Calculation for Hull Strength Construction in Offshore Structures
(A Case Study of 5000t Work Barge)

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Abstract

Ship classification societies such as Det Norske Veritas, American Bureau of Shipping, and Lloyd's Register have established standard calculation forms for hull loads, strength requirements, thickness of *hull plating, reinforcing stiffeners, girders, and other structures. This paper therefore used the relevant International Standards to compute, determine scantlings to obtain a good structural rigidity and the estimation of the weight of all components. With the help of the Classification of Ships' Rule and Regulation Part 2 and 3, No 3 of Lloyd's Register, various formulae were used to obtain various thickness of plates (side, bulk, deck etc) and frames. Results show that the maximum stress on the 5000 tonnes work barge should be* $83.33MN/m^2$ *while Maximum stress on deck and base were* $548.54MN/m^2$ *and* $304.1MN/m^2$ *respectively.*

Keywords: *Lloyd's Register, Hull strength, Maximum stress, Bulkhead, Double bottom*

1.0 Introduction

The ship structure provides the strength and stiffness to withstand all loads to be experienced. It also provides the local support for many hulls, machineries, electrical and electronics equipment and others required for the vessel to fulfill its intended functions [1]. According to [2], the "hull girder" is the structure that resists longitudinal bending consisting of the shell plating, deck, inner bottom and longitudinal bulkhead. The hull girder has to be able to provide the strength to withstand the full range of external or buoyancy loading, from still water to dynamic storm, sea conditions with full internal loading ranging from light ship weight, cargo, fuel, ballast etc.

The basic consideration of strength and stiffness on ship design structure must also include "factor of safety", cost weight, shock, vibration [3], fatigue, corrosion [4], fabrication and maintenance. The order of importance of these factors depends on the particular case under consideration

1.1 *Ship Hull Structure Elements*

The structural configuration of a barge does not differ much from other marine vessels. Most of the structural features are common to all vessel types [5]. The key structural elements of a ship's main hull with all parts labeled are shown in Figure 1.

The arrangement of the structural member must often involve a compromise with the other consideration such as space, arrangement, cargo handling or access. From [6], bulkheads are stiffened-plated structures primarily subjected to normal loads and secondary loads. There are three general types of bulkheads namely, tank boundaries, ordinary water tight bulkheads and miscellaneous non- watertight divisions, all of which perform an important function in general strength and rigidity of the entire hull structure.

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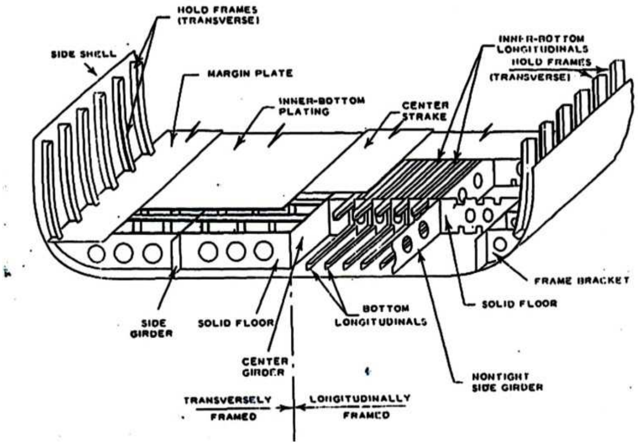

Figure 1. *Structural elements of a barge hull* [7]

All bulkheads are valuable as support, affording rigid terminals for deck and shell girders, longitudinal frames and vertical keels as well as a solid base for superimposed weight. These include superstructures and deck house. The stiffness is also designed to act as supporting element and must have negligible deflections.

The construction of double bottom offers several advantages over single bottom construction: it results in a strong bottom that is well adapted to withstand the upward pressure from the sea as well as the longitudinal hull girder bending stresses, especially the compression resulting from hogging stress. It can also withstand a considerable amount of bottom damage caused by grounding without flooding of the hold, or machinery space, provided the inner bottom remains intact. In some designs, it acts as fluid storage compartment. Finally, a smooth inner hull free of stiffening structure is produced which provides easier cleaning accessibility.

2.0 Materials And Methods

This work deals with the estimation of the principal dimensions, the structural analysis, hull configuration for structural rigidity, estimation of machineries and machine equipments. All design selections, estimation and calculation on board the work barge were done in accordance with the rules and regulations of classification authorities in various fields, areas or endeavors relating to this work.

2.1 Structural Analysis

In the design of ships, the structural analysis is to create structural elements with acceptable stress level that will keep the structure completely within the elastic range. This is to make that such structure does not undergo permanent deformation or fracture due to high level of stress. The structure must be designed to avoid excessive elastic deformation, which would change geometrically and make the structure to withstand imposed loading

The ship transverse strength must be strengthened because of the hydrostatic loadings, structural weight, reaction of weights, cargo due to the change of motion and impact of storm at sea. The bulkheads, decks, and tanks tops are special areas where the stiffness calculations need to be done appropriately to ensure the functioning of the work barge under consideration to be fulfilled [8].

2.2 Deck Plating

Lloyd's rule and regulations for the classification of ships [9] from Part 3 Chapters 5 Section 2 for deck plating of this capacity of offshore work barge. The thickness from 0.075L at the fore part is given from [10];

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

where
t = thickness of plating in mm
L = length

2.3 Double Bottom Plate

The depth and center girder thickness of the double bottom [9] is given by the formulas (in millimeters) as given below respectively [1],

$$d_{DB} = 32B + 190\sqrt{d} \qquad (2)$$

$$t = (0.008d_{DB} + 4)\sqrt{k} \qquad (3)$$

Where
d = *molded draft*
B = *breadth of the vessel*

For transverse frame thickness is given by the relation

$$t = (0.008d_{DB} + 1)\sqrt{k} \qquad (4)$$

For longitudinal frame thickness is given by the relation

$$t = (0.0075d_{DB} + 1)\sqrt{k} \quad (5)$$

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

$$t = 0.00136\,(S + 660)^4 \sqrt{k^2 LT} \quad (6)$$

2.4 Side Plate

For the side plate of the barge, from Lloyd's rules and regulation for the classification of ships from Part 3 Chapters 6, Section 3 [10], the plate thickness is given by the relation

$$t = (6.5 + 0.033L)\sqrt{\frac{KS_1}{S_b}} \quad (7)$$

2.5 Bulkheads

For the bulkheads plate of this capacity of work barge, from Lloyd's rule and regulation for the classification of ships [10] from Part 4, Chapter 1 Section 902) give the bulkhead thickness by this relation;

$$t = 0.004Sf\sqrt{h_4 K} \quad (mm) \quad (8)$$

$$f = 1.1 - \frac{h_A}{2500S} \quad (9)$$

Where

h_A = *Tank head*

S = *Space of member*

2.6 Stiffness

Calculations of the stiffness of the work barge is taken from the Lloyd's rules and regulations for the classification of ships from Part 4, Chapter 6, Section 4

2.7 Section Modulus

From basic strength of materials, the stress can be calculated using the formula [11] given below

1. $$Stress = \frac{Force\ (Load)}{Unit\ Area\ (m^2)} \quad (10)$$

2. $$Factor\ Of\ Safety = \frac{Yield\ Stress}{Max\ Design\ Stress} \quad (11)$$

From these equations we derive that

$$\frac{Force}{Unit\ Area} = \frac{Yield\ Stress}{Factor\ of\ Safety} \quad (12)$$

$$Unit\ Area = \frac{Force \times Factor\ of\ Safety}{Yield\ Stress} \quad (13)$$

Simple beam theory

$$M_B = S_M \sigma \quad (14)$$

Where,

M_B = *Bending moment*

S_M = *Sectional Modulus*

σ = *Unit Stress*

$$\sigma = M_B / S_M \quad (15)$$

$$\sigma = \frac{M_B \times C}{I} \quad (16)$$

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 is the Sectional moment of inertia about the neutral axis

Height of Neutral Axis $h_{NA} = \frac{\sum ah}{\sum a}$

(17)

This implies the height above the keel.

Second moment of area at the half section above base

$$= \Sigma ah^2 + I_0 \quad (18)$$

$$\Sigma \text{ Parallel axis term} = \Sigma a \times h^2_{NA} \quad (19)$$

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

$$Z\text{–Deck} = \frac{I_{NA}Full}{ShipHeight \quad I_{NA}} \quad (20)$$

Z –Base $= \frac{I_{NA} Full}{h_{NA}}$ (21)

Max. design stress = $\frac{Yield\ Stress}{Factor of\ Safety}$ (22)

Factor of safety is a design criteria that an engineered component or structure must achieve. $FS = UTS/R$, where FS: the factor of safety, R: the applied stress, and UTS: ultimate stress *(N/m^2)* [5].

Using the maximum bending moment included in the steel structure

Stress on Deck $= M_B / Z_D$ (23)

Stress on base $= M_B / Z_B$ (24)

3.0 Structural Arrangement and Calculations

Principal Dimensions

Length of ship	*80m*
Breadth of ship	*30m*
Draft of ship	*4.5m*
Depth of ship	*6.0m*
Displacement	*5000 tonnes*

1 Calculations of Strength, Resistances and Plates

a. *Deck Plating Calculations*

From equation (1)

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

$$C = \frac{D + 2.3 - T}{Height\ of\ Deck\ Above\ Load\ Line\ At\ F.P.}$$

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

$$S_b = standard\ frame spacing = 470 + \frac{L}{0.6}$$

For forward of 0.05L from F.P.

By substituting, we have

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

Hence standard frame spacing is approximately 600mm

S_1 = Spacing of secondary stiffness = 600mm

K = 0.66 (from table)

Therefore substituting into Equation 1

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

Hence selected thickness *(t)* for deck plating for the barge is approximately17mm.

The given parameters

t	=	*17mm*
L	=	*80m*
B	=	*30m*
Number of plate	=	*1*
Chosen density of steel	=	*8.5 tonnes/m^3*

$$Mass = t \times L \times B \times \rho \times PlateNumber$$

$$= 0.017m \times 80m \times 30m \times 8.5 tonnes / m^3 \times 1$$

$$= 346.8 tonnes$$

b. *Double Bottom Plate calculation*

The depth of the double bottom is given by the formula from equation 2

$$d_{DB} = 32B + 190\sqrt{d}$$

$$= 32 \times 30 + 190\sqrt{45}$$

$$= 1363.1mm$$

While the center girder thickness is given by the relation from equation 3

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

$$= (0.008 \times 1363.1 + 4)\sqrt{0.66}$$

$$= 12.11mm$$

From equation 4, transverse frame thickness becomes

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

$$t = (0.008 \times 1363.1 + 1)\sqrt{0.66}$$

$$= 0.967 mm$$

For longitudinal frame thickness is given by the relation

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

$$t = (0.0075 \times 1363.1 + 1)\sqrt{0.66}$$

$= 9.12mm \approx 10mm$

The inner bottom plate thickness from equation 6

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

$$t = 0.00136\ (600 + 660)^4\ \sqrt{0.66^2\ x80x4.5}$$

$= 6.06mm$

Selected thickness *t* for inner bottom plate

t = *10mm*

Therefore, given parameters

t = *10mm*
L = *78m*
B = *30m*
Plate number = *1*
Steel density = *7.89tonnes/m*^{3}

$$Mass = t \times L \times B \times \rho \times PlateNumber$$

$$= 0.01 \times 78 \times 30 \times 7.89 \times 1$$

$$= 184.63tonnes$$

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

Therefore, given parameters

t = *15mm*
L = *78m*
B = *30m*
Plate number = *1*
Density = *8.5 tonnes/m*^{3}

$$Mass = t \times L \times B \times \rho \times PlateNumber$$

$$= 0.015 \times 78 \times 30 \times 8.5 \times 1$$

$$= 298.3tonnes$$

c. *Side Plate*

The plate thickness is given from equation 7

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

The parameter given

$S_1 = S_b$ = *600mm*
K = *0.66*
L = *80m*

$$t = (6.5 + 0.033 \times 80)\ \sqrt{\frac{0.66 \times 600}{600}}$$

$= 7.43mm$

Selected thickness for side plate t = 10mm

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

$$Mass = t \times L \times B \times \rho \times PlateNumber$$

$$= 0.01 \times 80 \times 6 \times 7.89 \times 2$$

$$= 75.74tonnes$$

d. *Aft Side Plate*

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

$$Mass = t \times L \times B \times \rho \times PlateNumber$$

$$= 0.01 \times 30 \times 6 \times 7.89 \times 1$$

$$= 14.20tonnes$$

e. *Fore Side Plate 1*

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

$$Mass = 0.01 \times 30 \times 1.5 \times 7.89 \times 1$$

$$= 3.55tonnes$$

f. *Fore Side Plate 2*

Length (L) = 6.73m
Steel plate thickness (t) = 10mm
Breadth (B) = 30m
Height (D) = 6.73m
Number of plate = 1
Density = 7.89tonnes/m^3

$$Mass = 0.01 \times 30 \times 6.73 \times 7.89 \times 1$$

$$= 15.93tonnes$$

g. Bulkheads calculations

Bulkhead thickness given from equation 8;

$t = 0.004Sf \sqrt{h_4 K}$

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

h_A = Tank head = 600mm

S = Space of member = 15mm

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

Selected $f \approx 1.0$

Therefore,

$t = 0.004 \times 600 \times 1 \sqrt{6 \times 0.66} = 7.78mm$

Selected thickness for longitudinal bulkhead is

$t = 8mm$

Given parameters for

Steel plate thickness (t)= 8mm
Height = 6m
Length = 80m
Density of steel = 7.89tonnes/m^3
Number of plate = 2

$$Mass = t \times L \times B \times \rho \times PlateNumber$$
$$= 0.8 \times 6 \times 80 \times 7.89 \times 2$$
$$= 60.6tonnes$$

For Transverse Stiffeners

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

$f = 1.1 \frac{600}{2500 \times 12.5} = 1.081$

Height

Longitudi nal stiffness

Selected $f \approx 1.0$ Length of stiffness

Therefore,

Number of plate

$t = 0.004 \times 600 \times 1.0 \sqrt{6 \times 0.66} = 7.78mm$

Selected thickness for transverse bulkhead is

$t \approx 8.0mm$

Given parameters are:
Steel plate thickness (t) = 8mm
Height = 6m
Breadth = 30m

Density of steel = 7.89tonnes/m^3

Number of stee l= 6

$$Mass = t \times L \times B \times \rho \times PlateNumber$$
$$= 0.08 \times 6 \times 30 \times 7.89 \times 1$$
$$= 68.17tonnes$$

h. *Stiffness calculation*

From part 4, chapter 6, section 4(12), we have it that longitudinal stiffness for deck;

Longitudinal Stiffness for Deck
Breadth = 30m
Number of stiffness = 50
Section $152 \times 102 \times 8 = 15.35 Kg/m$
$Mass = 80 \times 15.35 \times 50 = 61.4tonnes$

Transverse Stiffness for Deck
Transverse space = 600
Length of transverse = 30m
Number of stiffness = 134
Section = 15.35Kg/m
$Mass = 80 \times 15.35 \times 50 = 61.7tonnes$

Longitudinal Stiffness on Side Plate
= 6m
Number of longitude
= 10
= 80

Section $152 \times 102 \times 8 = 15.35 Kg/m = 2$

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

Transverse Stiffness on Side Plate

Number of transverse stiffness = 134
Length of transverse = 6m
Length of stiffness = 6m
Section $152 \times 102 \times 8 = 15.35 Kg/m$
Number of plate = 2
$Mass = 6 \times 15.35 \times 134 \times 2 = 24.7 tonnes$

Longitudinal Stiffness on Bottom Plate (Double)

Breadth = 30m
Length of longitudinal = 75m
Number of bottom plate = 2
$Mass = 75 \times 15.35 \times 50 \times 2 = 115.1 tonnes$

Transverse Stiffness of Bottom Plate (Double)

Breadth = 30m
Length of transverse = 30m
Number of transverse = 134
Number of plate = 2
$Mass = 30 \times 15.35 \times 134 \times 2 = 123.4 tonnes$

Longitudinal Stiffness on Bulkhead

Number of longitudinal = 10
Length of longitudinal = 80m
Number of bulkheads = 2
$Mass = 10 \times 15.35 \times 80 \times 2 = 24.6 tonnes$

Transverse Stiffness on Bulkhead

Number of transverse = 134
Length of transverse = 6m
Number of bulkhead = 2
$Mass = 6 \times 15.35 \times 134 \times 2 = 24.7 tonnes$

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

Fore and Aft Side Plate

Given parameters
t = 6.0mm
Breadth =27m
Height = 3m
Number of plate = 2
$Mass = 0.006 \times 27 \times 3 \times 2 \times 7.89$
$= 7.67 tonnes$

Frames

Longitudinal frames thickness = 10mm
Total frame = 6
Total length = 50m
Number of plate = 2
$Mass = 50 \times 0.01 \times 6 \times 7.89 \times 2 \times 450 = 21.3 tonnes$
Transverse frame thickness = 10mm
Total frame = 3
Total length = 28mm
Number of plate = 2
$Mass = 28 \times 0.01 \times 3 \times 7.89 \times 2 \times 450$
$= 5.96 tonnes$

3.1 Strength Analysis

Ultimate tensile strength
$400 - 495 MN/m^2 = 26 - 32\ tonnes/m^2$
Yield stress
$230 - 250 MN/m^2 = 15 - 16\ tonnes/m^2$
Shearing strength $= 22\ tonnes/m^2$
From Barge Section in Table 1,
Height of Neutral Axis h_{NA}

$$= \frac{\sum ah}{\sum a} = \frac{0.95416}{0.44682} = 2.14m$$

This implies that Neutral Axis is 2.14m above the keel.
Second moment of area at the half section above base
$= \Sigma ah^2 + I_0 = 3.141 + 0.1728 = 3.313 m^4$
ΣParallel axis term
$= \Sigma a \ x \ h^2{}_{NA} = 0.44682 \times (2.14)^2 = 2.046 m^4$

I_{NA} = *Second moment of area of half section about the base – parallel axis term*
$= 13.3138 - 2.046$
$= 1.2678 m^4$

Therefore; I_{NA} (Full section) $= 1.2678 \times 2$
$= 2.5356m^4$
Full area $= 0.44682 \times 2$
$= 0.89364m^2$

$$Z\text{–}Deck = \frac{I_{NA}Full}{ShipHeight \quad I_{NA}}$$

$$= \frac{2.5356}{6.0 \quad 2.14} = 0.6569m^3$$

Z –Base

$$= \frac{I_{NA}Full}{h_{NA}} = \frac{2.5356}{2.14} \; 1.1849m^4$$

Factor of Safety $= 3$

$$Maximum\ design\ stress = \frac{Yield\ \ Stress}{Factor\ \ of\ \ Safety}$$

$$\frac{250}{3} = 83.33MN / m^2$$

Using the maximum bending moment included in the steel structure

$$Stress\ on\ deck = M_B / Z_D$$

$$= \frac{360.334}{0.6569} = 548.54MN / m^2$$

$$Stress\ on\ base = M_B / Z_B$$

$$= \frac{360.334}{1.18499} = 304.1MN / m^2$$

Noticeably, all the analysis given above directly or indirectly also helped to ascertain a good structural and overall stability of the barge [8].

4.0 Results and Discussion

The design of a 5000 tonnes work barge following rules and regulation has yielded several results from classification societies, laws, principles, experiments, calculations and assumptions etc. Similarly, the structural arrangement of the designed work barge will be taken into consideration in this section as part of the results.

The strength calculation of the work barge enables us to know its ability to withstand the stress or loads imposed on it. It also helps to maintain good structural stability. This provides adequate strength without the structures of the work barge yielding under normal condition of loading and even in emergency situation.

Appendix A shows the representation of the summary of the entire component on board the work barge while considering; the scantling, their thickness, quantity, their length and their weight in tonnes. These are capable of withstanding the hull, superstructures and all machineries.

Table 1. Scantling/Section Calculation of the barge

Items	*Scantlings*	*Area $(A)m^2$*	*Height (h)m*	*Moment (ah) m^3*	*2^{nd} moment $(ah^2)m^4$*	*Local 2^{nd} moment $(I_0)m^4$*
Strength deck	*5.4×17mm*	*0.0918*	*0.2*	*0.01836*	*0.00367*	
Longitudinal stiffness	*102 ×102 × 7.8*	*0.00224*	*2.35*	*0.0054*	*0.0129*	
Side	*5.4×10*	*0.054*	*0.2*	*0.0108*	*0.00216*	*6.1728*
plating Longitudinal	*102 ×102 × 7.8*	*0.00224*	*2.39*	*0.0054*	*0.0129*	
Side stiffness	*102 × 102 ×7.8*	*0.009224*	*14.39*	*0.0326*	*0.4134*	
Bottom plating	*29.4×10mm*	*0.294*	*3*	*0.882*	*2.646*	
		0.44652		***0.95416***	***3.141***	***0.1728***

5.0 Conclusion

From the Construction of the 5000 tonnes work barge, it can be concluded that one of the best ways to calculate the ship hull strength is by the use of classification society rules and regulations giving guidelines and formulae to the estimation, selection and calculation of various components, machineries, systems etc. of the ships or barge under design. The research work fits the time in all ramifications, now that most oil exploration and exploitation are gradually moving from the shore to the deep water offshore. Hence, several manpower will be needed to work offshore to exploit the resources deposited at very deep waters offshore. Therefore the necessary mechanical, marine and civil works that must be done at oil sites will be done on board the barge and personnel readily available for such services. Thus, solid structural arrangement needs to be done to ensure safe activities offshore.

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Appendix A: Summary of Components, Scantlings, Thickness and Weight

Structural Components	*Scantlings (mm)*	*Thickness (mm)*	*Quantity (No)*	*Unit Length (m)*	*Weight (Tonnes)*
1. Bottom plate (outer)	*75 × 30 × 15*	*15*	*1*	*75*	*298.4*
2. Bottom plate (inner)	*75 × 30 × 10*	*10*	*1*	*75*	*184.6*
3. Deck plate	*80 × 30 × 17*	*17*	*1*	*80*	*346.8*
4. Side plate	*80 × 6 × 10*	*10*	*2*	*80*	*75.74*

5. Force plate (rectangle)	30 × 1.5 × 10	10	1	30	3.55
6. Force plate (inclined)	30 × 6.73 × 10	10	1	30	15.93
7. Aft plate	30 × 6 × 10	10	1	30	14.2
Bottom Longitudinal stiffness	152 × 102 × 7.8		50	75	57.5
9. Deck longitudinal stiffness	152 × 102 × 8.0		50	80	61.4
10. Longitudinal bulkhead	3800 × 8	8	2	80	60.6
11. Transverse bulkhead	3800 × 8	8	8	80	88.04
12. Longitudinal bulkhead	152 × 89 × 8		20	80	24.6
13. Longitudinal bulkhead	152 × 89 × 8		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	152 × 102 × 8		408	6	37.536
18. Side plate longitudinal stiffness	152 × 89 × 8		20	6	24.6
19. Side plate transverse stiffness	152 × 89 × 8		266	6	24.472
20. Bottom flange	508 × 102 × 10		21	Different length	15.52
21. Deck flange	451 × 102 × 8		21	Different length	11.28
22. Side flange	406 × 127 × 8		14	Different length	6.08
23. Longitudinal bulkhead flange	406 × 102 × 8		14	Different length	5.68
24. Transverse bulkhead flange	406 × 102 × 8		36	96	10.28
25. Bottom angle stiffness	152 × 108 × 8		6	80	7.2
26. Top angle stiffness	152 × 108 × 8		6	80	7.2
27. Longitudinal pillars	152 × 152 × 10		12	6	1.728
28. Transverse deck beam	152 × 152 × 10		6	30	4.32
29. Transverse web moment			24	3.4	2.4
30. Girder	152 × 152 × 10		3	80	5.76
31. Outer bottom longitudinal	152 × 102 × 8		50	80	31
32. Inner bottom longitudinal	152 × 102 × 6		50	80	31
33. Outer boom Transverse	152 × 102 × 6		266	30	61.18