ISSN 2229-5518

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 accomplish through the three dimensional analysis[7] 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 formulas 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

• *Nitonye Samson, Department of Marine Engineering, Rivers State University of Science and Technology, Port Harcourt, Rivers State Nigeria. E-mail: nitonyes@yahoo.com*

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

$$t = (6.5 + 0.02L)C \sqrt{\frac{KS_1}{S_b}} \quad (1)$$

t = thickness of plating in mm
L = length 80m

$$C = \frac{D + 2/3 - T}{Height\ Of\ Deck\ Above\ Load\ Line\ At\ F.P.} \quad (2)$$

By

$$C = \frac{6 + 2.3 - 4.5}{1.5} = 2.53$$

$$S_b = \text{Standard frame spacing} = \left[470 + \frac{L}{0.6}\right] \quad (3)$$

For forward of 0.05L from F.P.
By substituting, we have

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

Hence standard frame spacing 600mm is selected
S_1 = S Spacing of secondary stiffness in mm = 600mm
K = 0.66 (from table)
Therefore by substituting into Equation 1

$$t = (6.5 + 0.02 \ x \ 80)2.53 \sqrt{\frac{0.66 \ x \ 600}{600}} = 16.65mm$$

Hence selected thickness (t) for deck plating fore his nature of barge is 17mm.
The given parameters
t = 17mm
L = 80m
B = 30m
Number of plate = 1
Chosen density of steel = 8.5 tonnes/m^3

$$Mass = t\ x\ L\ x\ B\ x\ p\ x\ Plate\ Number \quad (4)$$

By substituting
Mass 0.017 x 80 x 30 x 8.5 x 1 = 346.8tonnes

2.2 Double Bottom Plate Calculations

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

$$d_{DB} = 32B + 190\sqrt{d}\ mm \quad (5)$$

Where d = molded draft
B = breadth of the vessel
By substituting

$$d_{DB} = 32\ x\ 30 + 190\sqrt{45} = 1363.1mm$$

While the center girder thickness is given by the relation

$$t = (0.008\ d_{DB} + 4)\sqrt{k}\ mm \quad (6)$$

by substitution

$$t = (0.008\ x\ 1363.1 + 4)\sqrt{0.66} = 12.11mm$$

For transverse frame thickness is given by the relation

$$t = (0.008\ d_{DB} + 1)\sqrt{k}\ mm$$

by substitution

$$t = (0.008\ x\ 1363.1 + 1)\sqrt{0.66} = 9.67mm$$

For longitudinal frame thickness is given by the relation

$$t = (0.0075\ x\ d_{DB} + 1)\sqrt{k}\ mm$$

$$t = (0.0075\ x\ 1363.1 + 1)\sqrt{0.66} = 9.12mm$$

Selected t = 10mm
For the double-bottom plate of this capacity of work barge, from Lloyds rule and regulation fore the classification of ships from part 4, chapter 1, section 7 and 8. The inner bottom plate thickness has the relation

$$t = 0.00136\ (S + 660)^4 \sqrt{x^2 LT}\ \ (mm) \quad (7)$$

$$t = 0.00136\ (600 + 660)^4 \sqrt{0.66^2 x 80 x 4.5} = 6.06mm$$

Selected thickness t for inner bottom plate
t = 10mm
Therefore, given parameters
t = 10mm
L = 78m
B = 30m
P late number = 1
Steel density = 7.89tonnes/m3

$$Mass = t\ x\ L\ x\ B\ x\ p\ x\ Plate\ Number$$

By substitution
Mass = 0.01x78x30x7.89x1 = 184.63tonnes
Hence, from previous selection, for the outer bottom plate our selected t = 15mm
Therefore, given parameters
t = 15mm
L = 78m
B = 30rn
Plate number = 1

Steel density = 8.5 tonnes/m³

Mass = t x L x B x p x Plate Number

By substitution

Mass = 0.015x78x30x8.5x1 = 298.3 5tonnes

2.3 Side Plate Calculations

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

$$t = (6.5 + 0.03L)\sqrt{\frac{KS_1}{S_b}} \quad (8)$$

The parameter given

t	=	?
S₁S	=	600mm
K	=	0.66
L	=	80m

Therefore by substitution into Equation 1, we have

$$t = (6.5 + 0.033 \; x \; 80)\sqrt{\frac{0.66 \; x \; 600}{600}} = 7.43\text{mm}$$

Selected thickness for side plate t = 10mm

Mass = t x L x B x p x Plate Number

Steel plate thickness (t)	=	10mm
Length (L)	=	80mm
Height (D)	=	6rn
Number of plate	=	2

Mass = 0.01 *x* 6 *x* 80 *x* 7.89 *x* 2 = 75.74 *tonnes*

Aft Side Plate

Steel plate thickness (t)	=	10mm
Breadth (B)	=	30rn
Height (D)	=	6m
Number of Plate	=	1

Mass = 0.01 *x* 6 *x* 30 *x* 7.89 *x* 1 = 14.20 *tonnes*

Fore Side Plate 1

Steel thickness (t)	=	10mmm
Breadth (B)	=	30m
Height (D)	=	1.5m
Number of plate	=	1

Mass = 0.01 *x* 1.5 *x* 30 *x* 7.89 *x* 1 = 3.55 *tonnes*

Fore Side Plate 2

$$L^2 = 4.5^2 + 5^2$$

$$L = 6.73 \; m$$

Steel plate thickness (t) = 10mm

Breadth (B)	=	30m
Height (D)	=	6.73m
Number of plate	=	1
Density of steel	=	7.89tonnes/m³

Mass = 0.01 *x* 6.73 *x* 30 *x* 7.89 *x* 1 = 15.93 *tonnes*

Mass = 0.01 *x* 1.5 *x* 30 *x* 7.89 *x* 1 = 3.55 *tonnes*

2.4 Bulkheads Calculations

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

$$t = 0.004Sf\sqrt{h_4 K} \; (mm) \quad (9)$$

$$f = 1.1 - \frac{S}{2500s}$$

$$h_A = Tank \; head = 6m$$

$$S = Space \; of \; member = 15m$$

$$f = 1.1 - \frac{600}{2500 \; x \; 15} = 1.084$$

Selected f = 1.0

Substituting these values into Equation 1

$$t = 0.004x600x1\sqrt{6x0.66} = 4.78$$

Selected thickness for longitudinal bulkhead is t = 8mm

Given parameters for

Mass = t x L x B x p x Plate Number

Steel plate thickness (t)	=	8mm
Height	=	6rn
Length	=	80m
Density of steel	=	7.89tonnes/m3
Number of plate	=	2

Mass = 0.08 *x* 6 *x* 80 *x* 7.89 *x* 2 = 60.6 *tonnes*

For Transverse Stiffeners

$$t = 0.004Sf\sqrt{h_4 K} \; (mm) \quad (10)$$

$$f = 1.1 - \frac{600}{2500 \; x \; 12.5} = 1.081$$

Selected f = 1.0

Substitute gives values into Equation 2

$$t = 0.004x600x1\sqrt{6x0.66} = 4.78$$

Selected thickness for transverse bulkhead is t = 8mm Given parameters for

Mass = t x L x B x p x Plate Number

Steel plate thickness (*t*) = 8mm

Height	=	6m
Breadth	=	30m
Density of steel	=	7.89tonnes/m³
Number of steel	=	6

Mass = 0.08 *x* 6 *x* 30 *x* 7.89 *x* 1 = 68.17 *tonnes*

2.5 Stiffness Calculations

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

Longitudinal Stiffness for Deck

Breadth	=	30m
Number of stiffness	=	50
Section 152 x 102 x 8	=	15.35Kg/m

Mass = 80 *x* 15.35 *x* 50 *x* = 61.4 *tonnes*

Transverse Stiffness for Deck

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Transverse space = 600
Length of transverse = 30m
Number of stiffness = 134
Section = 15.35Kg/m

$Mass = 30 \ x \ 15.35 \ x \ 134 \ = 61.7 \ tonnes$

Longitudinal stiffness on side plate
Height = 6m
Number of longitudinal stiffness = 10
Length of stiffness = 80
Section 152 x 102 x 8 = 15.35Kg/m
Number of plate = 2

$Mass = 80 \ x \ 15.35 \ x \ 10 \ x \ 2 = 24.6 \ tonnes$

Transverse Stiffness on Side Plate
Number of transverse stiffness = 134
Length of transverse = 6m
Length of stiffness = 6m
Section = 152x102x8 = 15.35Kg/m
Number of plate = 2

$Mass = 6 \ x \ 15.35 \ x \ 134 \ x \ 2 = 24.7 \ tonnes$

2.6 Longitudinal Stiffness on Bottom Plate (Double)

Breadth = 30m
Length of longitudinal = 75m
Number of bottom plate = 2

$Mass = 75 \ x \ 15.35 \ x \ 50 \ x \ 2 = 115.1 \ tonnes$

Transverse Stiffness of Bottom Plate (Double)
Breadth = 30rn
Length of transverse = 30m
Number of transverse = 134
Number of plate = 2

$Mass = 30 \ x \ 15.35 \ x \ 134 \ x \ 2 = 123.4 \ tonnes$

Longitudinal Stiffness on Bulkhead
Number of longitudinal = 10
Length of longitudinal = 80m
Number of bulkheads = 2

$Mass = 10 \ x \ 15.35 \ x \ 80 \ x \ 2 = 24.6 \ tonnes$

Transverse Stiffness on Bulkhead
Number of transverse = 134
Length of transverse = 6m
Number of bulkhead = 2

$Mass = 6 \ x \ 15.35 \ x \ 134 \ x \ 2 = 24.7 \ tonnes$

Transverse Web Frame Side to Side
Total number of frames = 11
Total length of web with flange = 92.8mm
Flange = 80.28mm
Total transverse web frame length = 172.56mm

$Mass = 172.56 \ x \ 0.01 \ x \ 450 \ x \ 8.5 \ x \ 11 = 72 \ tonnes$

2.7 First Floor Deck (Tier) Superstructure Calculations

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

$$t = 5.5 + 0.02L \sqrt{\frac{KS}{S_b}} \quad (11)$$

By substitution (9)

$$t = (5.5 + 0.02 \ x \ 50)\sqrt{\frac{0.66 \ x \ 600}{600}} = 5.28mm$$

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

$Mass = 0.008 \ x \ 47 \ x \ 27 \ x \ 7.89 = 80.1 \ tonnes$

Side Plating for 1st Tier
From Lloyd's

$$t = [5.0 + 0.01L_3]\sqrt{K} \quad (12)$$

For L_3 = 49m
K = 0.66
By substituting

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

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

$h = 2.5 + 0.01L_2$ (13)
$L_2 = 49$m
$h = 2.5 + 0.01 \times 49 = 2.99$m
Selected height h= 3.0m
Giving parameters to calculate the mass
t = 6m
Length = 49
Height = 3m
Number of plate = 2

$Mass = 0.006 \ x \ 47 \ x \ 3 \ x \ 2 \ x \ 7.89 = 13.35 \ tonnes$

Fore and Aft Side Plate, given parameters
t = 6.0mm
Breadth = 27m
Height = 3m
Number of plate = 2

$Mass = 0.006 \ x \ 27 \ x \ 3 \ x \ 2 \ x \ 7.89 = 7.67 \ tonnes$

2.8 Bulkheads for First Tier

From Lloyd's Part 3 Chapter 8, Section 2 Thickness of Bulk-head

$$t = 0.003S\sqrt{Kh} \quad (14)$$

By substituting

$$t = 0.003x600\sqrt{0.66x3} = 2.53$$

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Selected thickness for bulkhead (longitudinal)

t = 5mm

Given parameters

t = 5mm

Height = 3m

Length of bulkhead = 132m

Density of steel = 7.89tonnes/m³

$$Mass = 0.005 \ x\, 3\, x \ 132\, x\, 7.89 \ = 15.6 \ tonnes$$

Selected thickness for bulkhead (transverse)

t = 5mm

Height = 3m

Length of bulkhead = 237rn

Density = 7.89tonnes/m³

$$Mass = 0.005 \ x\, 3\, x \ 237\, x\, 7.89 \ = 28.05 \ tonnes$$

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

$$Mass = 47 \ x\, 45\, x \ 7.89 \ = 16.7 \ tonnes$$

Transverse Stiffness for Deck

Transverse spacing = 600mm

Breadth = 27m

Number of stiffness = 78

Section = 7.89 tonnes/rn³

$$Mass = 27 \ x \ 7.89\, x\, 78 \ = 16.6 \ tonnes$$

Longitudinal Stiffness of Side Plates

Height = 3m

Number of longitudinal = 5

Length = 47

Number of plates = 2

$$Mass = 5\, x\, 47\, x\, 2 \ x \ 7.89 \ = 3.71 \ tonnes$$

Transverse Stiffness of Side Plates

Height = 3m

Number of transverse = 78

Number of plates = 2

$$Mass = 3\, x\, 78\, x\, 2 \ x \ 7.89 \ = 3.70 \ tonnes$$

Longitudinal Bulkhead Stiffness (Longitudinal)

Height = 3m

Number of longitudinal = 5

Length = 132

Density of Steel = 7.89 tonnes/m³

Number of plates = 1

$$Mass = 5\, x\, 132\, x\, 1 \ x \ 7.89 \ = 5.21 \ tonnes$$

Height = 3m

Number of transverse = 220

Density of steel = 7.89 tonnes/m³

Number of plates = 1

Transverse Bulkheads Stiffness (Longitudinal)

Height = 3m

Number of transverse = 237

Density of steel = 7.89 tonnes/m³

Number of plates = 1

$$Mass = 5 \ x\, 237\, x \ 7.89 \ = 9.4 \ tonnes$$

Transverse Bulkheads Stiffness (transverse)

Height = 3m

Number of transverse = 395

Density of steel = 7.89 tonnes/m³

Number of plates = 1

$$Mass = 3 \ x\, 132\, x\, 1\, x \ 7.89 \ = 9.4 \ tonnes$$

2.10 Frames

Longitudinal frames thickness = 10mm

Total frame = 6

Total length = 50m

Number of plate = 2

$$Mass = 50 \ x\, 0.01\, x\, 6\, x \ 7.89\, x\, 2\, x\, 450 \ = 21.3 \ tonnes$$

Transverse frame thickness = 10mm

Total frame = 3

Total length = 28mm

Number of plate = 2

$$Mass = 28 \ x\, 0.01\, x\, 3\, x \ 7.89\, x\, 2\, x\, 450 \ = 5.96 \ tonnes$$

Second Floor (Tier) Superstructure

For Deck Plating

From part 3, chapter 8, section 2[9] for L $\leq$ 100m is given by the relation;

$$t = 5.0 + 0.02 L_3 \sqrt{\frac{KS}{S_b}} \quad (15)$$

By substitution

$$t = (5.0 + 0.02\, x\, 49)\sqrt{\frac{0.66\, x\, 600}{600}} = 4.83mm$$

Selected thickness for deck plating second floor is t = 6mm

Given parameters

t = 6mm

Length = 40m

Breadth = 28m

Plate = 1

Density of steel = 7.89 tonnes/m³

$$Mass = 0.006\, x\, 40\, x\, 28 \ x \ 7.89\, x\, 1 \ = 53.02 \ tonnes$$

Side Plating for Second Floor

From Lloyd's

$$t = [4.0 + 0.01 L_3]\sqrt{K} \quad (16)$$

By substitution

$$t = [4.0 + 0.01 \ x \ 49]\sqrt{0.66} = 4.4mm$$

Selected side plate thickness t = 5mm

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

$h = 1.25 + 0.005L_2$

by substituting

$h = 1.25 + 0.005 \; x \; 49 = 1.5 \; m$

Selected height for second floor is 2.5m

Giving parameters to obtain the mass of side plate as:

t	=	5m
Length	=	49
Height	=	2.5m
Number of plate	=	2

$Mass = 0.005 \; x \; 49 \;\; x \; 7.89 \; x \; 2 \; x \; 2.5 \; = 9.7 \; tonnes$

Fore and Aft Side Plate

t	=	5.0mm
Breadth	=	28m
Height	=	2.5m
Number of plate	=	2
Density	=	7.89 tonnes/m^3

$Mass = 0.005 \; x \; 28 \;\; x \; 7.89 \; x \; 2 \; x \; 2.5 \; = 5.52 \; tonnes$

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;

$$t = t_1 + 1.5 \;\; (mm) \tag{17}$$

$$where \;\; t_1 = \frac{\alpha S}{1000\sqrt{K}} \tag{18}$$

$$and \;\; \beta = \log\left(\frac{\rho_1 K^2}{S^2} x \; 10^7\right) \tag{19}$$

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

$$P_1 = 2.5\phi_1\phi_2\phi_3 \;\; fyP_w tonnes \tag{20}$$

From tables

n	=	*Type correction factor*	=	1.0
P_w	=	*load on the type print*	=	6tonnes
P_1	=	*corrected patch load*	=	?
λ	=	*Dynamic configuration factor*	=	1.7
ϕ_1	=	*patch aspect ratio correction factor*	=	1.0
ϕ_2	=	*Panel aspect ratio correction factor*	=	1.0
ϕ_3	=	*wide patch load factor*	=	1.0
f	=	*landing decks over marred spaces*	=	1.15
γ	=	*location factor*	=	0.6

Substituting the following parameters into Equation 20, gives

$P_t = 2.5 \; x \; 1 \; x \; 1 \; x \; 1 \; x 1.5 \; x \; 0.6 \; x \; 6 \; = 10.35 \; tonnes$

Therefore, β from Equation

$$\beta = \log_{10}\left(\frac{10.35 \; x \; 0.66^2}{600^2} x \; 10^7\right) = \log_{10} \; 125.235 \;\; = \; 2.10$$

From the Tyre print chart

When β = 2.1 and v/s ≥ 1.0

α = 8

Substituting into Equation 2

$$\therefore \; t_1 = \frac{8 \; x \; 600}{1000\sqrt{0.66}} = 5.91m$$

$$\therefore \; t = 5.91 + 1.5 = 7.41$$

Selected thickness for helicopter landing area thickness is t = 20mm

Third Floor (Tier) Superstructure For deck plating,

Given parameters

t	=	20mm
Length	=	20rn
Breadth	=	20m
Plate No.	=	1
Density of steel	=	7.89 tonnes/m^3

Mass = 0.002x20x7.89x20x1 = 63.1 2tonnes

2.12 Stiffness for Third floor

Longitudinal Stiffness for Deck

Longitudinal spacing	=	600mm
Length	=	20m
Breadth	=	20m
Number of longitudinal members	=	33
Section	=	7.89 tonnes/m^3

$Mass = 20 \; x \;\; 7.89 \;\; x \; 33 \; = 5.21 \;\; tonnes$

Transverse Stiffness for Deck

Transverse spacing	=	600mm
Breadth	=	20m
No. of transverse	=	33
Section	=	7.89 tonnes/m^3

$Mass = 20 \; x \;\; 7.89 \;\; x \; 33 \; = 5.21 \;\; tonnes$

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 ware at any point about the still water wave is given as

$$H = 0.607\sqrt{L} \;\; = 5.43m$$

$$L = Overall \;\; Length \tag{21}$$

ISSN 2229-5518

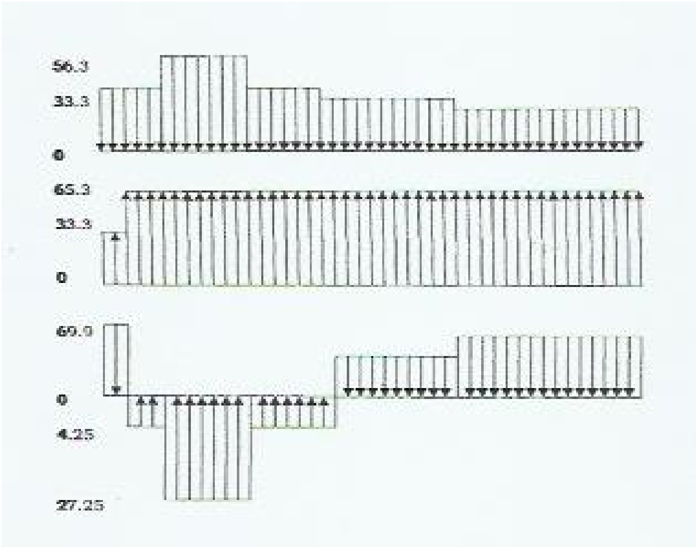

Figure 1: Shear Force Diagram of the Barge.

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 $9.81m/s^2$

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

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

$$H = \frac{5.43}{2} \cos \frac{2\pi x}{80} \qquad (22)$$

$\therefore$ *Buoyancy per unit meter*

$$= \rho bgh \div 1000 = 0.819 Cos \frac{2\pi x}{80} MNm \qquad (23)$$

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

$$= \int 0.819 Cos \frac{2\pi x}{80} dx \qquad (24)$$

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

at x = 0; A = 0

x = 30m

Wave shear force= 0.429MN

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

Therefore, Wave Bending Moment

$$= \int \frac{0.819\ x\ 80}{2\pi} Sin \frac{2\pi x}{80} dx$$

The condition that the bending moment is zero

at $x = 0$ gives

$$B = \frac{0.819\ x\ 80^2}{2\pi^2}$$

At $x = 40$M

The wave bending moment

$$\frac{0.819\ x\ 80^2}{2\pi^2}\left[1 + \cos \frac{2\pi 40}{80}\right] = 265.3 MNm \qquad (25)$$

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 - $495MN/m^2$

= 26 - 32 $tonnes/m^2$

Yield stress = 230 - $250MN/m^2$ = 15 -16 $Tonnes/m^2$

Shearing strength = 22 $tonnes/m^2$

We know that

1. $$Stress = \frac{Force\ (Load)}{Unit\ Area\,(m^2)} \qquad (26)$$

2. $$Factor\ Of\ Safety = \frac{YieldStress}{MaxDesignStress} \qquad (27)$$

From these equations we derive that

$$\frac{Factor}{UnitArea} = \frac{YieldStress}{Factor\ of\ Safety} \qquad (28)$$

$$\therefore UnitArea = \frac{Force\ x\ Factor\ of\ Safety}{YieldStress} \qquad (29)$$

ISSN 2229-5518

Simple beam theory

M_B = Sinσ

M_B = Bending moment

S_M = Sectional Modulus

σ = Unit Stress

$$\sigma = {M_B}/{S_M} \quad (30)$$

$$\sigma = \frac{M_B \times C}{1} \quad (31)$$

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)

1 = Sectional moment of inertia about the Natural axis

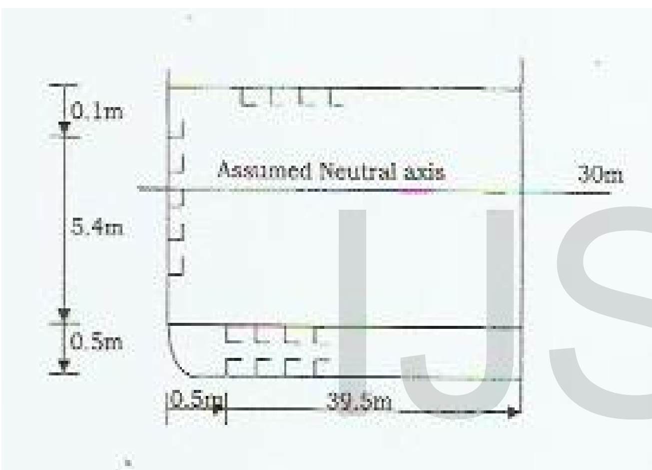

Figure 2: Barge Section

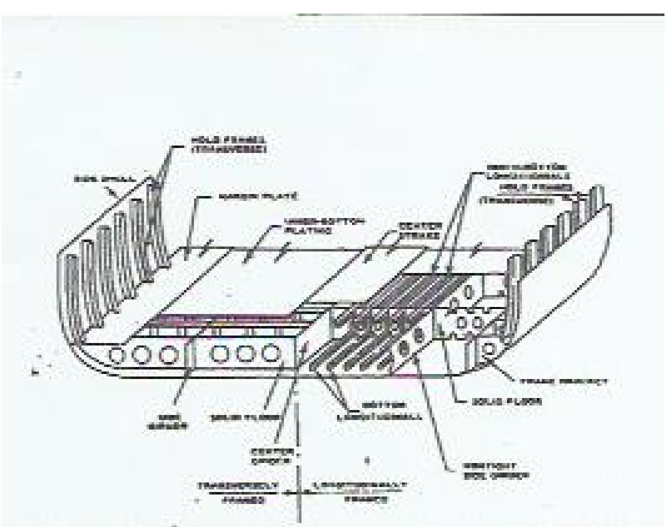

Figure 3: Structural element of the barge hull [13]

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.

$$\textit{Height of Neutral Axis } h_{NA} = \frac{\sum ah}{\sum a} \quad (32)$$

= 2.14m above the keel

Second moment of area of half section above base

$$= \Sigma ah^2 + I_0 = 3.3138m^4 \quad (33)$$

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

I_{NA} = Second moment of area of half section about the base – parallel axis term (35)

= $1.2678m^4$

Therefore; I_{NA} *(Full section)* = $2.5356m^4$

Full area = $0.89364m^2$

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

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

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

Factor of Safety = 3

Maximum design stress

$$\frac{Factor}{UnitArea} = \frac{YieldStress}{Factor\ of\ Safety} = 83.33MN/m^2 \quad (39)$$

Using the maximum bending moment included in the steel structure

$$\textit{Stress on Deck} = {M_B}/{Z_P} = 548.54MN/m^2$$

$$\textit{Stress on base} = {M_B}/{Z_B} = 304.1MN/m^2$$

2.16 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_P) basing on Reynolds number - R_n

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2. The residuary resistance (R_R) basing on Froud number F_r (that is, the wave-making resistance and Eddy Resistance).

$$\therefore Total\ Resistance\ R_T = R_F + R_B \quad (40)$$

$$R_F = C_F \frac{\rho v^2 s}{2} \quad (41)$$

$$R_R = C_R \frac{\rho v^2 s}{2} \quad (42)$$

C_T, C_F, C_R 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]

$$R_e = VL/v \quad (43)$$

In 1904 Blasins

$$C_F = R_F / 0.5\rho s v^2 \quad (44)$$

$$1.327 \left[\frac{VL}{V}\right]^{-\frac{1}{2}} \quad (45)$$

For laminar flow

While in 1921 Prandtl and Von Karma published the equation

$$C_F = R_F / 0.5\rho s v^2 \quad (46)$$

$$0.072 \left[\frac{VL}{V}\right]^{-\frac{1}{5}} \quad (47)$$

For turbulent flow

$$R_F = fsv^n \quad (48)$$

R_F	=	Resistance
s	=	total area surface (wetted surface)
v	=	speed (knots)

The wetted surface area s may be estimated using the Mumford formula

$$S = 1.7 L_{PP} \times d + \frac{\nabla}{d} \quad (49)$$

or Bruckhoffe's formula

$$S = \frac{(4d + B) \times L/2}{1.625 - C_B} \ (16) \quad (50)$$

L_{PP} = Length of the ship between perpendicular (ft)

d = draft of the ship

∇ = 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

$$R_A = 0.004 \ x \ 0.5B^2 \ x \ V_R^2 \quad (51)$$

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

$$R_A = C_A \ x \ 0.5\rho A_T \ x \ V^2 \quad (52)$$

Where C_A	=	Resistance coefficient
ρ	=	Mass density of air
A_T	=	Transverse project area of above water hull
V	=	Ship speed
A_T	=	$0.3A_1 + A_2$ (53)
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

L_{PP}	=	75.0m
B	=	30m
T	=	4.5m
∇	=	4900 tonnes
$L/\nabla^{1/2}$	=	4.53
V	=	6.43m/s
ρ	=	10.25kg/m^3
v	=	0.9425 x 10^{-6} m^2/s Kinematics viscosity coefficient at 25^{0}C seawater
C_p	=	0.993

$$\therefore \frac{V}{\sqrt{L}} = \frac{6.43}{\sqrt{75.0}} = 0.742$$

Reynolds number $R_n \ \frac{VL}{v} = 5.12 \ x \ 10^8$

Coefficient of Frictional Resistance C_F

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

From I.T.T.C.

R_n = 5.0×10^B

C_{F0} = 1.671×10^{-3}

R_n = 5.5×10^8

C_{FO} = $1.65\,1 \times 10^{-3}$

For $R_n = 5.12 \times 10^8$

By interpolation

$$\frac{0.12}{0.50} \; x \; 0.02 = 0.0048$$

$$\therefore C_{FO} = \left(1.6662 \; x\, 10^{-3}\right) \approx 1.67\, x 10^{-3}$$

But C_{FO} = $\dfrac{R_F}{\frac{1}{2}\rho V^2 S}$

$$= \frac{0.075}{\left[\log R_n - 2\right]^2} \quad (55)$$

dC_F = 0.4×10^{-3} for $L \leq 90$m

C_F = $2{,}07 \times 10^{-3}$

2.18 Coefficient of Residuary Resistance (C_{Ro})

From graph of CR, Vs, $\dfrac{\sqrt{V}}{L}$ [15]

$$\frac{L}{\nabla^{1/3}} = 4.53$$

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

Correction for (B/T)- ∇C_{RI}

$$\nabla C_{RI} = 0.12 \left[B/T - 2.07\right] x\, 10^{-7}$$

By substituting

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

Correction for Length of centre of buoyancy F_{CB}- ∇C_{R2}

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

$$For \quad \frac{V}{\sqrt{L}} < 0.6, \quad (56)$$

$$C_{R2} = a\left[\frac{V}{\sqrt{L}} - 0.6\right]\Delta L_{PP}$$

Where a = 0.75 for Cp = 0.993

3.9.1 Air and Wind Resistance

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

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

$$R_{AA} = 1.28 \; x \; \frac{1}{2}\rho A_T V_R^{\;2}$$

V_R = Apparent wind velocity or wind velocity relative to the ship In still air, $V_R = V$

ρ of air = 0.00238

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

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

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

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

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

(Taylor's formulas)

but C = 2.6

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

$$\therefore S = 2.6\sqrt{4900 \; x \; 77.625} = 1603.512m^2$$

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

$$= \frac{5.35 \; x\, 10^{-3} \;\; x\, 1025 \;\; x\, 6.43^2 \;\; x\, 1603.5}{2} = 181.8KN$$

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 barge

* Weight of steel + weight of tanks = 1,400 + 1,200

= 2,600 tonnes

Therefore; $\frac{2600}{80} = 32.5$ tones/m

**Weight at Helideck point*	=	7.5 tonnes/m
**Weight at first floor point*	=	4.0 tonnes/m
* *Weight at second floor point*	=	5.75 tonnes/m
* *Weight at crane point*	=	30.0 tonnes/m
* *Weight at machinery point*	=	1.75 tonnes/m
* *Weight at cargo point*	=	33.33 tonnes/m
* *Weight at others*	=	3.75 tonnes/m
Buoyancy force	=	65.33 tonnes/m

Table 1 Scantling/Section Calculation of the barge

Items	Scantlings	Area (A)m^2	Height (h)m	Moment (ah) m^3	2nd moment (ah^2)m^4	Local 2nd moment (I_o)m^4
Strength deck	5.4x17mm	0.0918	0.2	0.01836	0.00367	
Longitudinal stiffness	102 x 102 x 7.8	0.00224	2.35	0.0054	0.0129	
Side	5.4x10	0.054	0.2	0.0108	0.00216	6.1728
plating Longitudinal	102 x 102 x 7.8	0.00224	2.39	0.0054	0.0129	
Side stiffness	102 x 102 x 7.8	0.009224	14.39	0.0326	0.4134	
Bottom plating	29.4x10mm	0.294	3	0.882	2.646	
		0.44652		0.95416	3.141	0.1728

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

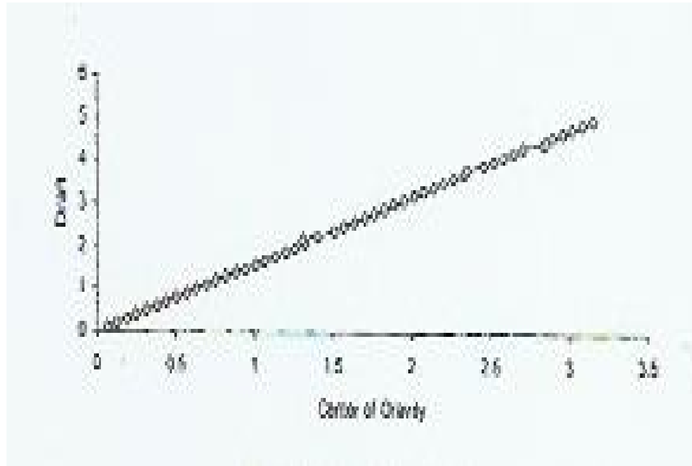

Figure 4: Draft Vs Centre of Gravity [1]

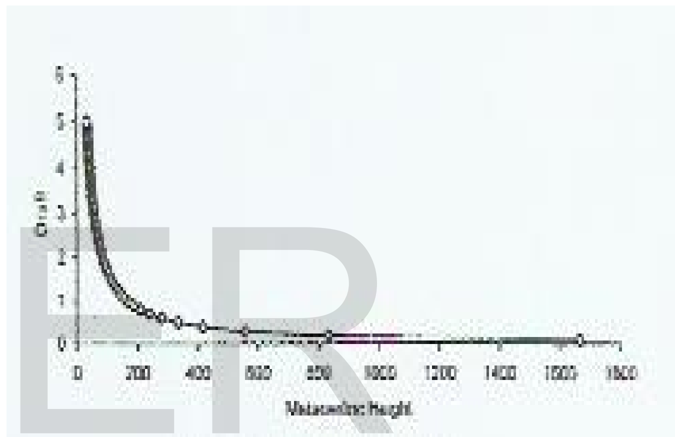

Figure 5 : Draft Vs Metacentric Height

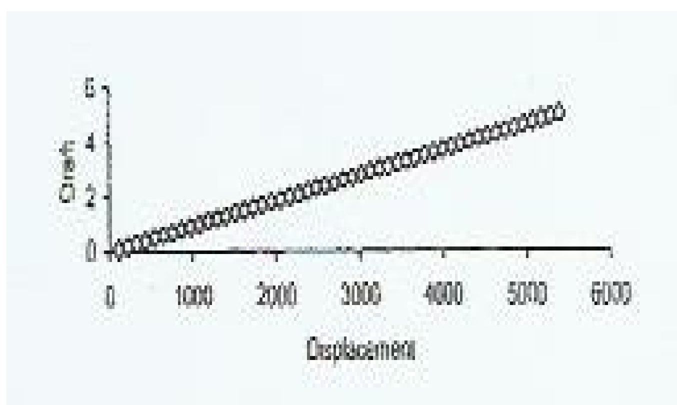

Figure 6: Draft Vs Displacement

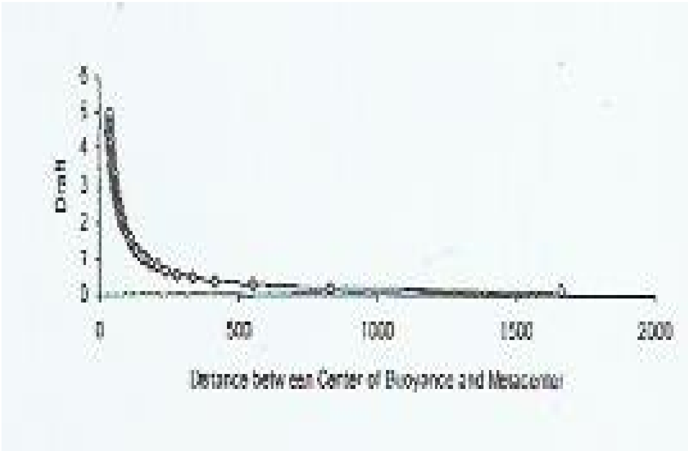

Figure 7: Draft Vs Distance between Centre of Bouyance and Metacenter

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 compare 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/m^2, haven a bending moment induced on the deck at 548.54MN/m^2 maximum and on the base at 304.1MN/m^2 maximum. Appendix 1 shows the results of all design calculations for the work barge.

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ISSN 2229-5518

5 APPENDIX 1

Table 3 Results of Design Calculations of the work barge

Components	Scantlings (mm)	Thickness (mm)	Quantity (No)	Unit Length (m)	Weight (Tonnes)
A. HULL					
1. Bottom plate (outer)	75x30x15	15	1	75	298.4
2. Bottom plate (inner)	75x30x10	10	1	75	184.6
3. Deck plate	80x30x17	17	1	80	346.8
4. Side plate	80x6x10	10	2	80	75.74
5. Force plate (rectangle)	30x1.5x10	10	1	30	3.55
6. Force plate (inclined)	30x6.73x10	10	1	30	15.93
7. Aft plate	30x6x10	10	1	30	14.20
8. Bottom Longitudinal stiffness	152x102x7.8		50	75	57.5
9. Deck longitudinal stiffness	152x102x8.0		50	80	61.4
10. Longitudinal bulkhead	3800x8	8	2	80	60.6
11. Transverse bulkhead	3800x8	8	8	80	88.04
12. Longitudinal bulkhead	152x89x8		20	80	24.6
13. Longitudinal bulkhead	152x89x8		264	6	24.288
14. Transverse bulkhead longitudinal stiffness)	152		20	15	4.6
15. "	"		60	30	27.6
16. "	"		30	7.5	3.6
17. Transverse bulkhead (transverse) stiffness	152x102x8		408	6	37.536
18. Side plate longitudinal stiffness	152x89x8		20	6	24.6
19. Side plate transverse stiffness	152x89x8		266	6	24.472
20. Bottom flange	508 x 102 x 10		21	Different length	15.52
21. Deck flange	451 x 102 x 8		21	Different length	11.28

Components	Scantlings (mm)	Thickness (mm)	Quantity (No)	Unit Length (m)	Weight (Tonnes)
22. Side flange	406 x 127 x 8		14	Dif. Length	6.08
23. Longitudinal bulkhead flange	406 x 102 x 8		14	Dif. length	5.68
24. Transverse bulkhead flange	406 x 102 x 8		36	96	10.28
25. Bottom angle stiffness	152 x 108 x 8		6	80	7.2
26. Top angle stiffness	152 x 108 x 8		6	80	7.2
27. Longitudinal pillars	152 x 152 x 10		12	6	1.728
28. Transverse deck beam	152 x 152 x 10		6	30	4.32
29. Transverse web moment			24	3.4	2.4
30. Girder	152 x 152 x 10		3	80	5.76
31. Outer bottom longitudinal	152 x 102 x 8		50	80	31.0
32. Inner bottom longitudinal	152 x 102 x 6		50	80	31.0
33. Outer boom Transverse	152 x 102 x 6		266	30	61.18
B. SUPERSTRUCTURE (1st FLOOR)					
1. Deck plate	47 x 23 x 8	8	1	47	80.1
2. Force plate	27 x 3 x 6	6	1	27	3.83
3. Aft plate	27 x 3 x 6	6	2	27	3.84
4. Side plate	47 x 3 x 6	6	2	47	12.07
1. Side plate longitudinal stiffness starboard port	152 x 89 x6		6	47	2.22
	152 x 89 x6		6	38	1.89
6. Side plate transverse stiffness	152 x 89 x6		141	3	2.82
7. Deck longitudinal stiffness	152 x 89 x6		45	47	16.59
8. Deck transverse stiffness	152 x 89 x6		79	27	16.59
9. Longitudinal bulkhead	152 x 89 x6	6	14	Dif. length	3.19

Components	Scantlings (mm)	Thickness (mm)	Quantity (No)	Unit Length (m)	Weight (Tonnes)
10. Transverse bulkheads	152 x 89x 6	6	15	Different length	4.10
11. Side flange	406 x 127 x 8		12	Different length	2.75
12. Longitudinal bulkhead flange	406 x 127 x 8		19	Different length	4.93
13. Transverse bulkhead flange	406 x 127 x 8		21	Different length	6.11
14. Deck angle stiffness	152x 108 x 8	8	2	47	1.42
15. Top angle stiffness	152x 108 x 8	8	2	47	1.42
16. Longitudinal pillars	152x 152 x 10	10	12	3	0.864
17. Transverse Deck beam	152x 152 x10	10	6	27	3.90
18. Transverse web			24	3.4	2.40
19. Angle web			120	3.4	0.6
C. SUPPER STRUCTURE (2ND FLOOR)					
1. Deck plate	40 x 28 x 6	6	1	40	53.02
2. Fore plate	28 x 2.5 x 5	5	1	28	2.76
3. Aft plate	28 x 2.5 x 5	5	1	25	2.76
4. Side plate (star board)	49 x 2.5 x 5	5	1	49	4.85
5. Side plate (Port)	40 x 2.5.5	5	1	40	3.95
6. Side plate longitudinal stiffness (starboard)	152 x 89 x 6		5	49	1.95
7. Side plate longitudinal stiffness (port)	152 x 89 x 6		5	40	1.60
8. Side plate transverse stiffness	152 x 89 x 6		164	2.5	3.28
9. Deck longitudinal stiffness	152 x 89 x 6		47	40	18.33
10. Deck transverse stiffness	152 x 89 x 6		164	28	36.08
11. Longitudinal bulkhead	40 x 2.5 x 5	5	6	40	23.7
12. Transverse bulkhead	7 x 2.5 x 5	5	28	7	16.52

Components	Scantlings (mm)	Thickness (mm)	Quantity (No)	Unit Length (m)	Weight (Tonnes)
13. Side flange	406 x 127 x 8		8	10.3	2.8
14. Longitudinal bulkhead flange	406 x 102 x 8		24	10.3	8.4
15. Transverse bulkhead flange	406 x 102 x 8		28	6.5	5.88
16. Deck angle stiffness	152x 108 x 8		4	40	2.4
17. Top angle stiffness	152x 105 x 8		4	40	2.4
18. Longitudinal pillars	152x 152 x 10		20	2.5	1.2
19. Transverse Deck beam	152x 152 x10		5	28	3.35
20. Transverse web			20		2.0
21. Angle web			250		1.28
D. SUPPER STRUCTURE (3RD FLOOR)					
1. Deck Plate	40 x 20 x 20	20	1	20	63.12
2. Deck Longitudinal stiffness	152 x 102 x 8		33	20	5.28
3. Deck transverse stiffness	152 x 102 x 8		33	20	5.28
4. Side flange	406 x 127 x 510		16	5.6	3.04
5. Deck angle stiffness	152 x 108 x 8		4	20	1.20
6. Longitudinal pillar	152 x 153 x 10		20	2.5	2.0
7. Transverse Deck beam	152 x 153 x 10		10	20	4.8
8. Transverse web			60		0.6
9. Longitudinal web			48		0.48
E. Estimations of Machineries, Tanks and others					
1. Crane		-	1	-	250
2. Helicopter	-	-	1	-	20
3. Generators	-	-	4	-	20
4. Purifiers	-	-	2	-	0.1
5. Ballast pumps	-	-	3	-	0.078
6. Service pumps	-	-	2	-	0.052
7. Fire/Bilge Pumps	-	-	3	-	0.078

Components	Scantlings (mm)	Thickness (mm)	Quantity (No)	Unit Length (m)	Weight (Tonnes)
8. Lathe Machine	-	-	1	-	1.36
9. Sawing Machine	-	-	1	-	0.2
10. Welding set	-	-	1	-	0.15
11. Press Unit	-	-	1	-	0.015
12. Tools and equipment	-	-	1	-	0.10
13. Fresh water transfer pumps	-	-	2	-	0.052
14. Sea water cooling pumps	-	-	2	-	0.05
15. Fresh Water cooling pumps	-	-	1	-	0.025
16. Sewage treatment plant	-	-	1	-	1.50
17. Water maker	-	-	1	-	4.0
18. Boilers	-	-	2	-	4.0
19. Laundry Machine	-	-	1	-	1.2
20. Air conditioner plant	-	-	1	-	2.0
21. Lube oil service pump	-	-	1	-	0.026
22. Refrigerators	-	-	2	-	0.03
23. Baking oven	-	-	1	-	0.02
24. Fresh water service pumps	-	-	2	-	0.05
25. Anchors	-	-	4	-	20.0
26. Fuel tanks	-	-	3	-	495.0
27. Fresh water tank	-	-	4	-	500.0
28. Hospital equipment	-	-	1	-	0.2
29. Canteen equipment	-	-	1	-	0.2
30. Toilet blocks	-	-	Many	-	0.7
31. Recreation room equipments	-	-	Many	-	0.15
32. Radio room equipment	-	-	Many	-	0.15
33. Office equipment	-	-	Many	-	0.45
34. Mass equipment	-	-	Many	-	0.30
35. Accommodation facilities	-	-	Many	-	0.30