AN ALTERNATIVE STRUCTURAL DESIGN FOR TANKERS

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ABSTRACT

The aim of this paper is to initiate an alternative design for tankers. The target of this investigation is to create a new structural arrangement for the double hull region of the tanker, using corrugated plates after replacing all the secondary support members such as longitudinals, floors, intercostal girders, brackets, stringers, stiffeners, frames, angle clips, bounding bars etc. This work has been mainly influenced to generate a shape with easy accessibility, well visibility and less complication to fabrication, since this portion of vessel is really congested for inspection and maintenance. However, this study is predominantly focused on the calculations of thicknesses and section modulii of the proposed corrugated plates and comparison with the required section modulii for a model vessel in the same region according to the classification rules. All the calculations have been carried out according to the "Common Structural Rules For Double Hull Oil Tankers", adopted by International Association of Classification Societies (IACS), which was issued in July 2009. As a model vessel the Yakumosan (Hull no. 3223), owned by Star Express Inc. is considered.

Keywords: *Tanker, Double hull, Corrugated plate, Section modulus, Web and Flange plate.*

1. INTRODUCTION

A tanker is used to transport liquid cargoes in bulk, the most common type being the oil tanker, which is also known as petroleum tanker. A wide range of other liquids are also carried in tankers such as liquefied petroleum gas (LPG), liquefied natural gas (LNG), chemicals (e.g., ammonia, chlorine and styrene monomer), fresh water, wine etc. Tankers ordered [6] after 1993 had to comply with the MARPOL double hull regulation. This is opposed to single hull tankers where one or more cargo holds are bounded in part by the ship's shell plating. In the double hull design the cargo tanks are completely surrounded by wing and double bottom tanks which can be used for ballast purposes. Therefore, this portion of the vessel needs continuous inspection, cleaning and maintenance. But due to the construction technique in conventional way, this region is crammed with a variety of support members such as longitudinals, floors, intercostal girders, brackets, stringers, stiffeners, frames, angle clips, bounding bars etc. To commence an alternative of all these members, this work has been prepared to suggest a design with a single cross sectional segment in the double hull region which will execute all the requirements of the IACS [1].

2. MODEL VESSEL

A VLCC named *Yakumosan* (Hull no: 3223) is considered as the model vessel, which is shown in Figure 1. The naming and launching ceremonies [2] for this 300,000 t class double-hull tanker were held at the Kure Shipyard of IHI Marine United Company Ltd. on November 28, 2008. MOL (Mitsui O.S.K. Lines, Ltd.) Chairman Kunio Suzuki named the ship and rope cutting honours went to Mrs. Yukie Yoshida, the wife of Mr. Genichi Yoshida, Executive Vice President of Mitsui & Company Ltd. The *Yakumosan* left on its maiden voyage to Saudi Arabia under the arch of a rainbow celebrating its bright future. This tanker offers the safest, most environment-friendly features such as double-hull fuel tanks and VECS (Vapour Emission Control Systems). Recently, it is transporting crude oil from the Middle East to Asia. The general particulars [5] of *Yakumosan* are shown in Table 1.

Table 1. General Particulars of the Model Vessel *Yakumosan*

Owner	Star Express Inc.
Builder	IHI Marine United
Hull No	3223
Ship Type	VLCC
Length (OA)	333.00 m
Length (BP)	324.00 m
Beam	60.00 m
Depth	29.00 m
Draught	19.20 m
DWT	300,000 t
GT	160,300 t

Main Engine	DU-Sulzer 7RT-flex 84T-D diesel x 1 unit
Maximum Continuous Revolution (MCR)	27,160 kW
Service Speed	15.8 kt
Classification	NK
Completion	November 28, 2008

Figure 1. The Model Vessel *Yakumosan* [2]

3. PROPOSED STRUCTURAL DESIGN

The purpose of this project is to develop a new double hull configuration for tankers. Since, the original mid-ship section of the model vessel has not been possible to collect; therefore it is assumed that the vessel has been built in a conventional way following the classification rules. In the proposed design, all the supporting members are replaced by simple longitudinal corrugated plates. The breadths of web and flange of these plates are taken as 1100 mm and 1000 mm respectively. Meanwhile, the corrugation angle of these plates is taken as 65 degrees. Moreover, there are two side girders in the double bottom region on each side of the centreline at a distance of 8748 mm and 17496 mm from the centreline as well as a centreline girder. In the double side region there are also two longitudinal girders at a distance of 8748 mm and 17496 mm from the bottom of the wing tank on each side (i.e., port side and starboard side). Since the mid-ship section of the proposed design as shown in Figure 2 is mainly focused on the double hull region of the vessel, therefore no structural members in the deck region are shown.

4. OVERVIEW OF THE WORK PROCESS

This study is mainly concentrated on the calculations of thicknesses and section modulii for the corrugated plates being considered. For this, proper sign conventions are used (i.e. x-axis is positive towards forward of the vessel, y-axis is positive towards port side of the vessel and z-axis is positive towards upward side of the vessel). Meanwhile, the calculations are based on a specific point of the vessel. Therefore, some particular points are considered. The co-ordinates of these points are as follows:

1. Longitudinally, only amidships is considered (i.e. $x = 162$)
2. Transversely, for double bottom: $y = +26, 0, -26$ and for double side: $y = +28, +29, +30, -28, -29, -30$ are considered.
3. Vertically, for double bottom: $z = 0, 1, 2$ and for double side: $z = 4, 19.2, 29$ are considered.

5. CALCULATIONS

5.1 Assumptionss

To simplify the calculations some assumptions are considered. They are as follows:

a) The cargo region of the tanker is parallel to the centre line of the vessel.
b) The double bottom tanks and double side tanks (i.e., wing tanks) are used for water ballast.
c) Ballast tanks are designed for ballast water exchange by flow-through method.
d) The position of the aft bulkhead is at $x = 65$ (i.e. $\approx 0.2L$) and the forward bulkhead is at $x = 290$ (i.e. $\approx 0.9L$). Therefore, the cargo tank region is in between $0.2L$ to $0.9L$.
e) The bilge starts at $y = +26$ in port side and $y = -26$ in starboard side.
f) Above $z = 4$, the local breadth at any draught is same as the breadth of the vessel.
g) Height of air pipe or overflow pipe is 1 m above the freeboard deck.

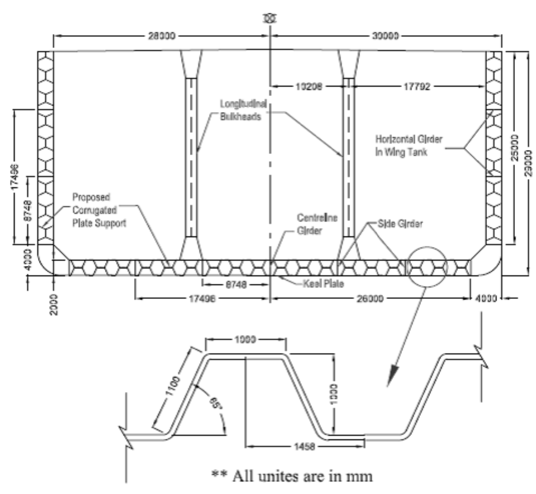

Figure 2. Midship Section of the Proposed Structural Design

5.2 Calculating Block Coefficient

An empirical formula developed by Ayre [4], is defined as: $\frac{L}{\nabla^{\frac{1}{3}}} = 3.33 + 1.67\frac{V}{\sqrt{L}}$

where: $L =$ rule length, in m = 324 m; $V =$ service speed, in knots = 15.80 knots; $\nabla=$ moulded displacement volume at the scantling draught, in m^3.

Hence: $\nabla = 308{,}338$ tonne

Meanwhile, according to IACS (Section 4/1.1.9.1), Block Coefficient at the scantling draught, C_b , is to be taken as: $C_b = \frac{\nabla}{L B_{WL} T_{sc}}$

where: B_{WL} = moulded breadth measured amidships at scantling draught waterline, in m = 60 m; T_{sc} = scantling draught, in m = 19.2 m.

Therefore: $C_b = \frac{308{,}338}{324 \times 60 \times 19.2} = 0.826$

Note: The numerical values of vessel's characteristics in this section are obtained from Table 1.

5.3 Double Hull Arrangement

The double bottom and double side tanks and spaces, protect the cargo tanks or spaces, and are not to be used for the carriage of oil cargoes. According to IACS (Section 5/3.2.1.1 & 5/3.3.1.1), the double bottom depth and double side width are both taken as 2.0 m.

5.4 Hull Envelop Plating

According to IACS (Section 8/Table 8.2.1), the thickness of plating in the cargo tank region is to comply with the appropriate minimum thickness requirements given in Table 2:

Table 2. Minimum Net Thickness for Plating in the Cargo Tank Region

Scantling Location	Net Thickness (mm)	
	Formula	Value
Keel Plating	$6.5 + 0.03L_2$	15.50
Bottom Shell	$4.5 + 0.03L_2$	13.50
Bilge	$4.5 + 0.03L_2$	13.50
Side Shell	$4.5 + 0.03L_2$	13.50
Upper Deck	$4.5 + 0.02L_2$	10.50
Hull internal tank boundaries	$4.5 + 0.02L_2$	10.50
Non-tight bulkheads and other plates	$4.5 + 0.01L_2$	7.50

where: L_2 = rule length, L, but need not be taken greater than 300 m (i.e., $L_2 = 300$ m).

According to IACS (Section 8/2.2.1.1), keel plating has to be extended over the flat of bottom for the complete length of the ship. The breadth, b_{kl}, is not to be less than: $b_{kl} = 800 + 5L_2$ mm.

Therefore: $b_{kl} = 800 + 5 \times 300 = 2300$ mm. Since, the breadth of keel plating is not to be taken less than 2300 mm; it is taken as 2500 mm.

5.5 Calculations of Corrugated Plate as a Primary Member in Double Bottom Region

According to IACS (Section 8/2.5.6.4), the net thickness, t_{net}, of the web and flange of corrugated plates are to be taken as the greatest value calculated for all applicable design load sets (i.e., each design load set corresponds a particular load component at a specific deign load combination, acceptance criteria set and some parameters such as dynamic load combination factors, metacentric height and radius of gyration), and given by:

$$t_{net} = 0.0158 b_p \sqrt{\frac{|P|}{C_a \sigma_{yd}}} \text{ mm}$$

where:

P = design pressure for the design load set being considered, calculated at the point, in kN/m^2

b_p = breadth of plate:

= b_f ; (for flange plating, in mm)

= b_w ; (for web plating, in mm)

C_a = permissible bending stress coefficient:

= 0.75 ; (for acceptance criteria set AC1)

= 0.90 ; (for acceptance criteria set AC2)

σ_{yd} = specified minimum yield stress of the material, in N/mm^2 = 235 N/mm^2

Since, corrugated plates are used as primary support members in the double bottom region, in the table for "Design Load Sets for Primary Support Members" of IACS (Section 8/Table 8.2.9), the specifications for "Double bottom floors and girders" are considered. The maximum values for each design load set in this region are shown in Table 3.

Table 3. Maximum Values Obtained from Calculations for Each Design Load Set

Design Load Set	Load Component	Design Load Combination	Acceptance Criteria Set	Value
1	Sea Pressures P_{ex}	S+D	AC2	197.83
2		S	AC1	193.06
12	Net Cargo Pressure-Sea Pressure $P_{in} - P_{ex}$	S+D	AC2	**296.40**
13		S	AC1	278.40

Notes:

1. The first column specifies the Design load sets which are considered for "Double bottom floors and girders" according to IACS (Section 8/Table 8.2.9).

2. The second column specifies the pressure load components of the design load set, which are defined in Table 4, according to IACS (Section 7/Table 7.6.1).
3. The third column specifies which column in the design load combination table of IACS (Section 7/Table 7.6.1) is to be applied for each design load set, where S denotes the static design load combination and $S+D$ denotes the static plus dynamic design load combination.
4. The forth column specifies the Acceptance Criteria Set.
5. The fifth column gives the maximum values for each Design Load Set obtained from calculations according to corresponding IACS formulas.

According to IACS (Section 7/Table 7.6.1), the design load combinations for each load component are given in Table 4.

Table 4. Design Load Combinations

Load Component		**Design Load Combination**	
		S	**S+D**
P_{ex}	Hull envelope	P_{hys}	$P_{hys}+P_{wv-dyn}$
P_{in}	Ballast tanks (BWE with flow-through method)	The greater of a) $P_{in-test}$ b) $P_{in-air}+P_{drop}$	$P_{in-air}+P_{drop}+P_{in-dyn}$

Notes:

1. P_{ex} = design sea pressure, in kN/m^2.
2. P_{in} = design tank pressure, in kN/m^2.
3. P_{hys} = static sea pressure at considered draught, in kN/m^2.
4. $P_{in-test}$ = tank testing pressure, in kN/m^2.
5. P_{in-air} = static tank pressure in the case of overfilling or filling during flow through ballast water exchange, in kN/m^2.
6. P_{drop} = added overpressure due to liquid flow through air pipe or overhead pipe, in kN/m^2.
7. P_{wv-dyn} = dynamic wave pressure for a considered dynamic load case, in kN/m^2.
8. P_{in-dyn} = dynamic tank pressure for a considered dynamic load case, in kN/m^2.
9. S denotes the static design load combination and $S+D$ denotes the static plus dynamic design load combination.
10. These values are obtained from the corresponding formulas of IACS.

5.5.1 Flange Plate Thickness

In the proposed design, the breadth of flange plate (i.e. b_f) is taken as 1000 mm. From Table 3 the greatest value (i.e. P) calculated for all applicable design load sets is 296.40 kN/m^2. Since, this greatest value is for design load set 12, therefore acceptance criteria set AC2 is to be considered.

Hence, for flange plate:

$$t_{net} = 0.0158 \times 1000 \times \sqrt{\frac{|296.40|}{0.90\times 235}} = 18.70 \text{ mm}$$

Therefore, flange thickness of the corrugated plate is 18.70 mm.

5.5.2 Web Plate Thickness

In the proposed design, the breadth of web plate (i.e. b_w) is taken as 1100 mm. Hence, for web plate:

$$t_{net} = 0.0158 \times 1100 \times \sqrt{\frac{|296.40|}{0.90\times 235}} = 20.57 \text{ mm}$$

Therefore, web thickness of the corrugated plate is 20.57 mm.

Meanwhile, according to IACS (Section 8/2.5.6.5), where the corrugated plate is built with flange and web plate of different thickness, then the thicker net plating thickness, t_{m-net}, is to be taken as the greatest value calculated for all applicable design load sets and is given by:

$$t_{m-net} = \sqrt{\frac{0.0005 b_p^2 |P|}{C_a \sigma_{yd}} - t_{n-net}^2} \text{ mm}$$

where:

t_{n-net} = net thickness of the thinner plating, either flange or web, in mm;

b_p = breadth of thicker plate, either flange or web, in mm

P = design pressure for the design load set being considered, calculated at the point in kN/m^2

C_a = permissible bending stress coefficient:
= 0.75 ; (for acceptance criteria set AC1)
= 0.90 ; (for acceptance criteria set AC2)

σ_{yd} = specified minimum yield stress of the material = 235 N/mm^2.

Since, flange is the thinner plating (i.e. 18.70 mm) therefore, for acceptance criteria AC2:

$$t_{m-net} = \sqrt{\frac{0.0005\times 1100^2 \times |296.40|}{0.90\times 235} - 18.70^2} = 22.32$$

Therefore, web thickness of the corrugated plates is 22.32 mm.

Hence, the thicknesses of flange and web of corrugated plates are taken as 18.70 mm and 22.32 mm respectively. Meanwhile, according to IACS (Section 6/Table 6.3.1), a local corrosion additions, t_{corr} , is to be considered for all structural elements in the cargo tank region and for the members which are "in and between ballast water tanks", the value is 3.0 mm. Therefore, the thicknesses of flange and web of corrugated plates are to be taken as 21.70 mm and 25.32 mm respectively.

5.5.3 Calculating Section Modulus

According to IACS (Section 8/Table 8.2.5), the minimum net section modulus, Z_{net} , is to be taken as the greatest value calculated for all applicable design load sets is given by:

$$Z_{net} = \frac{|P|\, s\, l_{bdg}^2}{f_{bdg}\, C_s\, \sigma_{yd}} \ \text{cm}^3$$

where:

P = design pressure for the design load set being considered and calculated at the calculation point = 296.40 kN/m^2 [Detail in Table 3]

f_{bdg} = bending moment factor: for continuous stiffeners and where end connections are fitted consistent with idealisation of the stiffener as having as fixed ends = 12 ; (for horizontal stiffeners)

l_{bdg} = effective bending span, in m

= 8.748 m [Detail in Figure 2]

s = stiffeners spacing, in mm

= 2×1458 mm [Detail in Figure 2]

= 2916 mm

C_s = permissible bending stress coefficient for the design load set being considered, to be taken as $C_s = C_{s-max} = 0.9$; (since, from Table 3.2 the maximum design pressure is for design load set 12, therefore AC2 is to be considered).

σ_{yd} = specified minimum yield stress of the material, in N/mm^2 = 235 N/mm^2

$$Z_{net} = \frac{|296.40| \times 2916 \times 8.748^2}{12 \times 0.9 \times 235} = 26{,}061 \ \text{cm}^3$$

Hence, the section modulus, Z, [3] of a single corrugation unit is taken as: $Z = \frac{1}{3} t_p d(3b + c)$

where:

t_p = thickness of the web plate

= 25.32 mm ; (as calculated above)

d = height of corrugation = 1000 mm

b = breadth of flange plate = 1000 mm

c = breadth of web plate = 1100 mm

All symbols are defined in Figure 3 and the values are obtained from Figure 2.

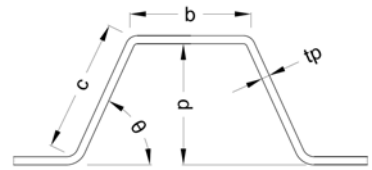

Figure 3. Configuration of a Single Corrugation

Therefore: $Z = \frac{1}{3} \times 25.32 \times 1000 \times (3 \times 1000 + 1100) = 34{,}604$ cm^3

which is greater than the required section modulus. Therefore, the proposed structure is feasible.

5.6 Calculations of Corrugated Plate as a Primary Member in Double Side Region

Since, corrugated plates are used as primary support members in the double side region, in the table for "Design Load Sets for Primary Support Members" of IACS (Section 8/Table 8.2.9), the specifications for "Side transverses" are considered. The maximum values for each design load set in this region are shown in Table 5:

Table 5. Maximum Values Obtained from Calculations for Each Design Load Set

Design Load Set	Load Component	Design Load Combination	Acceptance Criteria Set	Value
1	Sea Pressures P_{ex}	S+D	AC2	169.64
2		S	AC1	152.84
12	Cargo Pressures P_{in}	S+D	AC2	**315.59**
13		S	AC1	286.44

Note: All the particulars are similar to Table 3.

5.6.1 Flange Plate Thickness

In the proposed design, the breadth of flange plate (i.e. b_f) is taken as 1000 mm. From Table 5, the greatest value (i.e. P) calculated for all applicable design load sets is 315.59 kN/m^2. Since, this greatest value is for design load set 3, therefore acceptance criteria set AC2 is to be considered.

Hence, for flange plate:

$$t_{net} = 0.0158 \times 1000 \times \sqrt{\frac{|315.59|}{0.90 \times 235}} = 19.30 \ \text{mm}$$

Therefore, flange thickness of the corrugated plate is 19.30 mm.

5.6.2 Web Plate Thickness

In the proposed design, the breadth of web plate (i.e. b_w) is taken as 1100 mm. Hence, for web plate:

$$t_{net} = 0.0158 \times 1100 \times \sqrt{\frac{|315.59|}{0.90 \times 235}} = 21.23 \text{ mm}$$

Therefore, web thickness of the corrugated plate is 21.23 mm.

Same as before, flange is the thinner plating (i.e., 19.30mm) therefore, for acceptance criteria AC2:

$$t_{m-net} = \sqrt{\frac{0.0005 \times 1100^2 |315.59|}{0.90 \times 235} - 19.30^2} = 23.03$$

Therefore, web thickness of the corrugated plates is 23.03 mm.

Hence, the thicknesses of flange and web of corrugated plates are taken as 19.30 mm and 23.03 mm respectively.

Meanwhile, according to IACS (Section 6/Table 6.3.1), a local corrosion additions, t_{corr}, is to be considered for all structural elements in the cargo tank region and for the members which are "in and between ballast water tanks", the value is 3.0 mm. Therefore, the thicknesses of flange and web of corrugated plates are to be taken as 22.30 mm and 26.03 mm respectively.

5.6.3 Calculating Section Modulus

Similar to Section 5.5.3, the minimum net section modulus, Z_{net} , is to be taken as the greatest value (i.e., P = 315.59 kN/m^2) calculated for all applicable design load sets is given by:

$$Z_{net} = \frac{|315.59| \times 2916 \times 8.748^2}{12 \times 0.9 \times 235} = 27{,}748 \text{ cm}^3$$

And the section modulus Z of a single corrugation unit is taken as:

$$Z = \frac{1}{3} \times 26.03 \times 1000 \times (3 \times 1000 + 1100)$$
$$= 35{,}574 \text{ cm}^3$$

which is greater than the required section modulus. Therefore, the proposed structure is feasible.

6. RESULTS

The simple target of replacing all the support members from this region by a similar cross-sectional structure, has been successful by considering a special specification of corrugated plates (i.e., breadth of flange = 1000mm, breadth of web = 1100mm and corrugation angle of these plates = 65 degrees). In case of double bottom region, at the end of calculations, the thicknesses of the flange and web of the corrugated plates have been achieved 21.70mm and 25.32mm respectively. To evaluate these thicknesses, the structural strength assessment has also been performed by calculating the section modulus of this structure, and the value is 34,604cm^3, which is greater than 26,061cm^3 as required by IACS for stiffeners in the same region. Similarly, in double side region the thicknesses of the flange and web have been achieved 22.30 mm and 26.03 mm respectively. The section modulus of this structure is 35,574cm^3, which is greater than 27,748cm^3 as required by IACS for stiffeners in the same region.

7. CONCLUSION

The key intention of this paper has been to propose an alternative structural design for the double hull region of tankers and to establish that this new design meets the criteria of classification rules and offers better strength. In addition it offers a less complicated construction process due to the requirement of less welding and a more inspection friendly region which is easier to maintain as well. However, due to the involvement of a greater amount of plates, this structural will be expensive to build.

Nevertheless, the total achievement is still incomplete, since total section modulus of the mid-ship section and the finite element strength assessment of the structure is yet to be done. Therefore, it is further recommended to perform these analyses for the proposed structure and validate these theoretical calculations.

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