C = \frac{6 + 2.3 - 4.5}{1.5} = 2.53 \]
\[ S_b = \text{Standard frame spacing} = \left[ 470 + \frac{L}{0.6} \right] \]  

\[ S_b = 603 \text{mm} \]  

For forward of 0.05L from F.P.

By substituting, we have

\[ S_b = \left[ 470 + \frac{80}{0.6} \right] = 603 \text{mm} \]  

Hence standard frame spacing 600mm is selected

\[ S_t = S \quad \text{Spacing of secondary stiffness in mm} = 600 \text{mm} \]
\[ K = 0.66 \quad \text{(from table)} \]

Therefore by substituting into Equation 1

\[ t = (6.5 + 0.02 \times 80) \times 2.53 \sqrt{\frac{0.66 \times 600}{600}} = 16.65 \text{mm} \]  

Hence selected thickness (t) for deck plating for his nature of barge is 17mm.

The given parameters

\[ t = 17 \text{mm} \]
\[ L = 80 \text{m} \]
\[ B = 30 \text{m} \]

Number of plate = 1

Chosen density of steel = 8.5 tonnes/m³

\[ \text{Mass} = t \times L \times B \times p \times \text{Plate Number} \]  

By substituting

\[ \text{Mass} = 0.017 \times 80 \times 30 \times 8.5 \times 1 = 346.8 \text{tonnes} \]

2.2 Double Bottom Plate Calculations

The depth of the double bottom is given by the formula (in millimeters)

\[ d_{DB} = 32B + 190 \sqrt{d} \text{ mm} \]  

Where \( d \) = molded draft
\[ B = \text{breadth of the vessel} \]

By substituting

\[ d_{DB} = 32 \times 30 + 190 \sqrt{45} = 1363.1 \text{mm} \]  

While the center girder thickness is given by the relation

\[ t = (0.008 d_{DB} + 4) \sqrt{k} \text{ mm} \]  

By substitution

\[ t = (0.008 \times 1363.1 + 4) \sqrt{0.66} = 12.11 \text{mm} \]

For transverse frame thickness is given by the relation

\[ t = (0.008 d_{DB} + 1) \sqrt{k} \text{ mm} \]  

By substitution

\[ t = (0.008 \times 1363.1 + 1) \sqrt{0.66} = 9.67 \text{mm} \]

For longitudinal frame thickness is given by the relation

\[ t = (0.0075 d_{DB} + 1) \sqrt{k} \text{ mm} \]  

Selected t = 10mm

For the double-bottom plate of this capacity of work barge, from Lloyd’s rule and regulation for the classification of ships from part 4, chapter 1, section 7 and 8. The inner bottom plate thickness has the relation

\[ t = 0.00136 \left( S + 660 \right)^2 \sqrt{x^2 LT} \text{ (mm)} \]  

\[ t = 0.00136 \left( 600 + 660 \right)^4 \sqrt{0.66^2 \times 80 \times 4.5} = 6.06 \text{mm} \]

Selected thickness t for inner bottom plate

\[ t = 10 \text{mm} \]

Therefore, given parameters

\[ t = 10 \text{mm} \]
\[ L = 78 \text{m} \]
\[ B = 30 \text{m} \]

Plate number = 1

Steel density = 7.89 tonnes/m³

\[ \text{Mass} = t \times L \times B \times p \times \text{Plate Number} \]  

By substitution

Mass = 0.01x78x30x7.89x1 = 184.63 tonnes

Hence, from previous selection, for the outer bottom plate our selected t = 15mm

Therefore, given parameters

\[ t = 15 \text{mm} \]
\[ L = 78 \text{m} \]
\[ B = 30 \text{m} \]

Plate number = 1
Steel density = 8.5 tonnes/m³

**2.3 Side Plate Calculations**

From part 3 chapters 6, section 3 [4], the plate thickness is given by the relation

\[ t = (6.5 + 0.03L) \sqrt{\frac{K_S}{S_b}} \]  

(8)

The parameter given

- \( t = ? \)
- \( S/S = 600\text{mm} \)
- \( K = 0.66 \)
- \( L = 80\text{m} \)

Therefore by substitution into Equation 1, we have

\[ t = (6.5 + 0.033 \times 80) \sqrt{\frac{0.66 \times 600}{600}} = 7.43\text{mm} \]

Selected thickness for side plate \( t = 10\text{mm} \)

**2.4 Bulkheads Calculations**

From part 4, chapter 1 section 9 [11] and [12] give the bulkhead thickness by this relation;

\[ t = 0.004Sf' \sqrt{h_xK} \ (\text{mm}) \]  

(9)

\( f' = 1.1 - \frac{S}{2500} \)

\( h_x = \text{Tank head} = 6\text{m} \)

\( S' = \text{Space of member} = 15\text{m} \)

\[ f' = 1.1 - \frac{600}{2500 \times 15} = 1.084 \]

Selected \( f = 1.0 \)

Substituting these values into Equation 1

\[ t = 0.004 \times 600 \times 1 \sqrt{6 \times 0.66} = 4.78 \]

Selected thickness for longitudinal bulkhead is \( t = 8\text{mm} \)

Given parameters for

**2.5 Stiffness Calculations**

From part 4, chapter 6, section 4 [10], we have it that longitudinal stiffness for deck;

**Longitudinal Stiffness for Deck**

- \( L = 80\text{m} \)
- \( N = 50 \)
- \( S = 152 \times 102 \times 8 = 15.35\text{Kg/m} \)

**Transverse Stiffness for Deck**

- \( L = 80 \times 15.35 \times 50 = 61.4\text{ tonnes} \)

For Transverse Stiffeners

\[ t = 0.004Sf' \sqrt{h_xK} \ (\text{mm}) \]  

(10)

\( f' = 1.1 - \frac{S}{2500} \)

\( h_x = \text{Tank head} = 6\text{m} \)

\( S' = \text{Space of member} = 15\text{m} \)

\[ f' = 1.1 - \frac{600}{2500 \times 12.5} = 1.081 \]

Selected \( f = 1.0 \)

Substitute gives values into Equation 2

\[ t = 0.004 \times 600 \times 1 \sqrt{6 \times 0.66} = 4.78 \]

Selected thickness for transverse bulkhead is \( t = 8\text{mm} \)

Given parameters for
2.7 First Floor Deck (Tier) Superstructure Calculations

For Deck Plating From part 3, Chapter 5 and section 1 and 2
For \( L \leq 100m \) is given by the relations

\[
t = 5.5 + 0.02L \sqrt{\frac{KS}{S_b}}
\]  

(11)

By substitution

\[
t = (5.5 + 0.02 \times 50) \sqrt{\frac{0.66 \times 600}{600}} = 5.28mm
\]

Selected thickness for deck plating first floor is \( t = 8mm \) given parameters

| \( t \) | 8mm |
| \( Length \) | 47m |
| \( Breadth \) | 27m |
| \( Plate \) | 1 |
| \( Density of steel \) | 7.89tonnes |

\[
Mass = 0.008 \times 47 \times 27 \times 7.89 = 80.1 \text{ tonnes}
\]

Side Plating for 1st Tier

From Lloyd’s

\[
t = [5.0 + 0.01L_3] \sqrt{K}
\]

(12)

For \( L_3 = 49m \)

\[
K = 0.66
\]

By substituting

\[
t = [5.0 + 0.01 \times 49] \sqrt{0.66} = 4.5
\]

Selected thickness for side plate for first tier floor is \( t = 6.0mm \) similarly to obtain the height of the superstructure for first floor from Lloyd’s section 1.4.2

\[
h = 2.5 + 0.01L_3
\]

(13)

\[
L_3 = 49m
\]

\[
h = 2.5 + 0.01 \times 49 = 2.99m
\]

Selected height \( h = 3.0m \)

Giving parameters to calculate the mass

| \( t \) | 6m |
| \( Length \) | 49 |
| \( Height \) | 3m |
| \( Number of plate \) | 2 |

\[
Mass = 0.006 \times 47 \times 3 \times 2 = 13.35 \text{ tonnes}
\]

For Fore and Aft Side Plate, given parameters

| \( t \) | 6.0mm |
| \( Breadth \) | 27m |
| \( Height \) | 3m |
| \( Number of plate \) | 2 |

\[
Mass = 0.006 \times 27 \times 3 \times 2 = 7.67 \text{ tonnes}
\]

2.8 Bulkheads for First Tier

From Lloyd’s Part 3 Chapter 8, Section 2 Thickness of Bulkhead

\[
t = 0.003S \sqrt{K}h
\]

(14)

By substituting

\[
t = 0.003 \times 600 \sqrt{0.66 \times 3} = 2.53
\]
Selected thickness for bulkhead (longitudinal)
\[ t = 5 \text{mm} \]

Given parameters
- \( t = 5 \text{mm} \)
- Height = 3m
- Length of bulkhead = 132m
- Density of steel = 7.89 tonnes/m³

\[ \text{Mass} = 0.005 \times 3 \times 132 \times 7.89 = 15.6 \text{ tonnes} \]

Selected thickness for bulkhead (transverse)
\[ t = 5 \text{mm} \]

Height = 3m
Length of bulkhead = 237m
Density = 7.89 tonnes/m³

\[ \text{Mass} = 0.005 \times 3 \times 237 \times 7.89 = 28.05 \text{ tonnes} \]

2.9 Stiffness for First Tier

Longitudinal Stiffness for Deck
- Longitudinal spacing = 600mm
- Breadth = 27m
- Length = 47m
- Number of longitudinal stiffness = 45
- Sections = 7.89 tonnes/m³

\[ \text{Mass} = 47 \times 45 \times 7.89 = 16.7 \text{ tonnes} \]

Transverse Stiffness for Deck
- Transverse spacing = 600mm
- Breadth = 27m
- Number of stiffness = 78
- Section = 7.89 tonnes/m³

\[ \text{Mass} = 27 \times 7.89 \times 78 = 16.6 \text{ tonnes} \]

Longitudinal Stiffness of Side Plates
- Height = 3m
- Number of longitudinal = 5
- Length = 47
- Number of plates = 2

\[ \text{Mass} = 5 \times 47 \times 2 \times 7.89 = 3.71 \text{ tonnes} \]

Transverse Stiffness of Side Plates
- Height = 3m
- Number of transverse = 78
- Number of plates = 2

\[ \text{Mass} = 3 \times 78 \times 2 \times 7.89 = 3.70 \text{ tonnes} \]

Longitudinal Bulkhead Stiffness (Longitudinal)
- Height = 3m
- Number of longitudinal = 5
- Length = 132
- Density of Steel = 7.89 tonnes/m³
- Number of plates = 1

\[ \text{Mass} = 5 \times 132 \times 1 \times 7.89 = 5.21 \text{ tonnes} \]

Transverse Bulkheads Stiffness (Longitudinal)
- Height = 3m
- Number of transverse = 220
- Density of steel = 7.89 tonnes/m³
- Number of plates = 1

\[ \text{Mass} = 5 \times 220 \times 7.89 = 9.4 \text{ tonnes} \]

2.10 Frames

Longitudinal frames thickness = 10mm
Total frame = 6
Total length = 50m
Number of plate = 2

\[ \text{Mass} = 50 \times 0.01 \times 6 \times 7.89 \times 2 \times 450 = 21.3 \text{ tonnes} \]

Transverse frame thickness = 10mm
Total frame = 3
Total length = 28mm
Number of plate = 2

\[ \text{Mass} = 28 \times 0.01 \times 3 \times 7.89 \times 2 \times 450 = 5.96 \text{ tonnes} \]

Second Floor (Tier) Superstructure

For Deck Plating
From part 3, chapter 8, section 2(9) for \( L \leq 100 \text{m} \) is given by the relation;

\[ t = 5.0 + 0.02L \sqrt{\frac{KS}{b}} \]  

(15)

By substitution

\[ t = (5.0 + 0.02 \times 49) \sqrt{\frac{0.66 \times 600}{600}} = 4.83 \text{mm} \]

Selected thickness for deck plating second floor is \( t = 6 \text{mm} \)

Given parameters
- \( t = 6 \text{mm} \)
- Length = 40m
- Breath = 28m
- Plate = 1
- Density of steel = 7.89 tonnes/m³

\[ \text{Mass} = 0.006 \times 40 \times 28 \times 7.89 \times 1 = 53.02 \text{ tonnes} \]

Side Plating for Second Floor
From Lloyd's

\[ t = [4.0 + 0.01L] \sqrt{K} \]  

(16)

By substitution

\[ t = [4.0 + 0.01 \times 49] \sqrt{0.66} = 4.4 \text{mm} \]
Selected side plate thickness \( t = 5 \text{mm} \)

While the height of the second floor is given by the relation

\[
h = 1.25 + 0.005L_z
\]

by substituting

\[
h = 1.25 + 0.005 \times 49 = 1.5 \text{ m}
\]

Selected height for second floor is 2.5m

Giving parameters to obtain the mass of side plate as:

\[
t = 5 \text{m}
\]

\[
\text{Length} = 49
\]

\[
\text{Height} = 2.5\text{m}
\]

\[
\text{Number of plate} = 2
\]

\[
\text{Mass} = 0.005 \times 49 \times 7.89 \times 2 \times 2.5 = 9.7 \text{ tonnes}
\]

**Fore and Aft Side Plate**

\[
t = 5.0\text{mm}
\]

\[
\text{Breadth} = 28\text{m}
\]

\[
\text{Height} = 2.5\text{m}
\]

\[
\text{Number of plate} = 2
\]

\[
\text{Density} = 7.89 \text{ tonnes/m}^3
\]

\[
\text{Mass} = 0.005 \times 28 \times 7.89 \times 2 \times 2.5 = 5.52 \text{ tonnes}
\]

### 2.11 Helicopter Landing Area

From Part 3, Chapter 9, Section 3 and 5 [4]. The deck plate thickness \( t \), within the landing area is given by;

\[
t = t_i + 1.5 \text{ (mm)}
\]

where \( t_i = \frac{\alpha S}{1000\sqrt{K}} \)  

and \( \beta = \log \left( \frac{\rho . K^2}{S^2} \times 10^7 \right) \)

The plating is to be designed for the emergency landing; case taking

\[
P_1 = 2.5\phi_1\phi_2\phi_3 f y P_w \text{ tonnes}
\]

From tables

\[
\alpha = \text{Type correction factor} = 1.0
\]

\[
P_w = \text{load on the type print} = 6\text{tonnes}
\]

\[
P_1 = \text{corrected patch load} = ?
\]

\[
\lambda = \text{Dynamic configuration factor} = 1.7
\]

\[
\phi_1 = \text{patch aspect ratio correction factor} = 1.0
\]

\[
\phi_2 = \text{Panel aspect ratio correction factor} = 1.0
\]

\[
\phi_3 = \text{wide patch load factor} = 1.0
\]

\[
f = \text{landing decks over marred spaces} = 1.15
\]

\[
\gamma = \text{location factor} = 0.6
\]

Substituting the following parameters into Equation 20, gives

\[
P_1 = 2.5 \times 1 \times 1 \times 1 \times 1.5 \times 0.6 \times 6 = 10.35 \text{ tonnes}
\]

Therefore, \( \beta \) from Equation

\[
\beta = \log_{10} \left( \frac{10.35 \times 0.66^2}{600^2} \times 10^7 \right) = \log_{10} 125.235 = 2.10
\]

From the Tyre print chart

When \( \beta = 2.1 \) and \( v/s \geq 1.0 \)

\[
\alpha = 8
\]

Substituting into Equation 2

\[
\therefore t_i = \frac{8 \times 600}{1000\sqrt{0.66}} = 5.91 \text{m}
\]

\[
\therefore t = 5.91 + 1.5 = 7.41
\]

Selected thickness for helicopter landing area thickness is \( t = 20\text{mm} \)

**Third Floor (Tier) Superstructure for deck plating,**

Given parameters

\[
t = 20\text{mm}
\]

\[
\text{Length} = 20\text{m}
\]

\[
\text{Breadth} = 20\text{m}
\]

\[
\text{Plate No.} = 1
\]

\[
\text{Density of steel} = 7.89 \text{ tonnes/m}^3
\]

\[
\text{Mass} = 0.002 \times 20 \times 7.89 \times 20 \times 1 = 63.12 \text{ tonnes}
\]

### 2.12 Stiffness for Third floor

**Longitudinal Stiffness for Deck**

\[
\text{Longitudinal spacing} = 600\text{mm}
\]

\[
\text{Length} = 20\text{m}
\]

\[
\text{Breadth} = 20\text{m}
\]

\[
\text{Number of longitudinal members} = 33
\]

\[
\text{Section} = 7.89 \text{ tonnes/m}^3
\]

\[
\text{Mass} = 20 \times 7.89 \times 33 = 5.21 \text{ tonnes}
\]

**Transverse Stiffness for Deck**

\[
\text{Transverse spacing} = 600\text{mm}
\]

\[
\text{Breadth} = 20\text{m}
\]

\[
\text{No. of transverse} = 33
\]

\[
\text{Section} = 7.89 \text{ tonnes/m}^3
\]

\[
\text{Mass} = 20 \times 7.89 \times 33 = 5.21 \text{ tonnes}
\]

The shear force diagram gives a representation of the upward and downward forces acting on the work barge as shown in figure 1

### 2.13 Shear and Bending Moment

A work barge of overall length of 80m and length between perpendiculars as 75m has the breadth of 30m, depth of 6.0m and a maximum loading draft as 4.5m. The work barge is assumed to be statically stable on a sinusoidal wave, in which the height of the wave at any point about the still water wave is given as

\[
H = 0.607\sqrt{L} = 5.43\text{m}
\]

\[
L = \text{Overall Length}
\]


2.14 Wave Load Distribution

At a quarter length

Buoyancy moment = 45,937.50
Mass moment = 36,250 tonnes/m
Net Moment = Buoyancy – Mass Moment
= 9,687.50 tonnes/m

To convert to Nm, we will multiply by “g”, that is 9.81m/s²

Still water bending moment = 95,034.375Nm = 95.024MN

When we consider wave as a cosine form and will have the crests at the ends as

\[ H = \frac{5.43}{2} \cos \frac{2\pi x}{80} \]  
\[ \therefore \text{Buoyancy per unit meter} = \rho bh \cos \frac{2\pi x}{80} \text{ MNm} \]

We know that the integration of the force due to the Buoyancy gives us the shear force due to the wave.

\[ \int 0.819 \cos \frac{2\pi x}{80} \, dx \]

\[ \frac{0.819 x}{2\pi} \sin \frac{2\pi x}{80} + A \]

at \( x = 0; A = 0 \)
\( x = 30 \text{m} \)

Wave shear force = 0.429MN

On the other hand, integrating the wave shear force gives the wave bending moment

Therefore, Wave Bending Moment

\[ B = \frac{0.819 x}{2\pi^2} \left[ 1 + \cos \frac{2\pi x}{80} \right] \]

The condition that the bending moment is zero

at \( x = 0 \) gives

\[ B = \frac{0.819 x}{2\pi^2} \]

When \( x = 40 \text{M} \)

The wave bending moment

\[ \frac{0.819 x}{2\pi^2} \left[ 1 + \cos \frac{2\pi x}{80} \right] = 265.3 \text{MNm} \] (25)

Therefore, the total Bending Moment at sagging condition

= Still water moment + Wave moment = 360.334 MNm

2.15 Sectional Modulus

Properties of Mild Steel

Ultimate tensile strength = 400 - 495MN/m²
= 26 - 32 tonnes/m²

Yield stress = 230 - 250MN/m² = 15 -16 Tonnes/m²

Shearing strength = 22 tonnes/m²

We know that

1. Stress = \( \frac{\text{Force (Load)}}{\text{Unit Area (m²)}} \) (26)

2. Factor Of Safety = \( \frac{\text{Yield Stress}}{\text{Max Design Stress}} \) (27)

From these equations we derive that

\[ \frac{\text{Factor}}{\text{Unit Area}} = \frac{\text{Yield Stress}}{\text{Factor of Safety}} \] (28)

\[ \therefore \text{Unit Area} = \frac{\text{Force} \times \text{Factor of Safety}}{\text{Yield Stress}} \] (29)
Simple beam theory

\[ M_B = \sin \sigma \]
\[ M_B = \text{Bending moment} \]
\[ S_M = \text{Sectional Modulus} \]
\[ \sigma = \text{Unit Stress} \]

\[ \sigma = \frac{M_B}{S_M} \quad (30) \]
\[ \sigma = \frac{M_B \times C}{I} \quad (31) \]

Where \( C \) is the distance from the neutral axis (a line parallel to the base line from the Centriod of all the effective longitudinal strength members comprising the section)

\[ I = \text{Sectional moment of inertia about the Natural axis} \]

\[ \text{Figure 2: Barge Section} \]

\[ \text{Figure 3: Structural element of the barge hull [13]} \]

The barge section gives us an internal representation of the barge and how the stiffness is placed at different sections of the barge as shown in figure 2 and figure 3 shows the structural element of the work barge hull. And the table below shows the calculation of the sections, which helped in the force analysis of the work barge.

\[ \text{Height of Neutral Axis} h_{NA} = \sum \frac{a h}{a} \quad (32) \]
\[ = 2.14 \text{m above the keel} \]

\[ \text{Second moment of area of half section above base} \]
\[ = \sum ah^2 + I_o = 3.3138m^4 \quad (33) \]

\[ \Sigma \text{Parallel axis term} = \Sigma a x h^2_{NA} = 2.046m^4 \quad (34) \]

\[ I_{NA} = \text{Second moment of area of half section about the base parallel axis term} \]
\[ = 1.2678m^4 \]

\[ \text{Therefore; } I_{NA} \text{ (Full section)} = 2.5356m^4 \]
\[ \text{Full area} = 0.89364m^2 \]

\[ Z\text{–Deck} = \frac{I_{NA} \text{Full}}{\text{ShipHeight} - I_{NA}} = 0.6569m^3 \quad (36) \]

\[ Z\text{–Deck} = \frac{I_{NA} \text{Full}}{\text{ShipHeight} - I_{NA}} = 0.6569m^3 \quad (37) \]

\[ Z\text{–Base} = \frac{I_{NA} \text{Full}}{h_{NA}} = 1.1849m^4 \quad (38) \]

\[ \text{Factor of Safety} = 3 \]

\[ \text{Maximum design stress} \]
\[ \frac{\text{Factor of Safety}}{\text{Unit Area}} = \frac{\text{Yield Stress}}{\text{Factor of Safety}} = 83.33MN / m^2 \quad (39) \]

Using the maximum bending moment included in the steel structure

\[ \text{Stress on Deck} = \frac{M_B}{Z_{p}} = 548.54MN / m^2 \]
\[ \text{Stress on base} = \frac{M_B}{Z_{B}} = 304.1MN / m^2 \]

\[ 2.16 \text{ Resistance Calculations and Analysis} \]

To estimate the total resistance of this tonnage of work barge, it is commended to split this resistance into two components

1. The frictional resistance \((R_f)\) basing on Reynolds number - \(R_n\)
2. The residuary resistance \( R_R \) basing on Froude number \( F_r \) (that is, the wave-making resistance and Eddy Resistance).

\[
\begin{align*}
R_R &= R_f + R_B \\
R_f &= C_f \frac{\rho v^2 s}{2} \\
R_B &= C_B \frac{\rho v^2 s}{2}
\end{align*}
\]

\( C_T, C_f, C_B \) are the total frictional and residuary resistance coefficient respectively. The frictional resistance is the resistance due to the motion of the hull through a viscous fluid. It is as high as 80-85% of the total resistance in slow-speed vessel and as much as 50% in high-speed vessel. The value of friction divers in laminar flows and that of turbulent flows is shown below. Hence low at laminar flow with Reynolds Number \([14]\)

\[
R_s = \frac{VL}{\nu}
\]

In 1904 Blasins

\[
C_f = \frac{R_f}{0.5 \rho v^2} = 1.327 \left( \frac{VL}{V} \right)^{\frac{1}{2}}
\]

For laminar flow

While in 1921 Prandtl and Von Karma published the equation

\[
C_f = \frac{R_f}{0.5 \rho v^2} = 0.072 \left( \frac{VL}{V} \right)^{\frac{1}{2}}
\]

For turbulent flow

\[
R_f = f s v^n
\]

\( d \) = draft of the ship
\( V \) = Volume of displacement
\( C_B \) = Block coefficient
\( B \) = Beam

### 2.17 The Air Resistance \( (R_A) \)

This resistance is calculated from the experiment of Admiral Taylor’s empirical formula

\[
R_A = 0.004 \times 0.5 B^2 \times V^2
\]

Where \( B \) = Beam of the ship
\( V_R \) = Relative velocity of the wind
\( V_V \) = V (speed of the ship) in still air

\[
R_A = C_A \times 0.5 \rho A_f \times V^2
\]

Where \( C_A \) = Resistance coefficient
\( \rho \) = Mass density of air
\( A_f \) = Transverse project area of above water hull
\( V \) = Ship speed
\( A_f \) = 0.3\( A_1 + A_2 \)

Where \( A_1 \) = Main hull area
\( A_2 \) = super structure area

Others supposed to be estimated but considered negligible include

- Wake - making resistance \( (R_W) \)
- Eddy - making resistance \( (R_E) \)

Note: because the work barge is not self-propelled it will not have appendage resistance. From Guildhammer-Harold method of resistance calculation, usable values include

\[
\begin{align*}
L_{pp} &= 75.0m \\
B &= 30m \\
T &= 4.5m \\
\nV &= 4900 tonnes \\
L/\sqrt{V} &= 4.53 \\
V &= 6.43m/s \\
\rho &= 10.25kg/m^3 \\
\nu &= 0.9425 \times 10^6 m^2/s Kinematics viscosity coefficient at 25^\circ C seawater \\
C_p &= 0.993
\end{align*}
\]

\[
\frac{V}{\sqrt{V}} = 6.43 x 0.742 = 0.742
\]

Reynolds number \( R_s = \frac{vL}{\nu} = 5.12 \times 10^8 \)
Coefficient of Frictional Resistance $C_F$

$$C_F = C_F^0 + dC_F \quad (54)$$

From I.T.T.C.

$$R_n = 5.0 \times 10^8$$

$$C_{F0} = 5.5 \times 10^8$$

$$C_{FO} = 1.65 \times 10^{-3}$$

For $R_n = 5.12 \times 10^8$

By interpolation

$$0.12 x 0.02 = 0.0048$$

$$\therefore C_{FO} = 1.6662 \times 10^{-3} \approx 1.67 \times 10^{-3}$$

But $C_{FO} = \frac{R_F}{\sqrt{\frac{\rho}{V^2} S}}$

$$= \left[\log R_n - 2\right]^2$$

$$dC_F = 0.4 \times 10^{-3} \quad \text{for} \quad L < 90 \text{m}$$

$C_F = 2.07 \times 10^{-3}$

2.18 Coefficient of Residuary Resistance ($C_{R0}$)

From graph of $CR$, $V_S$, $\sqrt{\frac{V}{L}}$ [15]

$$\frac{L}{\sqrt{\frac{V}{L}}} = 4.53$$

$$\frac{V}{\sqrt{L}} = 0.742$$

Correction for (B/T) - $\nabla C_{RI}$

$$\nabla C_{RI} = 0.12 \left[\frac{B}{T} - 2.07\right] \times 10^{-2}$$

By substituting

$$\nabla C_{RI} = 0.552 \times 10^{-3}$$

Correction for Length of centre of buoyancy $F_{cb}$ - $\nabla C_{R2}$

For $\frac{V}{\sqrt{L}} \leq 0.6$, $C_{R2} = 0$

For $\frac{V}{\sqrt{L}} < 0.6$, $C_{R2} = \left[\frac{V}{\sqrt{L}} - 0.6\right] L_{pp}$

Where $a = 0.75$ for $C_p = 0.993$

3.9.1 Air and Wind Resistance

$$R_{AA} = C_{AD} x \frac{1}{2} \rho A_r V^2 \quad (57)$$

Admiral Taylor, from experiment in air derived a resistance coefficient of 1.28.

Area of air Resistance $A_T = 0.3 A_1 + A_2 = 2.235 \text{m}^2$

In still water $R_{AA} = 14.08$

Total Resistance $C_T = C_F + C_R = 3.35 \times 10^{-3}$

Assuming $C_T$ due to other resistances not taken into consideration, let

$$C_T = 3.35 \times 10^{-3}$$

$$R_T = C_T \frac{\rho V^2}{2} S$$

$$S = C_T \sqrt{\Delta L_{WL}} \quad (58)$$

(Taylor’s formulas)

but $C = 2.6$

$$L_{NL} = L_{PP} + 3.5\% \text{of} \ L_{PP} = 77.625 \text{m}$$

$$\therefore S = 2.6 \sqrt{4900 \times 77.625} = 1603.512 \text{m}^2$$

$$\therefore R_T = C_T \frac{\rho V^2}{2} S$$

$$= \frac{5.35 \times 10^{-3} x 1025 x 6.42^2 x 1603.5}{2} = 181.8 \text{KN}$$

3 RESULTS AND DISCUSSIONS

In anticipation of the barge floating in an upright condition at many different water lines (or draft) in the course of its services, it is usual to calculate, in advance, the main geometrical characteristics of the ship form. This data below shows the masses of steel structures and various loads on the barge.

1. Mass of the steel structure = 1,400 tonnes
2. Mass of first floor and loads = 200 tonnes
3. Mass of second floor and loads = 230 tonnes
4. Mass of third floor = 100 tonnes
5. Mass of Helicopter = 50 tonnes
6. Mass of crane load = 300 tonnes
7. Mass of machinery load = 70 tonnes
8. Mass of tanks loads = 1,200 tonnes
9. Mass of cargo loads = 1,000 tonnes
10. Mass of other loads = 300 tonnes

Evenly distributed load along the entire length of the work
The weight of the work barge was estimated to be 3361.1 tonnes with all necessary equipments, machineries, machine, tanks, pumps, plates, etc. there by having the capacity of carrying external load up to 1000 tonnes within the vessel depending on the safety factor and the available space. After design and estimation, it was observed that the center of gravity is acting at 2.84m above the keel (bottom) of the barge, 1.39m fore of the chosen centre (longitudinally) and 19mm port of the chosen centre (transversely). This is safe in ship design; it would have been unsafe if the centre of gravity acts above 3.0m from the bottom of the ship.

Looking at the hydrostatic curves, the perfect straight line suggests that the draft varies directly with the displacement of the barge shows its ability to withstand all stresses and float upright. Figures 4 to 7 shows the stability characteristics of the work barge with respect to draft and other parameters like the centre of gravity, meta-centric height, displacement and distance between center of buoyancy and meta-center.

Table 1 Scantling/Section Calculation of the barge

<table>
<thead>
<tr>
<th>Items</th>
<th>Scantlings</th>
<th>Area (mm²)</th>
<th>Height Dcm</th>
<th>Moment m²</th>
<th>2nd moment (mm³)</th>
<th>Local 2nd moment (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength deck</td>
<td>5.4x17mm</td>
<td>0.0018</td>
<td>0.2</td>
<td>0.0186</td>
<td>0.0037</td>
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<tr>
<td>Longitudinal stiffness</td>
<td>303 x 302 x 78</td>
<td>0.0024</td>
<td>2.55</td>
<td>0.0054</td>
<td>0.0129</td>
<td></td>
</tr>
<tr>
<td>Side</td>
<td>5.4x10</td>
<td>0.004</td>
<td>0.2</td>
<td>0.0106</td>
<td>0.00216</td>
<td>0.1728</td>
</tr>
<tr>
<td>Plating Longitudinal</td>
<td>303 x 302 x 78</td>
<td>0.00234</td>
<td>2.39</td>
<td>0.0094</td>
<td>0.0129</td>
<td>0.132</td>
</tr>
<tr>
<td>Side stiffness</td>
<td>303 x 302 x 78</td>
<td>0.00228</td>
<td>14.39</td>
<td>0.0326</td>
<td>0.0434</td>
<td></td>
</tr>
<tr>
<td>Bottom plating</td>
<td>29.4 x 10mm</td>
<td>0.234</td>
<td>5</td>
<td>0.483</td>
<td>0.0514</td>
<td>0.1928</td>
</tr>
</tbody>
</table>

Figure 4: Draft Vs Centre of Gravity [1]

Figure 5: Draft Vs Metacentric Height

Figure 6: Draft Vs Displacement
4 CONCLUSION

The results of this research shows that the deck would be in a compression stress while the bottom would be on a tensile stress. The stress obtained is within the allowable stress hence the vessel structure would be able to withstand all forms of stresses that the barge will encounter during all offshore operations. Also the results of the longitudinal transverse vertical centre of gravity and meta-centric height showed that the barge would be stable at all normal condition of loading.

In order to obtain the moment of inertia giving a safe stress with maximum material, the materials are disposed further away from the neutral axis and most efficiently converted to have its designed share of the stress. Hence the (strength) stress which the structure needed is withstands compared with the maximum allowable yield stressed from Lloyd’s handbook indicated that the barge structure would withstand the hogging and sagging and six motion of gyration that would undergo during the course of its service.

The analysis revealed that the hull form components weigh a total mass of 3361.1 ton and the moments along the X, Y and Z components were within the safe limit. This show that the barge can withstand a maximum stress of 83.33MN/m², haven a bending moment induced on the deck at 548.54MN/m² maximum and on the base at 304.1MN/m² maximum. Appendix 1 shows the results of all design calculations for the work barge.

5 REFERENCES

5 APPENDIX 1

Table 3 Results of Design Calculations of the work barge

<table>
<thead>
<tr>
<th>Components</th>
<th>Scantlings (mm)</th>
<th>Thickness (mm)</th>
<th>Quantity (No.)</th>
<th>Unit Length (m)</th>
<th>Weight (Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. HULL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Bottom plate (outer)</td>
<td>75x30x15</td>
<td>15</td>
<td>1</td>
<td>75</td>
<td>298.4</td>
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<tr>
<td>2. Bottom plate (inner)</td>
<td>75x30x10</td>
<td>10</td>
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<td>75</td>
<td>184.6</td>
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<tr>
<td>3. Deck plate</td>
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<td>17</td>
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<td>80</td>
<td>346.8</td>
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<tr>
<td>4. Side plate</td>
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<td>2</td>
<td>80</td>
<td>75.74</td>
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<tr>
<td>5. Force plate (rectangle)</td>
<td>30x1.5x10</td>
<td>10</td>
<td>1</td>
<td>30</td>
<td>3.55</td>
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<tr>
<td>6. Force plate (inclined)</td>
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<td>30</td>
<td>15.93</td>
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<tr>
<td>7. Aft plate</td>
<td>30x6x10</td>
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<td>1</td>
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<td>14.20</td>
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<tr>
<td>8. Bottom Longitudinal stiffness</td>
<td>152x102x7.8</td>
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<td>50</td>
<td>75</td>
<td>57.5</td>
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<tr>
<td>9. Deck longitudinal stiffness</td>
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<td>80</td>
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<tr>
<td>10. Longitudinal bulkhead</td>
<td>3800x8</td>
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<td>80</td>
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<td>8</td>
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<td>80</td>
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<td>13. Longitudinal bulkhead</td>
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<td>6</td>
<td>24.288</td>
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<td>14. Transverse bulkhead (longitudinal stiffness)</td>
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<td>15</td>
<td>4.6</td>
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<td>15. “</td>
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<td></td>
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<td>16. “</td>
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<td>7.5</td>
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<tr>
<td>17. Transverse bulkhead (transverse) stiffness</td>
<td>152 x 102 x 8</td>
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<tr>
<td>18. Side plate longitudinal stiffness</td>
<td>152x89x8</td>
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<td>6</td>
<td>24.6</td>
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<tr>
<td>19. Side plate transverse stiffness</td>
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<td>266</td>
<td>6</td>
<td>24.472</td>
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<td>508 x 102 x 10</td>
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<td>21</td>
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<td>11.28</td>
</tr>
<tr>
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<td>Thickness (mm)</td>
<td>Quantity (No)</td>
<td>Unit Length (m)</td>
<td>Weight (Tonnes)</td>
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<td>22. Side flange</td>
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<td>Diff. Length</td>
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<td>26. Top angle stiffness</td>
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<tr>
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<td>31. Outer bottom longitudinal</td>
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**B. SUPERSTRUCTURE (1st FLOOR)**

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<tr>
<th>Components</th>
<th>Scantlings (mm)</th>
<th>Thickness (mm)</th>
<th>Quantity (No)</th>
<th>Unit Length (m)</th>
<th>Weight (Tonnes)</th>
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<tbody>
<tr>
<td>1. Deck plate</td>
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<td>47</td>
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<td>14. Deck angle stiffness</td>
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<td>15. Top angle stiffness</td>
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<td>2</td>
<td>47</td>
<td>1.42</td>
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C. UPPER STRUCTURE (2nd FLOOR)

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<th>Thickness (mm)</th>
<th>Quantity (No)</th>
<th>Unit Length (m)</th>
<th>Weight (Tonnes)</th>
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<tbody>
<tr>
<td>1. Deck plate</td>
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<td>40</td>
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<td>28 x 2.5 x 5</td>
<td>5</td>
<td>1</td>
<td>28</td>
<td>2.76</td>
</tr>
<tr>
<td>3. Aft plate</td>
<td>28 x 2.5 x 5</td>
<td>5</td>
<td>1</td>
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<td>8. Side plate transverse stiffness</td>
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<td>406 x 127 x 8</td>
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<td>14. Longitudinal bulkhead flange</td>
<td>406 x 102 x 8</td>
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<td>15. Transverse bulkhead flange</td>
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